Chapter 1 - Introduction

This chapter introduces the learning potentials afforded by web-conferencing systems, and the need to research them. This is discussed in relation to teaching and learning computer programming online, which is the context for this study. Based on the lack of research in the field of teaching using web-conferencing and support from the literature for such analysis, the aims of the study are established. Finally the remaining chapters are outlined to explain how the structure of this thesis attends to the research aims.

1.1 Web-Conferencing Potentials

Modern technologies are providing teachers with new opportunities to create engaging and effective learning (Oliver, Harper, Wills, Agostinho, & Hedberg, 2007). Contemporary web-conferencing systems such as Adobe Connect (Adobe Systems Inc., 2008), Oracle Collaboration Suite (Cisco Systems Inc., 2008) and Elluminate Live (Elluminate Inc., 2008) allow a range of rich-media tools to be integrated, offering previously unavailable possibilities for instantiating synchronous online learning experiences. Voice over IP, text-chat, whiteboards, screen-sharing, communal note areas and so on provide a powerful suite of tools with which to present information, model processes, and share concepts.

Approaches to applying a transmissive or "teacher-centred" style of teaching in web-conferencing environments are self-evident. A low level of interpretation is required to understand how such systems can be used to present information since this is a typical use for which these systems are designed. The technological skill needed to conduct transmissive approaches to teaching is relatively low since once the environment is set up the flow of information is essentially unidirectional and there is little need to adjust the web-conferencing interface.

However solely applying delivery approaches to teaching is insufficient because to learn effectively people need to be engaged in learning activities (Britain, 2007). Laurillard (2002) advocates the need for discursive interaction between the teacher and students. An iterative dialogue provides learners with the opportunity to represent their understanding and enables the teacher to adjust the direction of the lesson based on the learning needs students demonstrate. Jonassen, Lee, Yang and Laffey (2005) emphasize the importance of applying collaborative learning approaches. By centring students in learning activities group-work approaches increase attention levels and provide students with the opportunity to engage in knowledge construction processes.

Yet there is sparse literature addressing how to utilize web-conferencing environments to engage more interactive and collaborative approaches to learning. As at 26th of February 2008 a search of the Educational Resources Information Centre (US Department of Education, 2008) returned 25 references relating to "web-conferencing" and 169 relating to "virtual classrooms". Almost all of these resources were using the terms to describe online learning generally rather than contemporary web-conferencing systems such as Adobe Connect (Adobe Systems Inc., 2008), Elluminate Live (Elluminate Inc., 2008) or Webex (Cisco Systems Inc., 2008). As well, there were no theses relating to web-conferencing in the Proquest thesis database (Proquest, 2008), nor any papers specifically addressing web-conferencing in the international journal of Computer Supported Collaborative Learning. This lack of research relating to learning design in web-conferencing environments provides motivation for this study.

Some web-conferencing systems enable users to dynamically design the interface according to the collaborative and representational requirements of the task at hand. This raises a raft of design questions. If teachers can adjust the size and placement of the tools in a web-conferencing environment, on what basis should they do so? What factors should influence the tools that are selected? How should the tools be arranged? In a live lesson there is little time for reflection, which heightens the need for a set of principles to guide design in web-conferencing environments.

Situating learning designs in the context of the learning domain is critical because of the unique processes and representational requirements that different subjects possess (Sharpe & Oliver, 2007a, 2007b). This study is conducted in the context of teaching and learning introductory computer programming as part of an online Graduate Diploma of Information Technology (GDIT). Introductory programming is a unique learning domain and one that has an active research community, particularly through the Association for Computer Machinery Special Interest Group in Computer Science Education (ACM SIGCSE). This has led to specialized research findings regarding effective approaches for teaching and learning computing.

For instance, Waite, Jackson and Diwan (2003) note student performance gains in a computer systems course from establishing a more interactive (conversational) classroom environment. Several researchers have noted the benefits of collaborative programming to develop students' capacities to write computing code (McDowell, Werner, Bullock, & Fernald, 2002; Nagappan et al., 2003; Williams & Upchurch, 2001). Whether and how such approaches may be effectively applied in a web-conferencing environment is an open question.

1.2 Support from the Literature for Studying Teaching and Learning Using Web-Conferencing

Computer Mediated Communication (CMC) is a generic term that incorporates "all forms of communication between individuals and among groups via networked computers" (Naidu & Jarvela, 2006, p. 98). Rather than simply mediating face-to-face teaching approaches, CMC provides a unique environment for learning and interacting that requires distinct researcher attention (Salmon, 2000, p. 39). Studying Computer Mediated Communication allows the communication patterns, forms, functions, conventions and subtexts to be better apprehended, which in turn allows an understanding of how people derive meaning within such contexts to be developed (Naidu & Jarvela, 2006, p. 96).

Conole (2007) places recent trends in CMC within the context of educational technology development:

> *While much of the early focus of activity in Internet developments was on content (and ways of creating, storing, retrieving and managing information), more recently interest has shifted towards the social potential of technologies…In essence, this suggests that there are three fundamental shifts: a shift from a focus on information to communication, a shift from a passive to more interactive engagement, and a shift from a focus on individual learners to more socially situative learning.*
>
> (pp. 81-82)

Computer Supported Collaborative Learning (CSCL) is the term to describe situations where "computer-mediated communication involves some kind of collaborative learning activity" (Naidu & Jarvela, 2006, p. 99). While collaborative learning using networked technologies has become a popular trend in education, research has indicated that simply using the technologies provides no guarantees of improved learning (Naidu & Jarvela, 2006, p. 97). The ambiguities that exist regarding how to use online technologies successfully suggests the need for their research:

> *CMC and CSCL interactions should be analyzed as a means of gaining insight into the processes of collaborative learning and trying to clarify what constitutes productive collaborative activity… What is the role of interactions for supporting productive joint engagement and shared understanding?... we should focus on investigating a variety of possibilities these environments make us interact, collaborate and share ideas. How and what kind new opportunities for interaction these environments provide?*
>
> (Naidu & Jarvela, 2006, p. 97)

In a review of the first decade of CSCL literature from 1995 to 2006, Suthers (2006) claims that the field needs to focus more attention on the intersubjective nature of learning – that is, how participants learn together. While CSCL has offered some significant insights into how individuals form understanding, it is surprisingly difficult to find CSCL literature relating to the way in which learners construct knowledge together (Suthers, 2006). Researching teaching and learning using web-conferencing offers an opportunity to further this research agenda by providing a specific instance of how intersubjective learning occurs in a technology based learning environment.

Reeves, Herrington and Oliver (2004) present a compelling vision for online collaborative learning, whereby learners enrolled in a common unit of study work together through the online medium to solve complex problems and complete authentic tasks. They believe that by being able to collaboratively solve authentic tasks online "the learning outcomes accomplished by these learners will be of the highest order, including improved problem solving abilities, enhanced communication skills, continuing intellectual curiosity, and robust mental models of complex processes inherent to the performance contexts in which their new learning will be applied" (Reeves, Herrington, & Oliver, 2004, p. 53).

However, in general, online learning falls short of this vision, at least in tertiary education:

> *There is little evidence that the developers of most online collaborative learning environments in postsecondary contexts have tried to reach, much less attained, the vision described above (Kearsley, 2000; Moore & Anderson, 2003; Phipps & Merisotis, 1999)… courses appear to remain constrained by traditional assumptions about the processes of instruction"*
>
> (Reeves, Herrington, & Oliver, 2004, p. 54)

Reeves, Herrington and Oliver (2004) argue that the reason that many online learning environments fail to engage innovative pedagogy is that they attempt to replicate face-to-face approaches rather than embracing the capacities of new technologies. They believe that the challenge for academic staff in transforming their pedagogy is more a conceptual one than a technological one, the basis of which lies in effectively applying what cognitive scientists and others have revealed about how people learn. Reeves, Herrington and Oliver (2004) call for research in this area. This study focuses upon how to derive and apply such understandings to engage effective learning in web-conferencing environments.

However the technological design component of CSCL also requires further investigation. Suthers (2006) proposes that the technology side of the CSCL research agenda should focus on the design and study of fundamentally social technologies, and that these should be "informed by the affordances and limitations of those technologies for mediating intersubjective meaning making" (p. 326). By understanding how affordances affect the learning process in specific instances and comparing and contrasting results in a variety of contexts it becomes possible to deduce those elements of technology design that are inconsequential and those that are essential (Dwyer & Suthers, 2005). Thus CSCL researchers and designers should be aiming to find and share collections of technological affordances that support participants' strategies and the provision of flexible forms of guidance (Suthers, 2006). This is a point of enquiry of this research.

Web-conferencing systems offer a wide array of modalities for facilitating collaboration and meaning making. If there are several available modes and they each have different characteristics, the decision needs to be made about which modes to use for a particular purpose. Kress et al (2001) point out the importance of a deliberate approach to making this decision because of its impact on the effectiveness with which meaning is shared:

> *Making a representation now goes well beyond simple encoding. It has become a matter of active, deliberate design, and meaning making becomes a matter of the individual's active shaping and reshaping of the resources that he or she has available, in the wish to make representations match intentions as closely as possible.*
>
> (p. 2)

This suggests that capturing and sharing successful patterns of collaboration and meaning making in web-conferencing environments is particularly useful because compared to single modality technologies (such as discussion boards or straight text-chat) design possibilities are more complex. Because the environment allows a great range of modalities to be integrated, achieving optimal designs is less straight forward. Determining and sharing effective ways to leverage the technology to support teaching and learning reduces the amount of experimentation required by first time designers.

Jonassen (2000) reflects on the use of rich media synchronous communication tools:

> *The truth is we do not really understand the best applications nor the limitations of synchronous communication…So what conditions are necessary for live discussions to be productive?*
>
> (p. 239)

Jonassen (2000) postulates two requirements for successful synchronous collaborations, namely, a purpose for the conversation (such as planning, debating, or problem solving) and an object or artefact in a shared workspace. He conjectures that when students are collaborating to construct some form of artefact in a shared solution space (such as a presentation, report, or problem solution) they will remain more intellectually focused than if they lack purpose or product (Jonassen, 2000). He also hypothesized that less structured, complex tasks promote more effectively engaged collaboration (Jonassen, Lee, Yang, & Laffey, 2005, p. 264). This research endeavours to detect whether and how the task type effects collaboration and learning.

In reflecting on the capacity of technology to support dialogic approaches to learning, Laurillard (2002) noted how Lyceum (an audio-graphics conferencing environment) almost supported her entire "Conversational Framework" single handedly:

> *"When Lyceum can import a runnable model to the shared area, then it will fulfil the requirements of the whole framework."*
>
> (Laurillard, 2002, p. 156)

Through its capacity to share a user's desktop for group operation web-conferencing environments allow runnable models (i.e. software packages) to be operated in a shared area. That is to say, technology has now come to a point where single applications can fully support the online collaborative learning approaches that Laurillard (2002) recommends. How to engage such approaches effectively is the subject of this research.

1.3 Background to This Study

1.3.1 An online Graduate Diploma of Information Technology

In December of 2003 the Division of Information and Communication Sciences at Macquarie University had received approval to create an online Graduate Diploma of Information Technology (GDIT). The course was to cater to graduates from disciplines other than computing who were interested in furthering their skills and qualifications in the computing domain. Completing the one year full-time (or equivalent part-time) GDIT program would provide these graduate students with the core knowledge and experiences contained in an undergraduate computing degree without needing to complete three years of full time study.

Offering the course online was seen as a way to provide improved access to students with competing work or domestic obligations. Rather than reusing existing materials and strategies the mandate was to develop new approaches that could then be rolled-out across the university and potentially beyond. The context was also seen as an excellent opportunity to develop methodologies for teaching and learning using online technologies by applying existing literature in the field to the project at hand. Utilizing web-conferencing allowed synchronous learning experiences to be provided, and this was seen as particularly important for developing programming process knowledge.

1.3.2 Design of the GDIT units

As a result of a systematic development process specifically tailored for the creation of online computing courses (Bower, 2006) the GDIT units of study were crafted so that each subject incorporated the following components:

1) **Multimedia Topic Overviews** for each week to provide the online learner with an approximately 20 minute introduction to key concepts and to provide direction through the content
2) **Screen Recorded Instruction** providing students with modelling of processes such as compiling, debugging, program design, and so on
3) Online multi-attempt, graded **Topic Quizzes** to check for basic comprehension of each topic before progressing to conceptual questions and practical activities
4) **Pre-class tutorial and practical exercises** which students were required to submit before their weekly online classes to develop their conceptual understanding and practical programming abilities (these carried a minor grade each ensuring that students have attempted the work and could thus meaningfully participate in lessons)
5) **In-class tutorial and practical exercises** which required no student preparation and were facilitated by the teacher during classes.

The units also included three optional on-campus workshops, and an assessment schedule that included at least two assignments and a final exam. All features were accessible via the Learning Management System (WebCT campus edition). The WebCT LMS provided links to all resources, a discussion board feature, and also the facility for students to submit their work.

A web-conferencing system was used to facilitate a two-hour online class each week to address pre- and in-class activities. This provided students with real-time access to the teacher and their peers from any location via the Internet.

1.3.3 The Web-conferencing environment

Several web-conferencing systems were investigated for use as the "virtual classroom" platform for the GDIT, including Webex (Cisco Systems Inc., 2008), Elluminate Live (Elluminate Inc., 2008) Adobe Acrobat Connect (Adobe Systems Inc., 2008) and Oracle Collaboration Suite (Oracle Pty. Ltd., 2008). After extensive testing (refer to Bower, 2006; Bower & Richards, 2005) the Adobe Acrobat Connect platform (formerly Macromedia Breeze) was selected on the basis of its powerful feature set, its ease of use, and its unparalleled capacity for users to design the interface. The platform provides the following facilities through any Flash (Adobe Systems Inc, 2008) enabled web browser:

- General Presentation Delivery – PowerPoints, or general documents (converted to FlashPaper format)
- Screen-sharing – entire desktop, application or window, with remote control capabilities
- Webcam – multiple speeds, ability to stream
- VoIP – adjustable broadcast quality to suit connection
- Text-chat – send to all or selected individuals
- Whiteboard – various colours/fonts/transparency levels, drag-and drop, undo, document overlay capabilities
- File Upload/Download – selected from computer or content library
- Polling – allowing questions to be composed and participants to vote
- Attendee List – including status indicator ('fine', 'slower' etc)
- Notepad – for textual contributions such as summaries, task instructions, and so on.

A default meeting room comprises three 'layouts' (predefined interface designs). Layouts consists of a number of windows or 'pods' that contain the different web-conferencing features.

The 'Sharing' layout consists of the 'Camera and Voice' pod for broadcasting a webcam and managing Voice Over IP communications, a 'Share' pod for broadcasting either a document, a whiteboard, or sharing the screen, a 'Note' pod for collaborative entry of textual information, a 'Chat' pod for conducting text-chat communications, and an 'Attendee List' pod which shows the participants in the room along with their privileges and status ('fine', 'talk slower' and so on). The 'Sharing' layout is shown in Figure 1.

The 'Discussion' layout also includes the 'Camera and Voice', 'Attendee List', 'Chat' and 'Note' pods, however the size and placement of these pods is different to the 'Sharing' layout (see Figure 2). For instance the chat pod is enlarged, allowing more text-chat to be reviewed at once. The Discussion layout also includes a 'Polling' pod (allowing participants to vote on facilitator prescribed options) as well as an enlarged 'Discussion Notes' pod which provides a second note-pod for typing text during discussions.

The 'Collaboration' layout again contains the 'Camera and Voice', 'Attendee List' and 'Note' pod in the left hand column of the browser window, however the main pod is a 'Share' pod containing a communal whiteboard (see Figure 3). This layout also includes a 'File-share' pod for exchanging files. The 'Chat' pod is also included below the whiteboard, though smaller in size than for the 'Discussion layout.

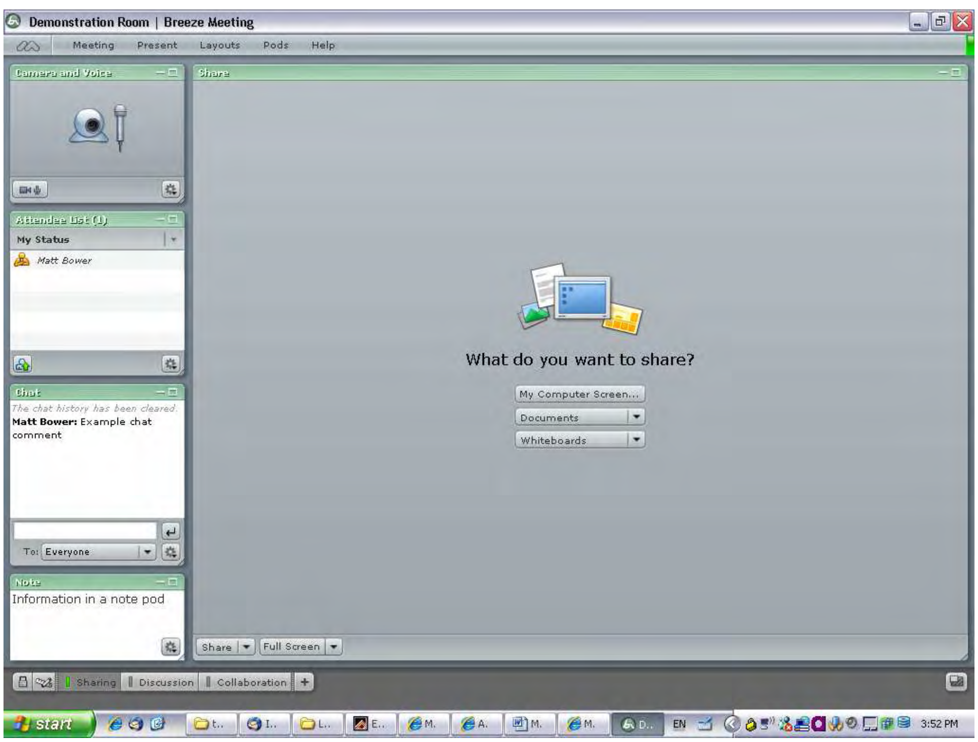

Figure 1 – 'Sharing' layout with (clockwise from top-left) 'Camera and Voice' pod, 'Share' pod, 'Note' pod, 'Chat' pod, 'Attendee List'

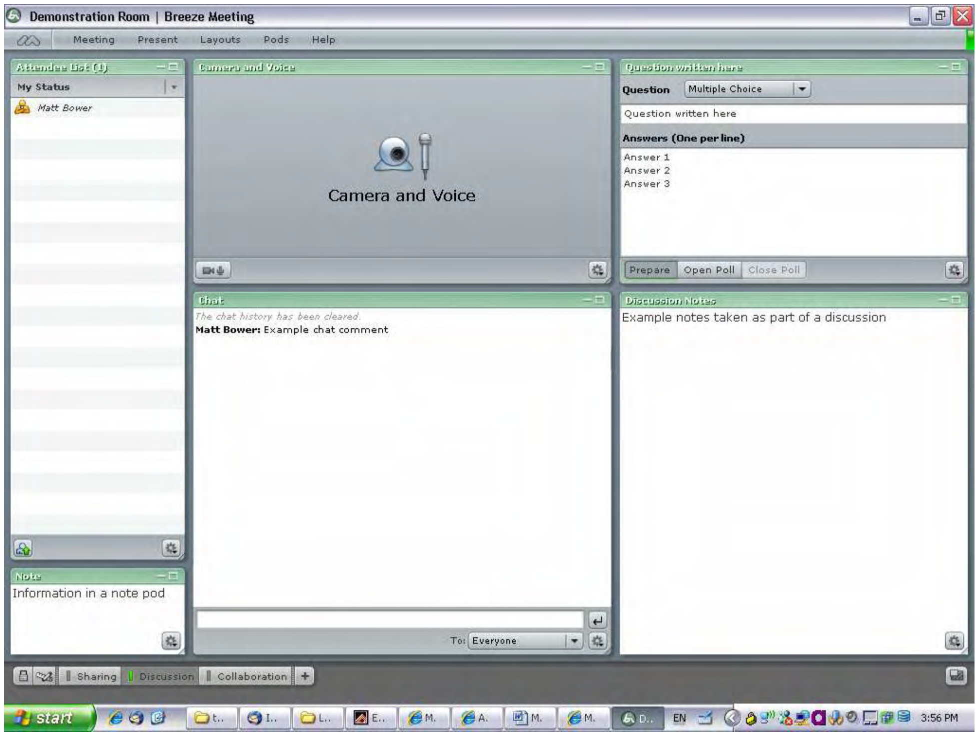

Figure 2 – 'Discussion' layout with (clockwise from top-left) 'Attendee list' pod, 'Camera and Voice' pod, 'Polling' pod, 'Discussion Notes' pod, 'Chat' pod, and 'Note' pod

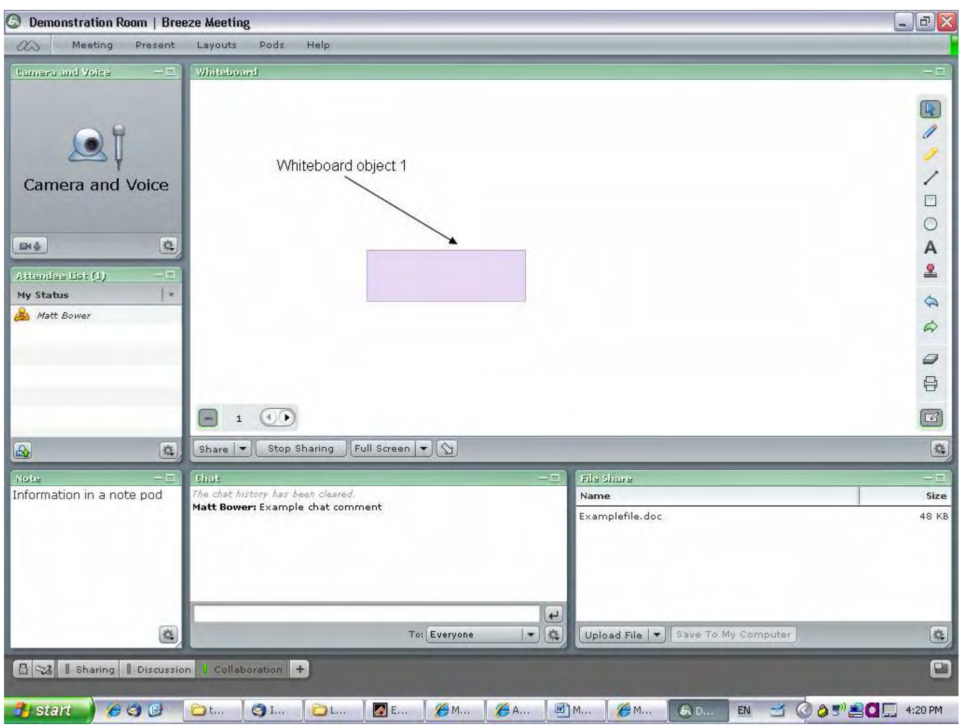

Figure 3 – 'Collaboration' layout with (clockwise from top-left) 'Camera and Voice' pod, 'Whiteboard' pod, 'File-share' pod, 'Chat' pod, 'Note' pod, and 'Chat' pod.

The user can toggle between layouts using tabs at the bottom of the browser window. Each of the pods in a layout can be instantly resized, drag-and-dropped, created or deleted. As well, new layouts can be created so that a room can have several pre-designed layouts. These can be selected by clicking the tabs at the bottom of the browser window. This allowed layouts to be redesigned to meet the collaborative requirements of the learning task, either in advance or during a learning episode.

The meeting 'host' (or super-user) can spontaneously adjust the access control of 'presenters' and 'participants' to each of the tools. Finally, all sessions have the capacity to be recorded, on which basis the data for this study has been derived.

1.3.4 The problem

A pilot implementation (which will be referred to as "Iteration 0") of the course was run in Semester 1 of 2005 (February-June) with five students. This was seen as an opportunity to test the design of the GDIT and become familiar with teaching using the web-conferencing environment. However, although the participant-researcher had several years of face-to-face teaching experience, a degree in computing and postgraduate qualifications in online education, approaches to best practise teaching through the web-conferencing environment were neither obvious nor intuitive.

The unfamiliarity of the environment and the lack of support from the literature meant that several important questions regarding teaching and learning using web-conferencing environments remained unanswered:

- What are the different representational possibilities of tools in the web-conferencing environment, and under what circumstances should these be deployed?
- How should tools be effectively applied in combination to capitalize upon the synergies between them?
- Does teaching and learning using the web-conferencing environment impose any limitations on the learning process as compared to face-to-face environments, and if so, how are these constraints best addressed?
- What is the effect of different types of activity designs upon collaboration and learning in the web-conferencing environment, especially in relation to gauging student understanding and providing appropriate feedback?
- How much influence can the teacher have on the collaboration and learning that transpires in the web-conferencing environment, and in what way?
- How does the teacher's implementation and management of the learning episodes in the web-conferencing environment impact upon the discourse that transpires?
- What is the influence of the content of the task on collaboration and learning in the web-conferencing environment, either by virtue of the type of knowledge being addressed or the character of those tasks?
- What sort of technological competencies are critical for teaching and learning in web-conferencing environments, and what are the consequences of not having these?
- Does the capacity to dynamically adjust the interface during a lesson or learning episode change the nature of teaching, and if so how?
- What principles or framework should be used to guide the design of learning episodes in web-conferencing environments?

This study has arisen from the opportunity and the need to better understand how to design for learning in a web-conferencing environment. The approach adopted applies scientific methods and reasoning to the design, development, implementation, and analysis of teaching and learning using this contemporary online technology, with the aim to forming a clearer understanding of its nature. By reporting transparently about the methods of study and analysis the intention is that readers will be able to evaluate the extent to which the outcomes presented may be relevant to other situations. The final chapter of this thesis returns to the questions posed above and tenders ways in which the results of this study may transfer to other contexts.

1.4 Research Question

This study provides an opportunity to observe how teachers and learners act and react within a rich media multifaceted online learning environment. While the study generally endeavours to investigate the nature of teaching and learning using web-conferencing, the primary purpose of this study is to provide a framework for educators to make sensible design decisions when teaching and learning in web-conferencing environments. This is encapsulated in the research question for this study:

> ***How do the interface, task type and activity design influence collaborations and learning in a web-conferencing environment?***

This question encompasses all the unanswered issues regarding teaching and learning using web-conferencing that were raised in the proceeding section. It allows the nature of teaching and learning to be represented, the mediating function of the web-conferencing interface to be explored, different types of activity designs to be investigated, and the role of the content knowledge to be analyzed.

The research question moves beyond the "what" of teaching and learning computing using web-conferencing to seek out cause-and-effect relationships and how they can best be used. Thus the teacher's role in the implementation and management of designs forms a part of the research question. By focusing on a technology that allows the interface to be spontaneously adjusted, the question implies a mandate to examine dynamic design potentials.

This question provides a "non-trivial" and "somewhat open-ended" basis for this study that can be empirically addressed by the data being considered, thus providing an appropriate point of enquiry in the given context (Herring, 2004). Addressing these more open ended and holistic questions allows attention to be shifted from the commonly adopted focus on curriculum to a broader focus on "shaping the environment for learning" (Jewitt, 2006). It is intended that transparent and thick description approaches adopted in this research promote transferability of findings, so that the outcomes of this study may also inform and progress other learning domains and the field of technology based learning generally.

1.5 The Context

1.5.1 The learning domain

This research focuses specifically on collaborations in the two hour weekly online class for the subject (Unit) "ITEC100 – Introduction to Software Development". ITEC100 is the core introductory computer programming unit for the GDIT, where students learn the fundamentals of writing computer programs (in Java). As a four credit point graduate course the pace and amount of content covered was greater than an undergraduate introduction to programming course, covering basic programming syntax and semantics, objects and classes, polymorphism and inheritance, Applets and GUIs, arrays and ArrayLists, as well as error handling and file operations.

In order to acquire domain specific teaching and learning understandings accumulated by the computer science education community extensive review of the literature was conducted, including a review of approaches to online learning of computing (described in Bower, 2007b) and collaborative approaches to learning computing (Bower & Richards, 2006). This computing education literature provided critical background knowledge for the design and implementation of learning episodes in this study. However, at a meta-level, the fundamental consideration is the process of applying domain specific knowledge (whatever the domain) to the development and execution of learning activities.

1.5.2 A key ancillary technology – the Integrated Development Environment

In order to compile computer programs an Integrated Development Environment (IDE) is often utilized. The IDE used in ITEC100 was BlueJ (BlueJ Development Team, 2008), which is specifically designed for beginner Java programmers (see Figure 4).

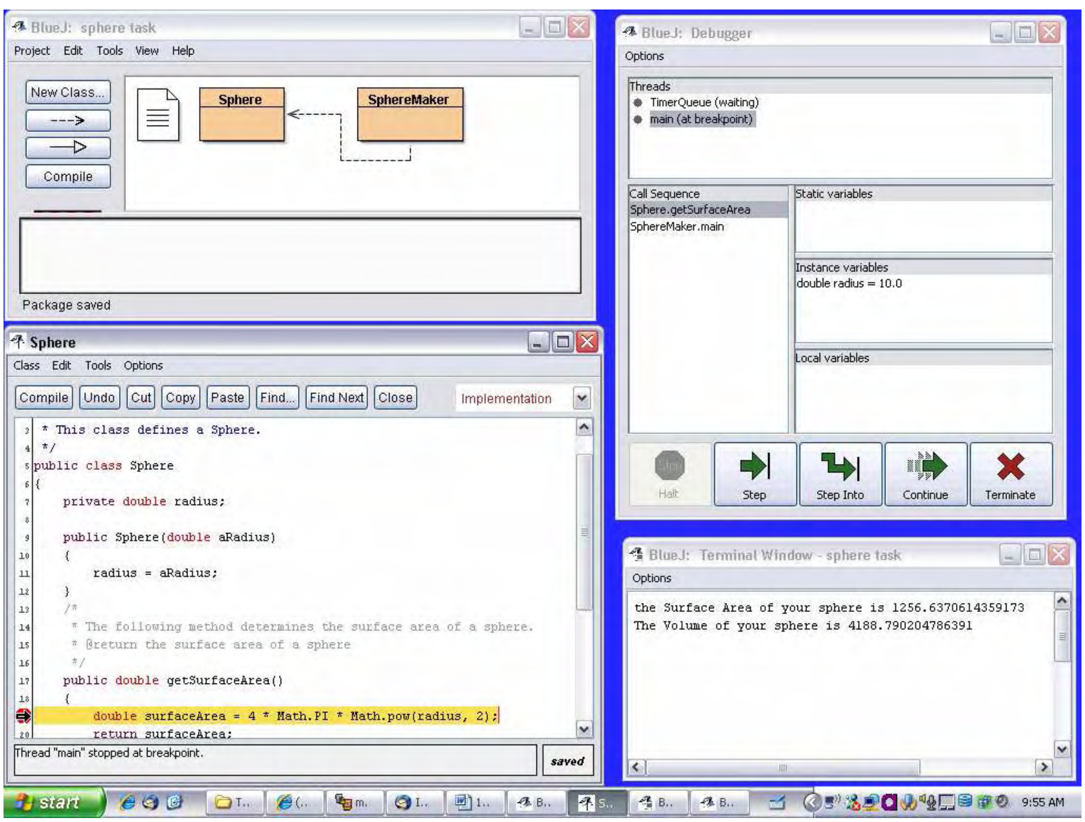

Figure 4 – A screenshot of the BlueJ IDE, showing (clockwise from top-left) a Project window, the Debugger window, the Terminal window, a source code file

All students and the teacher had the BlueJ IDE installed on their own machine. The IDE could be incorporated into lessons by virtue of being broadcast to or between students using the screen-sharing feature of the web-conferencing environment.

The BlueJ IDE forms an integral part of many learning episodes analyzed in this research project by virtue of its role in demonstrating and facilitating programming processes. It provides iconic representation of each source code file, as well as the relationships between them (see Figure 4). The environment differentiates certain types of variables and keywords in source code files using colour, and provides the ability to highlight text in yellow. BlueJ can run Applications or Applets, as well as pipe program output to a terminal window if required. The BlueJ IDE also includes a debugger for detecting errors in programs and supporting their correction. All source code files, the project window, the terminal window and debugger are displayed in a separate window, allowing them to be spatially arranged to meet the preferences of the user.

1.5.3 The students

Students who undertook the online GDIT were graduate students (or students with commensurate professional experience that qualified them to enter the course) from a discipline other than computing that wished to extend their IT knowledge and skills. There were 26 students who enrolled across the three semesters that were analyzed in this study, of which 20 completed the unit[1]. Of the 20 students who completed the subject, ten were enrolled in 2005 Semester 2, seven in 2006 Semester 1, and three in 2006 Semester 2. This decline in enrolments across semesters was commensurate with other courses at Macquarie University and other universities generally (Cassel, McGettrick, Guzdial, & Roberts, 2007). Of the 26 students, 9 were female and 17 were male.

In order to limit the scope of this research, differences in approaches to collaboration arising from individual students were not analyzed. The emphasis of this study is how learning design and implementation can affect interaction and to collaboration at a class or group level.

1.6 Structure of This Thesis

To address the research questions identified for this investigation, three semesters of introductory computing lessons taught in the web-conferencing environment were studied. A mixed methods approach to research was adopted; a design-based research review of the three entire semesters of lessons was conducted, as well as a multimodal discourse analysis of selected learning episodes. The design-based research involved redesigning the environment based on evolving findings, providing an emphasis on process. As well the design-based research enabled the integration of qualitative observations across the entire dataset. On the other hand the multimodal discourse analysis was performed ex post facto on a sample of the data, providing an emphasis on product. The multimodal discourse analysis methodology allowed more detailed and objective analysis to be performed.

This thesis describes the development, analysis, and results of the research, and is set out as follows. In Chapter 2 literature relevant to technology based teaching and learning is described in order to situate this current research study within the field and draw upon

[1] Students who did not complete the unit dropped out at the beginning of semester (all within the first four weeks of semester) and hence contributed relatively little to class collaborations.

appropriate frameworks for analyzing the data. After identifying Engeström's (1987) Activity Theory based upon a socio-constructivist view of learning as an appropriate framework for analysis, a synthesis of literature relating to the design and use of learning technologies is provided. This incorporates literature relating to affordance analysis (Gibson, 1979), Multimedia Learning Principles (Mayer, 2005a), cognitive load (Sweller, 2005a), distributed cognition (Hollan, Hutchins, & Kirsh, 2000) as well as previous research relating to educational user interface design.

Attention then turns to literature addressing the types of activity that occur in educational contexts, from transmissive or 'teacher-centred' approaches to more guided or 'teacher-led' approaches, to more group-work or 'student-centred' approaches. The role of the teacher in managing activity, conversational approaches (Laurillard, 2002) and the nature of interacting in a distributed context (Neale, Carroll, & Rosson, 2004) are all considered. The types of tasks that may be prescribed are then discussed, in the context of how mental models are formed. Anderson and Krathwohls' (2001) Taxonomy of Learning, Teaching and Assessing is selected as a general framework for classifying the types of knowledge that learning tasks may address, and a hierarchy of computer programming specific tasks is also presented. The SOLO Taxonomy (Biggs & Collis, 1982) is identified as an appropriate means of assessing the formedness of mental models. Interactions between technology design, activity design and task design are also discussed to provide an integrated understanding of how the three dimensions of analysis adopted in this research interrelate.

Chapter 3 outlines the research methodology adopted in this study. A rationale for using a mixed methods approach is presented and the particular approaches adopted are described. First the design-based research methodology is discussed and justified in relation to the research aims. Approaches to redesigning the learning environment in the three iterations (semesters) are explained, which at the risk of oversimplification can be summarized as follows:

- **Iteration 1** (Semester 2 of 2005): Consolidation of the more instructive approaches adopted in the Iteration 0 trial, using primarily standard graphical interface designs. This iteration offered a baseline for the design-based research analysis.
- **Iteration 2** (Semester 1 of 2006): Use of collaborative spaces to facilitate more student-centred learning approaches. Activities and interfaces purposefully designed to engage more student involvement.
- **Iteration 3** (Semester 2 of 2006): Refinements to the designs and use of collaborative spaces from Iteration 2. More conversational approaches to interaction were facilitated by pervasive use of student audio.

Approaches to analyzing and reporting the data collected in the design-based research review are also described.

Following this the approach to performing the multimodal discourse analysis is described and justified. This includes the method of sampling the 24 learning episodes (eight tasks across three iterations) as well as the approaches to transcription, segmentation and coding. Ways in which the validity and reliability of the study were upheld in both strands of analysis are explained throughout the Chapter 3.

Chapter 4 and Chapter 5 present the results of performing the design-based research review and the multimodal discourse analysis respectively. The design-based research results characterize each of the three iterations, and describe the effects of strategic redesigns on collaboration and learning. The role of the interface, activity design and task are discussed, as well as interactions between these factors. These design-based research results are presented before the multimodal discourse analysis in order to provide a broader illustration of the activity that transpired throughout this research study. This allows the in-depth multimodal discourse analysis that follows to be appreciated in context.

The multimodal discourse analysis results presented in Chapter 5 use three iterations of one task to exemplify the approach to coding and analysis process. This provides an illustration of how the global coding results that are then presented were derived. The results of the statistical analyses are then described in order to portray the effects of the different factors analyzed upon collaboration. Qualitative interpretations regarding the effect of interface, activity design and task that were formed as part of the multimodal discourse analysis process are also reported.

Chapter 6 triangulates the results from the design-based research and multimodal discourse analysis to present evidence-based implications for teaching and learning in web-conferencing environments. On this basis a framework of nine learning designs for teaching in web-conferencing environments is presented. The implications of this study for technology-based learning, possibilities for future work and summative comments are also provided in this chapter. Data and analysis for the design-based research and the multimodal discourse analysis are contained in Appendix A and Appendix B respectively.

Chapter 2 - Literature Review

After introducing Activity Theory and socio-constructivism as frameworks for considering teaching and learning in web-conferencing environments, this chapter discusses approaches to technology, activity and task design. The technology design section incorporates multimedia learning principles, cognitive load theory and distributed cognition. Then teacher-centred, teacher-led and student-centred activity designs are discussed in relation to prevailing collaborative learning theory (such as the Conversational Framework, Laurillard, 2002). Approaches for classifying types of tasks are presented, and the SOLO Taxonomy (Biggs & Collis, 1982) is described as a means of assessing students' mental model representations. Interactions between technology, activity and content design are also discussed.

2.1 The Approach of This Review

Although the prevalence of web-conference based teaching is growing, research into teaching using web-conferencing has not kept pace. This lack of research was evidenced in Chapter 1 by the scarce literature relating to teaching and learning in web-conferencing environments. As such, many of the principles and approaches at the designer's disposal are necessarily derived from research and literature of related fields. Section 1.2 of Chapter 1 explained the need for and relevance of this research so that the literature review in Chapter 2 could be used prospectively to report on the theories and research that inform the design, measurement and analysis adopted in the body of this study.

This thesis is about design. While there is scarce literature specifically relating to learning design in web-conferencing environments, there is a wide array of literature from other fields that is relevant to the process. To exclude any of this literature that either informs the design process or guides the measurement and analysis of those designs would be to compromise the effectiveness of this study. As such, a large number of fields and principles are introduced in this literature review, each of which will be applied in later sections of this study. This literature is organised and synthesised as much as possible to provide a guiding framework for the design and analysis conducted in this study, but not to the extent that learning design becomes portrayed as myopic, rigidified or algorithmic.

The term "learning design" can be used to describe the "learners and a space where they act with tools and devices to collect and interpret information through a process of interaction with others" (Oliver, Harper, Wills, Agostinho, & Hedberg, 2007, p. 65). In the framework adopted in this study learning designs consist of three interrelated components:

- **Technology design** – designing the interface of the web-conferencing environment (*tool*)
- (inter)**Activity design** – framing how participants will interact during in the learning episode (the degree of collaboration between *subjects*)
- **Task design** – designing the curriculum matter of the task, both content knowledge and processes addressed, in the particular learning domain (*object* of study).

These are the three components identified for study in this research project – how the interface, activity design and type of task influence collaboration and learning. They relate to the tool, subject and object of Engeström's (1987) Activity Theory framework.

After introducing Activity Theory as the overarching framework for considering teaching and learning in web-conferencing environments and adopting a socio-constructivist perspective of learning design, the technology design, (inter)activity design, and the design of the task are each discussed with relation to the literature and this study. Interactions between these three aspects of learning design are implicitly addressed throughout the discussion, but also explicated in the final section to this Chapter.

2.2 An Activity Theory Analytic Framework

Activity Theory (Engeström, 1987) is a powerful framework for considering the design and development of Constructivist Learning Environments because the assumptions are consonant with those of constructivism, situated learning, distributed cognitions and everyday cognition (Jonassen & Rohrer-Murphy, 1999). Kuutti (1996) broadly describes Activity Theory as "a philosophical framework for studying different forms of human praxis as developmental processes, both individual and social levels interlinked at the same time" (p. 25). Activity Theory is a clarifying and descriptive tool rather than a strongly predictive theory, whose purpose is to understand the unity of consciousness and activity (Nardi, 1996, p. 7). Activity Theory provides a particularly powerful lens through which to study intersubjective learning in university distance educational contexts, because of its focus upon the relationships that exist among those involved in an activity (Greenhow & Belbas, 2007).

The fundamental principle underpinning Activity Theory is that activity cannot be understood or analyzed outside the context in which it occurs. This means that when analyzing human activity not only the kinds of activities must be examined, but also the goals and intentions, the products of activity, the rules and norms adopted and the community in which activities occur (Jonassen & Rohrer-Murphy, 1999). Its holistic approach to explaining activity and its capacity to integrate with other contemporary learning theories makes Activity Theory a suitable framework with which to analyze teaching and learning in the web-conferencing environment.

Activity systems (Engeström, 1987) represent the components and interrelations of activities, as generalized in Figure 5.

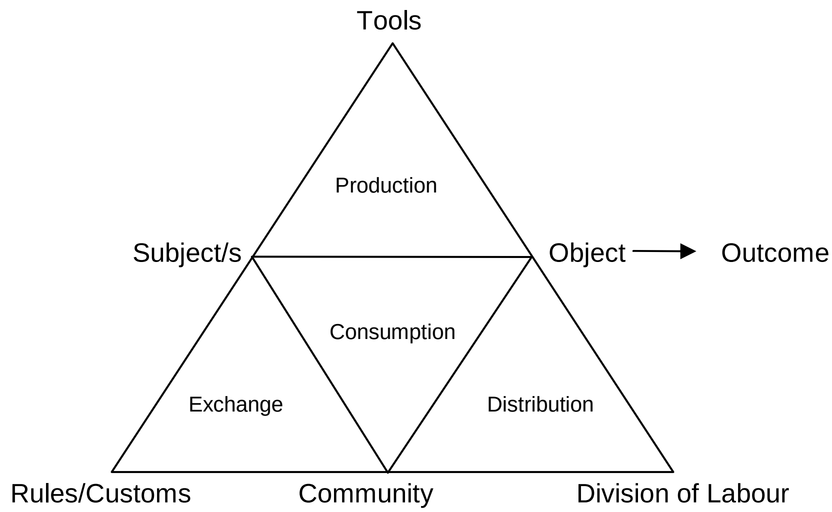

Figure 5 – Engeström's (1987) Activity Theory Framework

The components of an activity system can be summarized as follows:

- Tools – resources used in the transformation process, either physical such as computers, or mental such as heuristics
- Subject – the individual or group of participants engaged in the activity
- Object – the physical or mental product being developed
- Community – the interdependent aggregate who share a set of social meanings
- Rules – social regulations that inherently guide (to some extent) the actions or activities acceptable by the community, so that the signs, symbols, tools, models, and methods that the community use will mediate the process
- Division of labour – prescription of task specialization for members within the community.

(Greenhow & Belbas, 2007; Jonassen & Rohrer-Murphy, 1999)

In the activity system being studied the central tool for facilitating activity (and the main tool analyzed) is the web-conferencing environment. The web-conferencing environment mediates all communications that occur through the multiple representational modalities it offers. Uniquely, the tool possesses the inherent capability to redesign the functions deployed (both the type of pod and their arrangement) through the flexible interface it provides. The fact that the interface can not only be prepared in advance but also dynamically adjusted during class implies a new set of potentials for teachers.

The subjects involved in the activity system being studied are the individual students from the three iterations of teaching the introductory programming subject, as well as the teacher. In Activity Theory the emphasis is on detecting general broad patterns of activity (Nardi, 1996), which is in accordance with this study's focus upon class and group level analysis rather than individual students.

The objects are the learning resources and artifacts being developed as part of studying the learning domain (computing), such as tutorial questions, source code files, collaborative concept maps and so on. The objects of study may also be the mental products derived from the learning episode. However these can only be assessed by their representation in the web-conferencing environment through the use of whiteboards, discourse, or other communication channels.

The community is the students and teacher who comprise a class. Note that there are three communities studied in this analysis, one for each semester observed. This aspect of the research design is explicated in the next chapter, but the underlying rationale is based upon on the grounds that analyzing three communities in a similar but evolving environment allows a greater understanding of activity to be developed than from studying a single community in isolation.

The rules are protocols and conventions of interaction that are negotiated and/or assumed by the teacher and the students. This includes the modalities that are adopted in the web-conferencing environment for the purposes of representing (such as text, audio, webcam broadcast, screen-sharing) and the ways in which those modalities are used under different circumstances.

The division of labour relates to how activity is divided between the students and teacher. This not only involves distribution of responsibilities, but often sharing of responsibilities. The division of labour can be determined by the teacher (in the case of more prescriptive instructional approaches) or students (in the case of more student-centred learning).

Analyzing the web-conferencing environment in the context of an activity system allows technology to be viewed within a holistic context, as a facilitator of learning rather than its source. In light of Activity Theory, the technology is a tool to connect the student with the learning materials, all within the context of the rules and division of labour enacted by the community (Jonassen, Lee, Yang, & Laffey, 2005). In adopting an activity theoretic perspective the design of the technology should incorporate how the norms and approach to distributing task components is to be performed by the group (Bellamy, 1996).

The primary focus of activity systems analysis (particularly when analyzing learning) is the top triangle of the model that encompasses the Tool/s, Subject/s and Object/s (Jonassen, 2002; Jonassen & Rohrer-Murphy, 1999). Known as the "production" subsystem, these three interacting components leads to accomplishment of the activity outcomes. This study focuses upon how the components of the Production subsystem interrelate, i.e., the web-conferencing environment, the participants, and object of study (in this case, computing). These relate to the technology design, the (inter)activity design, and the content of the task, which are the components of learning design that are scrutinized in this research.

2.3 A View of Learning Design in Technology-Based Environments

2.3.1 Perspectives on learning

Learning design can be approached from a variety of philosophical perspectives. The view of learning adopted in an educational design and research project is critical as it determines the objectives of the design process and the lens through which data are analysed and reported. Greeno, Collins & Resnick (1996) and Mayes & Freitas (2007) present three fundamentally different yet somewhat compatible perspectives from which learning design can be viewed:

- **The associationist perspective -** where learning is seen as building patterns of behaviours using sequences of activity followed by feedback, and encompasses the research traditions of associationism, behaviourism and connectionism (Mayes & Freitas, 2007).

- **The cognitive perspective –** where learning is considered to be the development of schema using an individual's attention, memory and concept formation processes, and includes the influential cognitive research areas of schema theory, information processing theories, levels of processing theories, mental models, and metacognition (Mayes & Freitas, 2007).

- **The situated perspective –** whereby all learning is considered to be 'situated' in the social and cultural context, and includes Wenger's (1998) communities of practice approach, Collins et al (1991) cognitive apprenticeships, and Bandura's (1977) vicarious learning (Mayes & Freitas, 2007).

Each of these perspectives has valuable principles to guide and inform the analysis of teaching and learning in web-conferencing environments. To select one of these perspectives in preference to the others would be to lose the useful aspects of the other two, resulting in a narrower approach to design and analysis. Fortunately "Constructivism" (particularly socio-constructivism) provides a more holistic view of learning by incorporating valuable aspects of all three perspectives (Mayes & Freitas, 2007).

2.3.2 Constructivism

With its emphasis on concepts as tools to be understood through use rather than as self contained entities to be delivered through instruction, as well as by placing the learner's search for meaning through activity as central to the learning process, constructivism has elements of the cognitive approach. In so far as constructivism emphasizes learning-by-doing and the importance of feedback, it incorporates aspects of the behaviourist tradition. As well, with attention to sociological aspects of learning,as exemplified by Lave's (1988) 'situated cognition' Vygotsky's (1978) Zone of Proximal Development, constructivism also contains elements of the situated perspective (Mayes & Freitas, 2007).

Constructivism asserts that learning occurs through a continual process of constructing, interpreting and modifying internal representations of reality based on our experiences (Hedberg, 2003). Proponents of knowledge construction approaches argue that engaging in tasks requiring active building of coherent mental structures (as opposed to response strengthening and information acquisition approaches) facilitates better integration of knowledge with existing schema, greater retention and higher transfer to other contents (Mayer, 2005a; Mayes, 2006).

At least two different approaches to constructivism are distinguished within the literature; cognitive constructivism which has been derived from the Piagetian tradition, and socio-cultural constructivism derived from the Vygotskian approach (Jonassen, Lee, Yang, & Laffey, 2005; Mayes, 2006; Mayes & Freitas, 2007). Cognitive constructivists focus on learners' internal meaning making and conceptual change processes, whereby individuals adapt to their environment by constructing and equilibrating knowledge structures. On the other hand socio-constructivism is based on the premise that understanding originates in our society and culture, and individual cognition results from interpersonal interaction with our social environment (Jonassen, Lee, Yang, & Laffey, 2005).

Computer Supported Collaborative Learning (CSCL) is based on more socially oriented theories of knowledge construction and meaning making (Jonassen, Lee, Yang, & Laffey, 2005). The web-conferencing environment is in essence a collaborative tool. To analyze learning in web-conferencing environments from the sole perspective of internal meaning making without focusing upon how social interaction effects learning would be to ignore a major component of the context of this study. This research study aims to investigate the impact of teacher and student interactions upon learning. Thus socio-constructivism provides a more appropriate view of learning for this research than cognitive constructivism.

2.3.3 Socio-constructivism

Jonassen (2000) describes social constructivism:

> *Social constructivists believe that learning is the dynamic interplay between the activities that people engage in and the sense of that activity that they socially negotiate. Knowledge in this view is not an object that is acquired and possessed by individuals. Rather, it is embedded in the social relations and identities of the learners as well as in the conversations and social discourse they use to make meaning of the activities and events they are a part of…Learning, at least to some degree, results from social negotiation of meaning. When learners share ideas, question each other's beliefs, argue about the meaning of something, they are building community knowledge as well as establishing their identity.*
>
> (pp. 231-232)

Adopting a social-constructivist perspective in this study allows the role of the web-conferencing environment in mediating collaboration and discourse to be highlighted. The socio-constructivist view encourages an emphasis upon how cognition is distributed among individuals and artifacts to enable the negotiation of meaning (Jonassen, Lee, Yang, & Laffey, 2005) which is in accordance with interactive, technological and task focus being adopted. In so far as socio-constructivism describes learning as being based upon the mediated interaction of participants and objects, it is also in sympathy with Activity Theory. This provides an alignment between the analytic framework and the view of learning being adopted in this study.

A socio-constructivist view of learning implies several principles for the design of meaningful learning environments. Learning environments should:

1. facilitate the active engagement of students (Hedberg, 2003; Jonassen, 2000; Land & Hannafin, 2000)
2. support the construction of knowledge (Hedberg, 2003; Jonassen, 2000)
3. enable social negotiation of meaning (Hedberg, 2003; Jonassen, 2000; Land & Hannafin, 2000)
4. utilize authentic tasks and contexts (Hedberg, 2003; Jonassen, 2000; Land & Hannafin, 2000)
5. emphasize the critical role of prior learning in meaning construction (Land & Hannafin, 2000)
6. encourage reflective thinking on learning processes (Hedberg, 2003) through the articulation of strategies (Jonassen, 2000) and the appropriate application of technology (Land & Hannafin, 2000).

This study investigates how to apply these principles in the web-conferencing system to create effective socio-constructivist learning environments. In the next section literature relating to educational technology design is reviewed and synthesized in order to derive an integrated framework for designing the web-conferencing interface. Following this, design possibilities for activity between students and the teacher are presented based on instructive, interactive and collaborative theories of learning. Then the role of the task type (content and processes) in creating learning designs is discussed.

2.4 Technology Design

2.4.1 Introduction

The functional requirements of educational interfaces differ from those in commercial contexts, primarily because in education the interface is responsible for supporting the "forming" of concepts rather than merely "informing" existing ones. This has caused some developers to posit that educational user interface design requires its own approaches and specialized theoretical HCI frameworks (Rappin, Guzdial, Reallf, & Ludovice, 1997; Sedig, Klawe, & Westrom, 2001).

This section derives a principled basis for the designing the interface of the web-conferencing learning environment. First the 'media' and 'affordance' views of learning technologies are compared and contrasted, and the affordance view is selected for its ability to emphasize features of technology that influence learning. Then principles for the design of interfaces are distilled from the literature. After this an integrated framework for the development of user interfaces is proposed that is based upon the fields of cognitive sciences, previous HCI research relating to education, and collaborative and multimedia learning.

2.4.2 Views of learning technologies

2.4.2.1 The media debate

In the 1990s prominent educational researchers Richard E. Clark and Robert Kozma debated the role of the instructional medium in learning. Clark presented the position that "there is strong evidence that many very different media attributes accomplish the same learning goal" and therefore since "there is no single media attribute that serves a unique cognitive effect for some learning task, then the attributes must be proxies for some other variables that are instrumental in learning gains" (Clark, 1994, p. 22). On the other hand Kozma (1994) advocated shifting the focus from whether or not certain media 'cause' learning to one of 'how' media affect learning. He argued that certain media possess particular characteristics that can make them either more or less suitable for creating certain kinds of learning environments.

There is strong support for the view that it is not the media that ultimately affects the amount of learning that occurs. Meta-analysis summarizing dozens of media comparison studies reporting no significant differences in learning caused specifically by the instructional media (Dillon & Gabbard, 1998). Richard Clark (2005b) cites Salomon (1984) Schramm (1977) and Meilke (1968) as supporting this claim. The foundation of Clark's argument is that no single media attribute serves a unique cognitive effect for any one learning task, and therefore the attributes must be proxies for some other variables that are instrumental in learning gains (Clark, 1994, p. 22).

Ruth Clark (2005a) emphasizes that the goal of instruction regardless of delivery media is to "help learners encode new lesson content into existing schemas in long-term memory in a way that supports retrieval back into working memory when needed at a future time and situation" (p. 596). In response to Richard Clark's (2005b) argument "there is no credible evidence of learning benefits from any medium or combination of media that cannot be explained by other non multimedia factors" (p. 98) and Ruth Clark's encouragement to search for ways that technologies can be applied to support the development of student schema, the concept of 'affordances' is introduced as an alternative to 'media' for considering educational technologies by emphasizing the possibilities for learning that different tools allow.

2.4.2.2 Affordances

Affordances have been used as a basis for examining learning technologies in a number of contexts (Conn, 1995; Gall & Breeze, 2005; Hartson, 2003; Kirschner, Strijbos, Kreijns, & Beers, 2004; Scarantino, 2003). Although the term 'affordance' has been frequently applied in educational contexts, it has been used with several different meanings (Hartson, 2003; McGrenere & Ho, 2000). Gibson (1979) first coined the term 'affordance':

> *The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment.*
>
> (p. 127)

In the original elaboration that Gibson provides, an 'affordance' is present as long as the organism is physically able to undertake the required action, and as long as the possibility of executing that action is present. For instance, a post-box is a 'letter-mailing-with-able' object with relation to a physically able adult, whether or not it is perceived as such. As Gibson describes "an affordance is not bestowed upon an object by a need of an observer and his act of perceiving it" (1979, p. 139). This implies that although affordances may be specified in stimulus information (for instance, visual, auditory, kinaesthetic) users may still need to learn to detect this information (Turner, 2005). It is only once affordances are detected that they become meaningful and valuable to the user (Turner, 2005, p. 790).

This emphasis is extended by the other frequently cited definition of affordances, proposed by Donald Norman (1998):

> *the term affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used. A chair affords ('is for') support and, therefore, affords sitting. A chair can also be carried.*
>
> (p. 9)

Norman's (1998) definition suggests that an affordance is only real once it is perceived. Applying this to educational technologies, students must perceive the affordances at their disposal before the affordance is considered actualised. This emphasises the critical need for designers to create affordances that signal how they should be utilised (Norman, 1998).

The distinction between Gibson's and Norman's definition of affordances is important, because it determines whether or not the term 'affordance' encompasses usability or just utility (Kirschner, Strijbos, Kreijns, & Beers, 2004). Gibson's frame of reference focuses upon the fundamental characteristics of the object in relation to the user, which is a question of utility. Norman places more emphasis on how an object is perceived, which relates to usability and not just utility. As well, Norman couples affordances with past knowledge and experience, whereas Gibson does not. For instance the perceived affordance offered by scroll bars on a graphical user interface are more a result of conventional understanding about how the widgets work than the inherent properties they possess (Norman, 1999).

In this thesis Gibson's original definition of affordance will be used so as to make the clear distinction between usefulness and usability. This distinguishes the user (student) and the environment (web-conferencing system) so that the relationship can be scrutinized. It is then possible to analyze the difference between the affordance and students' propensity to use them in novel and complex ways, without any potential for confusion. This also provides an opening to discuss the teacher's role in illuminating how the affordances of the tool can be optimally used, i.e., to help students to perceive the potentials of the affordances.

Affordances provide an appropriate approach for the analysis web-conferencing environments because of their emphasis upon the functionality of the design rather than the media which delivers it. In this way designers can focus on the collaborative and cognitive facilities required to enable learning instead of the carrier of the forms of representation, the latter of which have not been demonstrated to influence learning (Clark, 2005b). For a complete affordance categorization scheme along with a methodology of how this can be used to select learning technologies that match the learning requirements of tasks, refer to Bower (2008).

2.4.3 Principles for designing educational technologies

In identifying affordances as an appropriate view for considering learning technologies, attention can be focused on how to leverage affordance potentials to successfully engage learning. A review of literature relating to educational technology development resulted in the identification of four principles to guide the design of learning technologies.

2.4.3.1 Operational transparency

Firstly, the student's reflection should be focused on the content of learning rather than how to operate the technologies (Laurillard, 2002). This means that features afforded by an interface should be signalled in a way that makes them operationally transparent, so that students do not spend unnecessary time trying to understand how they function. The usability of tools influences the ability of the tool to mediate learning and the extent to which they are used (Cheng & Beaumont, 2004).

2.4.3.2 Supporting construction

Secondly, emerging technologies should be applied in way that has learners actively analyzing information and constructing knowledge (Jonassen, 2000; Tu, 2005). When computer technologies are used as intellectual partners to support representing, reflecting and higher order learning they become "cognitive tools" (Herrington & Kervin, 2007) or "mindtools" (Jonassen, 2000). In this light educational technology should be designed in a way that enables students to represent their ideas, understandings, and beliefs (Jonassen, 2000). By amplifying learners' capacity to manipulate and interrelate information, technology can support knowledge construction by transcending the limitations of the mind (Jonassen, 2000).

2.4.3.3 Enabling collaboration

Learning technologies should enable intuitive collaboration (Lipponen & Lallimo, 2004). Tu (2005) points out that technology can particularly effective at supporting collaborative decision making. This emphasis upon collaboration for achieving learning through negotiation and the construction of communal artifacts aligns with the principles of Activity Theory (Bellamy, 1996), as well as with the constructivist view of learning adopted in this study.

2.4.3.4 Facilitating expression

Also, when designing and utilizing technology based learning environments educators need to be particularly sensitive to how the absence of visual and other non-verbal cues may affect collaboration (Jonassen, Lee, Yang, & Laffey, 2005). The capacity to gauge sentiments through technology based learning environments may be difficult if textual communication is the only modality provided. If possible, interface designers should provide the capacity for students to effectively express non-content related matter.

Given these principles, the educator's challenge is to apply these principles to interface design based on the extensive literature relating to what is known about how students learn. Effective user interface design is a complex task, and a holistic approach requires the consideration of many interrelated factors.

2.4.4 Scientific underpinnings of educational technology design

There are several bodies of knowledge relating to how students learn that provide understanding into how to design effective educational user interfaces. Educational designers and technologists can either decide to utilize one particular theory in the development of user interfaces at the exclusion of others, or they can attempt to take a more synergistic approach that integrates wisdom from several fields. Cognitive science, Cognitive Load Theory, Multimedia Learning Principles and social learning theories all provide insight into how educational user interfaces may be more effectively designed. This section introduces relevant understandings from each of these fields. On this basis an integrated approach to interface design in the web-conferencing environment is presented.

2.4.4.1 Cognitive sciences

Although a socio-constructivist view of learning emphasizes the role of others in forming understandings, learning ultimately takes place in the mind of individuals. While the exact cognitive processes underpinning learning are dependent on the individual and task at hand, neuroscientists and cognitive psychologists have been able to deduce some general mechanics of cognition that underpin learning.

Learning commences by capturing student *attention*. Stimuli may target auditory receptors (for example, by using verbal instructions), visual receptors (for instance, by using images or text), or both. If students' vigilance network was adequately active to signal their orienting network, which in turn engages their executive network, the likelihood is that the information will reach their working memory (Byrnes, 2001, p. 85).

Images that do enter the visual buffer only have about 1 second to be interpreted and important information to be *selected* before being lost, and the auditory system retains speech-like patterns for only about 2-3 seconds (Anderson, 1995, p. 48). Selection involves coordination of the right brain to process the vast amounts of information being received by the students' sensory fields and their left brain to select individual elements from their perceived environment that are identified as required for further processing (Sylwester, 1995, p. 50).

To make sense of the transmitted stimuli so that they can then further process the information received, students need to *retrieve* relevant records[2] relating to the task from permanent (long term) memory. The ease with which they are retrieved depends on the 'string' of the record (degree to which it can be retrieved from memory and made available to consciousness, dependent on the amount of practice undertaken) and the 'activation level' of the record (extent to which the record is consciously engaged at a particular time) (Byrnes, 2001, p. 51).

The schema retrieved from permanent memory can then be used in working memory for processing with the external information that has been received, providing the opportunity for *comprehension* to occur. For instance, textual information may be interpreted by the orthographic processor (which processes written letters and words), the meaning processor (which interprets the meaning assigned to words) and the context processor (which constructs a coherent interpretation of the task, often called the 'referential representation' or 'situational model') (Seidenberg & McClelland, 1989).

Once information has been comprehended it needs to be *synthesized* into an appropriate schema if learning is to occur. That is to say, working memory needs to assimilate the new information into existing schema. Alternatively if that new information contradicts existing mental constructs then new schema need to be constructed, which is referred to as 'accommodation' (Slavin, 1994). This ability to purposefully combine declarative, procedural, and conceptual knowledge with information received from the environment in a strategic, efficient and context sensitive underpins the process of problem solving (Byrnes, 2001, p. 148).

When students have integrated the new information and updated their schema, details of the learning episode need to make their way back into ('permanent') *memory*. When first learning skills, memories will naturally contain both foreground and background elements of the experience (Sylwester, 1995, p. 94). Findings suggest that time is required for the brain to fully consolidate memory traces and transform them into permanent records, and the process is supported by active processing and elaboration tasks (Byrnes, 2001, p. 56).

However, for deep learning to have occurred, it is not enough for episodic and declarative aspects of the experience to be allocated to memory; *abstraction* of the experience into semantic and conceptual forms is required. This requires important aspects of the short-term experience to be translated into more context free permanent records (Sylwester, 1995, pp.

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[2] A record is a "mental representation of an item of information that is permanently stored in memory" (Byrnes, 2001, p. 50).

47, 94). In this way the facts and procedures that underpin the activity can contribute to the learner's conceptual knowledge base from which future problems can be solved (transfer).

This summary describing the stages of attention, selection, comprehension, retrieval, synthesis, memorization and abstraction has formed the foundation of several instructional models within education, such as Gagne's Conditions of Learning framework (Gagné, 1985) and subsequent refinements (Clark, 2003; Clark & Lyons, 2004). While the cognitive stages identify just some aspects of brain functioning involved in learning and only at a broad level, an understanding the sorts of cognitive processes that need to take place in the human mind in order for learning to occur allows educators to create interface designs that account for each of these steps.

2.4.4.2 Cognitive Load Theory

Intimately related to the cognitive stages underpinning learning is Cognitive Load Theory. Cognitive load refers to the amount of mental processing that is required by an individual when performing a task (van Merriënboer & Ayres, 2005). The success of a learning episode depends on the extent to which the cognitive load being placed upon students is appropriate. Working memory is able to store approximately seven (plus or minus two) pieces of distinct information simultaneously, and between two and four units can be actively processed at any one time (Sweller, 2005a, p. 21). If the requirements of the learning task exceed this capacity the learner must discard some of the units of information, meaning that they cannot immediately construct complete schema. The educational interface provided determines the cognitive load in at least two respects; well designed interfaces reduce the cognitive load required to operate them, and the interface determines the cognitive efficiency with which concepts are represented.

Three types of cognitive load are identified by van Merriënboer and Ayres (2005, pp. 6-7):

1. *Intrinsic* cognitive load – cognitive load resulting from the natural complexity of the information that must be processed, as a function of element interactivity.
2. *Extraneous* cognitive load – cognitive load caused by inappropriate instructional designs that fails to focus working memory resources on the relevant components for schema construction.
3. *Germane* cognitive load – the 'effective' cognitive load resulting from the amount of effort the individual undertakes in order to construct schema and automate processes (for instance, making the effort to process a variety of examples and interrelate them).

It is important to point out that intrinsic, extraneous and germane cognitive load are additive (Sweller, 2005a). To this extent, educators need to ensure their learning designs reduce extraneous cognitive load caused by inappropriate instructional approaches so that working memory can be dedicated to intrinsic and germane cognitive load. If reducing extraneous and germane cognitive load to their minimum still results in a number of interacting elements that cause cognitive overload, then the educational designer needs to consider ways to reduce the intrinsic cognitive load of the task, such as by reducing the scope and complexity of the learning episode (Mayer, 2005b; Reigeluth, 1980; van Merriënboer & Ayres, 2005).

Cognitive load is reduced as learners group several pieces of related information into a singular integrated conceptual unit (for examples, see Aharoni, 2000; Rist, 1995). Once students can perceive a collection of information as a unified structure, they can treat the information as a single unit in working memory rather than multiple units, hence reducing cognitive load. Thus any processes or instruction that facilitates the synthesis of objects into conglomerate 'chunks' frees up working memory, providing cognitive resources that can be dedicated to other aspects of a learning episode.

2.4.4.3 Multimedia Learning Principles

A scientific understanding of cognition and it's implications for cognitive load has led to research into and the subsequent development of several principles regarding learning through multimedia. Prominent expert in the field, Richard Mayer, defines multimedia as "the presentation of both words (such as spoken text or printed text) and pictures (such as illustrations, photos, animation, or video)" (2005a, p. 2). There are several principles from multimedia learning research that inform educational user interface design.

According to the '*multimedia principle*', people learn more effectively from words and pictures than from words alone (Fletcher & Tobias, 2005). The explanation for this phenomenon is that the coding of words and images involves processes that are to a significant degree both independent in so far as they involve separate cognitive units, but also additive in so far as they are capable of interacting with and complimenting one another (Pavio, 1986). This effect is supported by other research studies reporting superior transfer of learning when narration is accompanied by animation compared to narration or animation deployed in isolation (Fletcher & Tobias, 2005, p. 117).

Closely related to the multimedia principle in understanding how different presentation media interact is the '*modality principle*' (Low & Sweller, 2005). The modality principle states that presenting some of the instructional content in visual mode and other parts of the material in auditory mode can lead to more effective learning than representing the entire content using only visual modes or auditory modes. This differs from the previous 'multimedia principle' in that the information in the two modes are not elaborating one another but rather complimenting one another. The explanation for the improvement in comprehension relies on the fact that the visual-spatial scratch pad and the phonological loop can process different types of information both independently and simultaneously, at least to some extent (Low & Sweller, 2005, p. 148). Therefore complimenting visual information with an auditory explanation is more cognitively effective than complimenting visual information with text (another visual form).

According to the 'redundancy effect' information that is unnecessarily repeated in different forms can result in inefficient learning (Mayer, 2005b, p. 184; Sweller, 2005b). This is explained by the extra and unnecessary cognitive load that is placed on learners to process the redundant information. For instance, including textual explanations that repeat information contained in an audio-visual presentation can negatively affect student learning. As well, if an elaboration repeats information that was already contained in earlier explanation without providing any additional interpretation or interrelation of the knowledge, then the exclusion of that additional information may enhance learning (Sweller, 2005b).

The '*split-attention effect*' describes how people learn more effectively when words and pictures are physically and temporally integrated (Ayres & Sweller, 2005; Mayer, 2005b). Placing related information in close time or space proximity reduces the cognitive load caused because learners having to mentally integrate multiple sources of information that would otherwise be 'split'. Separating information physically requires students to determine which elements relate to one other and how they are associated. Separating information by time imposes an added burden of requiring students to accurately store a representation of an element in memory (at a stage where that representation may be unfamiliar or not be fully formed) and then relate it to material presented at a later stage.

Salomon's (1994) *Symbol System Theory* advocates that appropriate matching of the modality to the nature of the information being communicated reduces the level of elaboration and recoding required for learner comprehension. For instance, if students require instruction on how to perform a computer based process, then a page of textual description or verbal instruction is a less effective means of communication than an audio-annotated desktop recording. This is an example of 'transfer-appropriate processing' (Bransford, 1979).

The process of emphasizing the parts of an instructional sequence that require greater attention improves learning (Mayer, 2005b). '*Signalling*' (or 'highlighting') may be static or dynamic. Static signalling takes the form of using visual effects to emphasize important elements of the learning materials, for instance, using 'metacommunicative' strategies such as text highlighting, central placement of diagrams, or increasing the size of a learning object (Hatcher, 2003; Rouet & Potelle, 2005). Dynamic signalling includes using auditory instruction or a pointer tool to direct student attention to the material upon which they should focus.

Personalization within the environment being provided through the use of familiar voice and language can lead to deeper learning (Mayer, 2005c). Several studies across a range of contexts demonstrate positive learning effects by using language that is conversational rather than formal, and a voice with a familiar rather than foreign accent. Note that research into applying personalization in ways not directly associated to the information being broadcast (for instance, having the image of the speaker within the interface) bear no substantial educational gains (Mayer, 2005c).

There are several other multimedia learning principles that researchers have identified (Mayer, 2005a), for instance guided discovery and self-explanation. While these can play an important role in the delivery of computer based learning, the focus of the technology design is on more general and instantaneous aspects of interface use that apply to all educational contexts rather than on the task type being applied. As such coverage of more task oriented theories is deferred until later sections.

2.4.4.4 Collaborative and active learning

Computer Supported Collaborative Learning (CSCL) is a field that has emerged from Computer Mediated Communication (CMC) as its own sub-discipline of study (Jonassen, Lee, Yang, & Laffey, 2005, p. 247). Collaborative learning approaches prime the activation of social response in the learner which can in turn increase the active cognitive processing by the learner (Mayer, 2005c, p. 202). This leads to an increased effort in selecting, organizing and integrating information, which results in greater transfer of problem solving capacities (Mayer, 2005c). Collaborative learning also affords the opportunity for instant access to troubleshooting support, as well as the capacity to learn 'vicariously' (Bandura, 1977). Interface designs influence collaborations by determining the extent to which loose or tightly coupled interactions are possible, and through the task management capacities they afford. (Neale, Carroll, & Rosson, 2004). In this section, key aspects of socio-constructivist theories are briefly described as they relate to educational user interface design.

Vygotsky's (1978) classic socio-cultural theory of learning is foundational to CSCL. The "zone of proximal development" is defined as the learning that is made possible through the help of more capable peers, adults, or social artifacts. Under this (and other related) socio-constructivist theories, the role of the educational user interface designer becomes one of facilitating collaborations for meaning to be efficiently constructed and shared. Vygotsky (1978) also emphasizes the role of "scaffolding" learning with supporting instructional materials or processes, such as cues, heuristics, hints, examples and so on. In terms of interface design, scaffolding should provide learners with access to support when required without interrupt the main flow of the learning experience.

"Situated cognition" is another learning theory with a sociological basis. Wilson and Myers (2000) identify aspects of situated cognition with implications for user interface design, including:

- Integrating levels of scale – viewing individual cognition within the larger physical and socially constructed context of interactions, tools and meanings
- Constructed meaning – a shift in focus from individual meaning making to groups and communities making use of shared rules and facts
- Meaning construction as a social activity – participants develop shared ways of responding to patterns and events which creates a culture or system of discourse.

(Wilson & Myers, 2000)

Situated cognition emphases the role of the interface as a mediator for social construction of artifacts and meanings.

The inter-reliance between participants is extended even further by "distributed cognition theory", which views understanding as being shared between people and artifacts. Distributed cognition theory "extends the reach of what is considered cognitive beyond the individual to encompass interactions between people and with resources and materials in the environment" (Hollan, Hutchins, & Kirsh, 2000, p. 175). The two central principles of distributed cognition are the broadening out of both the boundaries of unit of analysis and the range of mechanisms that may be assumed to participate in cognitive processes (Hollan, Hutchins, & Kirsh, 2000). Because distributed cognition focuses on all the elements involved in cognitive processes (not just those that occur in the mind) aspects of the immediate and potentially distant environment are inextricably incorporated into the approach and required to understand how the system achieves its goal. Because the mechanisms of cognition are not assumed to be encompassed solely within individuals (for example, analysis may relate to how an airline cockpit remembers flight information) more holistic models of knowledge creation can be posited and verified (Hutchins, 1995). For instance, models can incorporate cognitive processes that are distributed across members of a group or involve interactions between internal and external representations.

Hollan et al. (2000) identify some core principles implied by distributed cognition theory. In particular:

- people establish and coordinate different types of structure in their environment
- it takes effort to maintain coordination
- people off-load cognitive effort to the environment whenever practical
- there are improved dynamics of cognitive load-balancing available in social organization (p. 190).

Under such a model the user interface needs to support the effective management of structure for shared representations. Components of distributed cognition systems are inter-reliant on one another in order for complete understandings to be formed, thus requiring heightened attention to the sociomaterial context when designing technology based environments for learning (Bell & Winn, 2000).

2.4.4.5 Previous efforts in educational user interface design

The task of designing educational user interfaces is also informed by previous attempts reported in the literature. This final section of literature review focuses on findings from previous design of applications, which offer specialized, tailored and pragmatic recommendations on how to create effective educational user interfaces.

Research by Sedig et al. (2001) identified two crucial ways in which interface design can support schema construction: by engaging students at the level of concepts rather than just operations on objects, and by providing a fading approach to scaffolding that requires students to take on cognitive load from the environment as their understanding improves. In their experiments relating to students' manipulation of geometric objects, Sedig et al. (2001) found that an interface design based on concept manipulation led to greater understanding of geometric concepts than an interface based on object manipulation. As well, the concept manipulation interface that incorporated a fading approach to scaffolding led to greater skill development than the interface that preserved all scaffolding throughout the learning sequences. If the objective is to make students learn concepts then interfaces that engage students at the level of concepts and facilitate their developing ownership of those concepts provides a direct means of achieving learning goals.

Hollan et al. (2000) note that the way in which users manipulate icons, objects, and emergent structure "is not incidental to their cognition; it is part of their thinking process, part of the distributed process of achieving cognitive goals" (p. 190). In their analysis of users' interactions with a multi-scale application (Pad++), they observed how users left certain portals open to remind them of potentially useful information or to keep changes nicely visualized; shifted objects or resized them to emphasize their relative importance; and move collections of things in and out of their primary workspace to keep certain information in close proximity but tend to more pressing currently pressing concerns. Hollan et al (2000, p. 190) recommend designing user interfaces that provide spatial flexibilities (such as those that simplify choice, those that simplify perception, and spatial dynamics that simplify internal computation), in order to support such approaches to distributed cognition.. Providing learners with the capacity to rearrange and resize objects within the interface allows spatial organization of elements that most effectively supports their particular cognitive and collaborative requirements at various stages of the concept formation process.

Research by Zhang (1997) identified how the interface can be used to support distributed problem solving. Observations indicated how information in external representations could be acquired, analyzed, and processed by perceptual systems alone without having to retrieve internal schemata from memory. Zhang's model highlights the way in which appropriate external representations can reduce the difficulty of a task by supporting recognition-based memory or perceptual judgments rather than recall.

Demetriadis et al. (1999) identify the importance of intuitiveness and transparency for educational user interfaces. Intuitiveness is described as interfaces that use proper and easily understandable metaphors, while transparent interfaces are those that do not interfere with the learning process. Selecting suitable and familiar metaphors of interaction with the interface allows users to quickly become accustomed with the way to accomplish tasks, "easily remembering and effectively using interface options in order to reach their goals" (p. 287). They describe how a transparent interface supports learners by allowing them to concentrate on the learning materials and processes without being distracted by the medium through which they are operating.

A study of a remote robotic camera system allowed Luff et al. (2003) to identify how interfaces that provide inter-participant awareness support collaborative processes. In order to allow participants to take effective action they note the importance of interfaces which:

- indicate the location, orientation, and frame of reference of others
- allow participants to determine their standpoint with regard to others
- enable participants to determine who has changed shared objects and spaces
- provide a means for users to coordinate interactions with the environment (referring, invoking, grasping, manipulating, addressing, discussing) (Luff et al., 2003, p. 78)

Luff et al. (2003) also recommend providing these functionalities within a stable constellation of artifacts and spaces so that participants may act with respect to a presupposed coherent environment.

Vu et al. (2000, p. 52) discuss the need to matching the design of user interfaces to the level of user expertise. In their analysis of the role of metacognition in expertise and expertise development, they observe how some graphical user interfaces support a more top down approach to completing tasks (i.e. perform multiple features at once) whereas other aspects support more deconstructed, sequential operation. To this extent a graphical user interface can be designed to support more expert versus novice interactions, depending on the user's familiarity with the tools provided within a system.

Based on an analysis of group construction of jigsaws, Johnson and Hyde (2003) emphasize the importance of supporting the development of generic problem solving and collaborative capacities. Their analysis noted how operational mental models that participants utilized (referred to as "Task Knowledge Structures") were underpinned by more generic set of schema. They propose that such higher level "Fundamental Knowledge Structures" – general capabilities such as how to problem solve or collaborate – have a substantial impact on the success of group efforts. Designing interfaces that facilitate the development of Fundamental Knowledge Structures (for instance through the collaborative and problem solving processes they facilitate) also supports students to abstract skills beyond the technological context in which they are being used (Salomon, 1992).

2.4.5 An 'Integration of Theories' framework

These broad-spread but pervasively relevant bodies of knowledge all contribute to the task of educational user interface design. An integrated approach for applying these theories is presented below to provide a consolidated view of how the literature can be applied. The approach presented is neither meant to be algorithmic nor prescriptive. Rather, it demonstrates how the previously discussed findings as well as practical design experience can be interrelated in order to design educational user interfaces.

The framework is presented in terms of the underlying responsibilities of the educational user interface designer, as outlined in the previous sub-sections of literature review. These are:

- attending to stages of cognition
- applying multimedia learning principles
- enabling collaboration
- balancing cognitive load.

Central to this model is that cognition stimulation, application of multimedia learning principles, and collaboration enablement are underpinned by the process of cognitive load balancing (as represented diagrammatically in Figure 6).

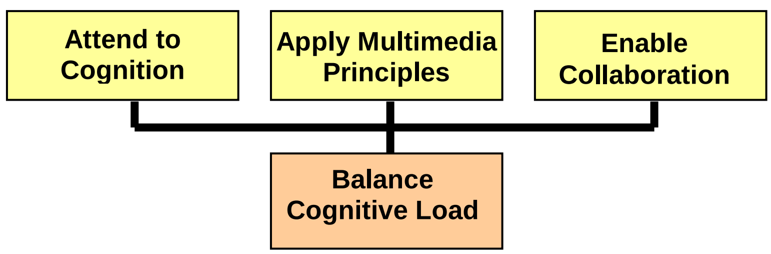

Figure 6 – The four responsibilities of educational user interface designers

The details of the framework are represented in Table 1 and Table 2 below.

Table 1 describes how specific strategies from the literature can be used to support instructive and collaborative aspects of the different stages of cognition. Balancing cognitive load has been separated out into a separate table (Table 2) to denote the way in which it is a background role continually being performed while attending to the stages of cognition, applying multimedia learning principles and enabling collaboration. Note however that the tables are designed to be used in conjunction with one another, so that cognitive load is being managed while students are learning and collaborating.

It is not proposed that all strategies from the two tables need be applied in all applications because some strategies may act as substitutes for others or may not be appropriate for the context at hand. Nor is it implied that the framework is exhaustive in the strategies it articulates – as the technology design field matures other findings will undoubtedly be of benefit to the development process. However, the approach demonstrates how the components of cognition, multimedia learning principles, the chosen level of collaboration, and appropriate levels of cognitive load can all be synergistically considered when designing the web-conferencing interface.

Table 1 – Integration of Theories Framework: Attending to cognition, finessing media, enabling collaboration

	Instructive →	Collaborative
1. Attention	• Providing an aesthetically engaging interface design (exploiting colour, light, and movement if purposeful and not distracting) • Engaging tone with language familiar to learner (Mayer, 2005c)	• Providing interfaces facilitating and emphasizing expression – e.g. chat, colour, rich media sharing and representation of resources and ideas • Provide dynamic collaborative aspects within the interface – motion and sound
2. Selection	• Implicit signalling (metacommunicative) tactics such as increased font size and colour highlighting (Hatcher, 2003; Rouet & Potelle, 2005) • Explicit signalling such as voice commentary directing students' attention to specific aspects of the learning material or use of arrows with associated text explaining importance (Mayer, 2005b) • Adjusting the size and placement of tools/information within a multi-tool interface to emphasize relative importance	• Providing access to tools that support text delimiting (such as font options), emphasis within diagrams (such as colour) and the capacity to indicate focus (such as pointer tools) • Provide the ability to also use audio to direct others' attention when using visual communications (such as aspects of a whiteboard upon which to focus) • Provide the opportunity to move/resize tools and information within the collaborative space to emphasis content that deserves current focus (Hollan, Hutchins, & Kirsh, 2000)
3. Retrieval	• Providing diagrammatic, textual and auditory cues that activate the required prior knowledge (Vygotsky, 1978)	• Provide shared spaces to conduct discourse related to the task (chat tools, collaborative notes areas) allowing memories to be activated (Byrnes, 2001) • Provide spaces supporting brainstorming tasks (such as whiteboards)
4. Comprehension	• Transfer appropriate processing - matching the form of the specification / demonstration closely to the circumstances under which it will be required (Bransford, 1979; Salomon, 1994; Slavin, 1994, p. 199). • Represent information in visual and auditory forms – Multimedia Principle (Fletcher & Tobias, 2005) • Physically and temporally integrate related information – reducing split-attention effect (Ayres & Sweller, 2005; Mayer, 2005b) • Textual and audio scaffolding (Vygotsky, 1978)	• Providing spaces to ask questions (e.g. chat, discussion board) providing support from more capable peers through the Zone of Proximal Development (Vygotsky, 1978) • Providing public spaces to post thoughts allowing students to be exposed to the mental models being formed by others and thus learn vicariously (Bandura, 1977) • Providing the capacity for students to move and resize tools to communicate their perceptions of relationships between information and its relative importance (Hollan, Hutchins, & Kirsh, 2000)

5. Synthesis	• Explicit provision of problem solving heuristics (e.g., textual descriptions, or expert commentary via audio), supporting Fundamental Knowledge Structures (Johnson & Hyde, 2003) • Create interfaces that engage learners with concepts rather than the objects upon which the objects act (Sedig, Klawe, & Westrom, 2001)	• Spaces for collaborative concept formation and problem solving – promoting shared and distributed cognition (Hollan, Hutchins, & Kirsh, 2000; Wilson & Myers, 2000) • Synchronous communications (chat, audio) to support the tightly coupled collaborative interactions required for problem solving. (Engeström, 1987; Neale, Carroll, & Rosson, 2004)
6. Memory	• Posting of pertinent information to support cognition (Zhang, 1997) • Encouraging active processing of information by providing opportunities for practice (Sylwester, 1995, p. 95) and elaboration (Byrnes, 2001, p. 56) – promoting automaticity.	• Providing shared spaces for posting of pertinent information to be remembered • Providing opportunities for student centred collaboration about pertinent information, assisting recollection and transfer (Mayer, 2005c)
7. Abstraction	• Providing multiple examples in proximal physical/temporal spaces to facilitate comparison and contrast • Provision of interfaces that encourage particular problem solving approaches, thus supporting the transfer of skills outside the context in which they are being used (Salomon, 1992)	• Providing the capacity for students to place concepts physically/temporally to support comparison and contrast • Providing spaces for students to jointly summarize their findings and propose heuristics • Providing mechanisms for students to signify related elements between examples

Table 2 – Integration of Theories Framework: Balancing cognitive load

Intrinsic	Decrease intrinsic cognitive load by: • providing an interface that allows cognitive and collaborative operations appropriate for the ability of the level of the learner (Vu, Hanley, Strybel, & Proctor, 2000) • reducing the complexity of examples / tasks and reducing the scope of the learning episode, for instance by splitting up large tasks into smaller ones (Mayer, 2005b; Reigeluth, 1980; van Merriënboer & Ayres, 2005) • facilitating the 'chunking' of related information into single conceptual constructs (Aharoni, 2000; Rist, 1995)
Extraneous	Decrease extraneous cognitive load by: • removing superfluous / repetitive information – Redundancy Principle (Mayer, 2005b, p. 184; Sweller, 2005b) • using multiple media to allow dual processing rather than representing all information in one form – Modality Principle (Low & Sweller, 2005) • providing interfaces that are based on familiar paradigms of interaction with controls that attract minimal attention (Demetriadis, Karoulis, & Pombortsis, 1999) • providing the opportunity to move information from intra-cognitive to external spaces – distributed cognition (Hollan, Hutchins, & Kirsh, 2000; Zhang, 1997) • Proving the capacity for participants to effectively orient themselves amongst other participants and resources (Luff et al., 2003)
Germane	Increase germane cognitive load by: • prescribing more challenging, holistic, problem solving tasks (van Merriënboer & Ayres, 2005) • encouraging students to deeply process and interrelate knowledge

When designing educational tasks and interfaces for collaboration it is also important to consider that there will be a range of technological communication skills required, and that this will place a load on cognition. The more tools that students are required to operate, the less familiar those tools, and the more demanding their application, the greater the cognitive load. Technological pre-training before the learning task is undertaken can provide students with more cognitive resources to focus on the to-be-learned material (Clarke, Ayres, & Sweller, 2005; Morrison & Anglin, 2005, p. 95).

Having integrated findings from the literature to develop a framework for designing interfaces in a way that accounts for the type of interactions desired, the next section discusses relevant theory and possibilities relating to the type of activity that may be encouraged.

2.5 (Inter)Activity Design

2.5.1 Introduction

The design of the activity forms is a critical aspect of learning design being analyzed in this research (alongside the technology design that was discussed in the previous section and the content or task design that will be discussed in the next section). Decades of research indicate that the activity in which the learner engages, and the outcomes of that activity significantly impact upon learning (Beetham, 2007). One of the implications of adopting Activity Theory as a view for considering learning design is that environments need to effectively facilitate collaboration between students and experts, and between students and their peers (Bellamy, 1996).

Beetham (2007) makes an important distinction between the activity in which students engage and the task type:

> *tasks are required of learners by the demands of the curriculum. Activities are engaged in by learners in response to the demands of the task.*
>
> (Beetham, 2007, p. 26)

That is to say, the content that needs to be addressed as part of the curriculum can be addressed using a variety of different 'activity designs' (ways students engage with the task and with each other). The activity design relates to how students interact, whereas the task design relates to the conceptual content (object) being considered.

First, three different types of activity design will be identified to form a framework for designing and analysing activity in this study – teacher-centred (transmissive), teacher-led (interactive) and student-centred (collaborative). Following this, relevant research relating to the implementation of activity designs in technology based learning environments.

2.5.2 Types of activity design

Task ownership is a critical feature of activity design, and one that distinguishes one learning design from another (Kirschner, Strijbos, & Kreijins, 2004). The level of task ownership determines the mode of interaction between the teacher and students. Ruth Clark (2005a) identifies three such types of activity designs for e-learning:

1. **Teacher-centred (receptive)** – transmission based information delivery approaches, where the lecturer communicates a stream of information to students.
2. **Teacher-led (directive)** – these approaches use a deductive instructional approach (Clark, 2005a). Small chunks of content, examples or demonstrations, may be presented, followed by periods of student activity such as practice or question answering. Feedback and interaction between the teacher and student occurs. This sort of approach involves roughly equal information flow between lecturer and students about the concepts being discussed.
3. **Student-centred (guided discovery)** – more inductive learning environments in which learners complete a series of goal-related tasks. Collaborative learning approaches are based on this approach, whereby student-to-student flow of concept forming discourse is central and the teacher adopts a more facilitory role.

Clarke (2005a) suggests that student-centred approaches are more likely teach far-transfer skills where learners build more flexible mental representations that can be applied to a variety of situations. As well, different approaches to instruction may be appropriate for different levels of understanding. Clark (2005a) comments how this may apply:

> *the effectiveness of any one e-learning lesson is shaped by the context in which it is deployed. Thus a given lesson that is effective for novice learners who need to build specific procedural skills will be less effective for more experienced learners who need to build mental models that they can apply to diverse situations.*
>
> (p. 594)

An open question is the extent to which different types of activity design (levels of task ownership) are more appropriate for different levels of mental model formation. That is, whether or not the development of students' mental models at the various levels is best facilitated by different modes of interaction between participants.

The three categories are not designed to provide an unequivocal hierarchical system. In a classroom setting such as the web-conferencing environment both the teacher and students are present and to some extent participate in activities. Students can comment in teacher-centred learning episodes just as the teacher can interject during student-centred activities. However observing where ownership for the activity resides (with the teacher, teacher leading students, or centred upon the students) provides a common vocabulary for discussing approaches to in-class interaction. As these form the basis of differentiating activity designs in this study, literature relating to their nature is explicated below.

2.5.2.1 Teacher-centred activity designs

Transmission approaches may more appropriate when students in the class are yet to form understandings about a particular topic (Magliaro, Lockee, & Burton, 2005). When students have no pre-existing schema they may need to be presented with a clear and coherent kernel upon which to found their understandings, to accommodate it within existing schema, and subsequently elaborate their model. Transmission approaches can provide students with exemplars and demonstrations that can create a basis for participation in more active learning tasks (Magliaro, Lockee, & Burton, 2005).

Offering a "cognitive apprenticeship" is one approach espoused as effective for developing advanced performance in a learning domain (Collins, Brown, & Holum, 1991). Expert modelling offers educators the capacity to impart not only subject matter knowledge but also attitudes, thought processes, problem solving techniques and a whole range of other underlying skills that are often not addressed in more student-centred approaches. In the field of computing, Andrew Hunt and David Thomas (2000) identify that programmers who are skilled at their business need to be fast adapters, inquisitive, critical thinkers, realistic and in many respects jack-of-all-trades. These are not skills that are easily taught. However, expert modelling provides a means of cultivating these skills in a manner that is contextually embedded.

Landa's (1976) Algo-heuristic theory can be deployed specifically to support expert modelling. Algo-heuristic theory deconstructs the conscious and especially unconscious mental processes that underlie expert learning, thinking and performance in any domain. The theory presents a system of techniques for getting inside the mind of expert learners and performers to uncover the underlying processes involved. These are then decomposed into elementary components – mental operations and knowledge units – which can in turn be used to teach algorithmic and/or heuristic based tasks. Integrating algo-heuristic approaches within an expert modelling sequence enables students to be exposed to both implicit and explicit expertise development mechanisms.

2.5.2.2 Teacher-led activity designs

Teacher-led activity designs represent a movement from transmissive to interactive learning. Robins et al. (2003) articulates this contemporary educational trend:

> *recent shifts in educational practices are tending towards a focus not on the instructor teaching, but on the student learning, and effective communication between teacher and student. The goal is to foster 'deep' learning of principles and skills, and to create independent, reflective, life-long learners. The methods involve clearly stated course goals and objectives, stimulating the students' interest and involvement with the course, actively engaging students with the course material, and appropriate assessment and feedback.*
>
> (p. 156)

However Laurillard (2002) points out that it is not just conducting a dialogue with students that influences learning, but how it is conducted. For instance, 'Socratic dialogue' is interactive instructional technique, but is an authoritarian approach that lacks an explicit focus on the goal of learning. Because it is a rhetorical technique students' conceptual development may be impeded, and to the extent that it does not reveal all of the participants' conceptions the level of student understanding cannot be fully gauged. As Laurillard (2002) points out:

> *Tutors generally have little trouble in articulating their own view, whatever the medium; that is their art. The more difficult trick for them is to give the student the space to express theirs, and to encourage them to elaborate it sufficiently.*
>
> (p. 148)

Laurillard (2002) presents a Conversational Framework as a means to effectively progress from transmissive to more interactive teaching approaches in academic environments. It is based upon an epistemology that situates learning as a relationship between the student and the world that is mediated by the teacher. The framework views the interrelationship between the teacher, student and content as "a continuing iterative dialogue between teacher and student, which reveals the participants' conceptions, and the variations between them, and these in turn will determine the focus for further dialogue" (p. 71).

Underpinning the Conversational Framework is a set of requirements for all learning in academic settings:

- it must be an iterative dialogue;
- which must be discursive, adaptive, interactive and reflective;
- and which must operate at the level of descriptions of the topic;
- and at the level of actions within the related tasks.

(Laurillard, 2002, p. 86)

The emphasis on the interactive and constructive processes of the Conversational Framework aligns directly with socio-constructivist view of learning adopted in this study. According to Laurillard (2002) the five necessary and interdependent aspects of constructing understanding in socially mediated contexts of are:

1. apprehending the structure of the discourse – organizing and structuring content into a coherent whole by distilling pertinent information from the narrative
2. interpreting the forms of representation – interpreting and applying semiotic systems to transition between concepts and events and their representations
3. acting on descriptions of the world – manipulating and combining representations to generate further descriptions of the world
4. using feedback – adjusting actions and descriptions on the basis of intrinsic and extrinsic feedback in order to meet goals
5. reflecting on the goal-action-feedback cycle – analyzing how feedback relates to the goal and action at a meta level.

(pp. 60-61)

The web-conferencing environment being studied is a novel environment for this to be achieved. The discourse is multimodal through unique and varying syntheses of flexible media, forms of representation may use the same or different modalities as that used for discussion and may be interwoven or separated, actions on descriptions of the world are determined by the affordances of the environment, the feedback can be multi-channel with new possibilities for directing communication to different groups of participants, and reflection can occur in a shared activity space.

The ways in which these five requirements can be satisfied is represented in the complete Conversational Framework model, illustrated in Figure 7 below. Teacher and student both operate at the level of descriptions of the topic goal as well as actions on a task environment. The arrows represent learning and teaching activities that constitute the dialogic relationships both within and between the two participants.

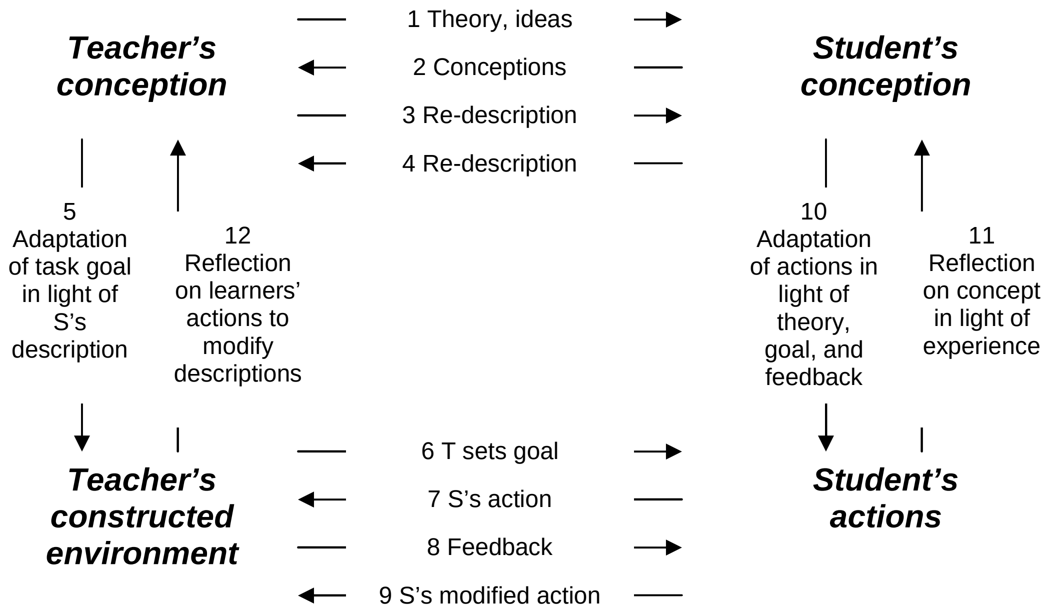

Figure 7 – Laurillard's (2002) Conversational Framework

The model highlights important flows and formations in the learning process which can be summarized as:

- discursive processes – the exchange of conceptions at the level of the topic goal (activities 1- 4).
- adaptive processes – internal adjustments by teacher and student leading to changes in actions on the basis of discursive processes (activities 5 and 10)
- interactive processes – activities at the task level regarding the setting and accomplishment of the goal (activities 6 to 9)
- reflective processes – internal reflection upon operations at the task level in order to redefine conceptions at the level of description of the topic goal (activities 11 and 12).

(Laurillard, 2002, p. 86)

Critically, the model highlights the importance of discursive (conversational) flows to enable learning. Laurillard (2002) argues that different learning technologies are appropriate for facilitating the different processes, and provides examples for each. However, with its capacity to support discursive, adaptive, interactive, and reflective processes within the one application, the web-conferencing environment is able to support the entire Conversational Framework. Thus, the web-conferencing system can be used to completely mediate teacher-led learning using Laurillard's (2002) Conversational Framework.

Waite et al (2004) has applied conversational approaches in computing in response to research indicating a reluctance of computing students to interact. To engender change in the student culture, Waite et al (2004) proposed the following three interventions:

1. Developing a "conversational classroom" in order to demonstrate the advantages of collaboration. This is achieved by the professor facilitating a discussion of the

material relevant to a particular class session instead of giving a lecture of the material.
2. Providing students with explicit approaches to group decision making that they can then incorporate into the process of completing assignments
3. Devaluing the weighting of assignments to emphasize their instructional nature (processes rather than products).

Waite et al. (2003) describe how transforming the classroom into a more conversational environment (both between students and with the professor) led to a doubling of the percentage of A grades that students in their distributed systems course achieved. The transformation from traditional transmission approaches to a more engaged and participatory environment promoted the development of shared understandings. The collaborative model requires students to adopt a more active, responsible approach to their education. The two primary resources for implementing their approach are techniques for creating interaction and techniques for creating a sense of authentic engagement (Waite, Jackson, & Diwan, 2003). Persistence and commitment to emergence were identified as critical to creating and sustaining the system as a whole.

2.5.2.3 Student-centred activity designs

Student-centred activity designs endow students with ownership over the activity. One of the most espoused forms of student-centred that is particularly relevant for teaching in the web-conferencing environment is collaborative learning. As previously mentioned, benefits of collaborative learning include greater attention to task by virtue of heightened stimulation (Mayer, 2005a), deeper learning through more active participation (Mayer, 2005a) and the opportunity to learn vicariously (Bandura, 1977). Waite et al (2004) points out that collaborative learning allows students to overcome third order ignorance, or situations when students do not know that they do not know.

The application of group-work approaches responds to industry criticism that graduates lack collaborative skills (Waite, Jackson, Diwan, & Leonardi, 2004) and provides students with interoperative abilities that they will require in the workforce (Beck, Chizhik, & McElroy, 2005). Collaborative approaches also offer social and generic skills benefits such as the development of collaborative support networks. Collaborative environments are also highly valued by students for the range of discursive learning opportunities they afford (Laurillard, 2002).

One synchronous collaborative learning approach that has been extensively investigated by computer science education researchers is that of pair programming. Objective benefits of implementing such approaches have included:

- Lower failure and marginal pass rates (Chase & Okie, 2000; McDowell, Werner, Bullock, & Fernald, 2002; Nagappan et al., 2003)
- Better overall performance on projects and examinations (McDowell, Werner, Bullock, & Fernald, 2002; Nagappan et al., 2003)
- higher quality code (Nagappan et al., 2003; Williams & Upchurch, 2001)
- faster production of code (Nagappan et al., 2003)

Researchers also note that pair programming can provide social and affective benefits such as:

- a more productive and less frustrating laboratory environment (Nagappan et al., 2003)
- more self sufficient learners (Nagappan et al., 2003)
- increased learner satisfaction (Williams & Upchurch, 2001)
- team-building and communication skills development (Williams & Upchurch, 2001).

There is evidence that other collaborative activity designs besides pair-programming are successful for improving computing learning outcomes. In Beck et al's (2005) investigation of cooperative learning in introductory computing courses cooperative learning groups performed significantly better than non-cooperative learning groups. Gonzalez (2006) found that by transforming the latter part of introductory programming lectures to involve group activities students were significantly more likely to attempt, complete and pass the subsequent computing subject. For more examples of how collaborative learning can support improved learning outcomes in computing refer to a review by Bower and Richards (2006).

There are several factors requiring consideration when implementing student-centred approaches. For instance, a level of individual accountability is required for collaborative learning environments to succeed (Kirschner, Strijbos, & Kreijins, 2004; Slavin, 1990). At the same time group-work often imposes greater time demands than instructive approaches, especially if groups struggle to synchronize their activity (Daigle, Doran, & Pardue, 1996). The way in which teachers address this issue may also be able to assist in promoting individual accountability and more effective interaction. For instance Beck et al. (2005) note gains in assigning content roles (Variable Manager, Program Reader, Method Executor, Facilitator) rather than functional roles (keyboard operator, mouse operator) as a way to reduce the breadth of content upon which novice computing students need focus. This approach reduced the likelihood of cognitive overload by restricting the novel conceptual material that they needed to manage at the same time as promoting individual accountability and coordination of activity.

While it is important to have students participating in activities, research on learning indicates that meaningful learning "depends on the learner's cognitive activity during learning rather than on the learner's behavioural activity" (Mayer, 2005a, p. 15). Learning activities where students are highly active but do not have to build new schema and elaborate existing ones result in less effective learning than if they are required to construct knowledge.

2.5.3 Coordinating activity

A crucial aspect of applying activity designs in the web-conferencing environment is understanding the pertinent factors relating to the implementation and management of those designs. Neale, Carroll & Rosson (2004) provide a model of activity awareness for analyzing the coordination of activity. This is represented in Figure 8. They discuss how the communicative requirements of an activity affect collaborations:

> *Contextual factors underlie all collaborative activities and shape how the work is structured. Work can be loosely or tightly coupled based on the communication demands of the activities. More tightly coupled work requires greater demands on communication. The greater the work coupling, the greater the demand for coordinated behaviors as well.*

(p. 115)

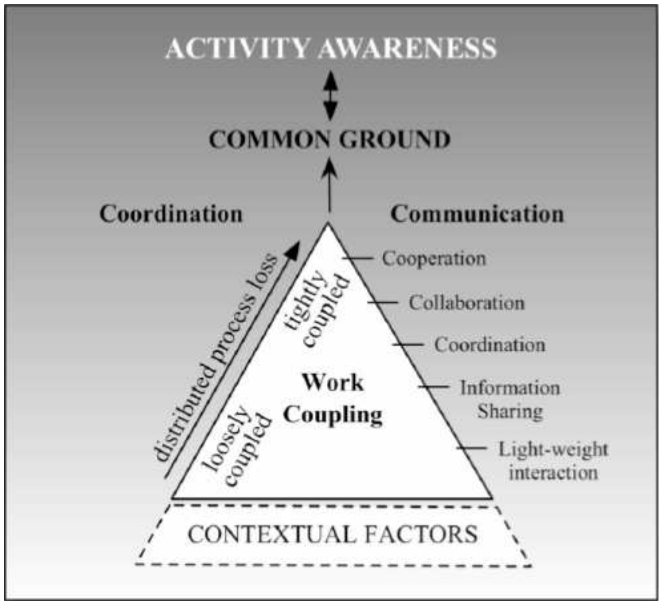

Figure 8 – Neale, Carroll & Rossons' (2004) Activity Awareness model

In their model coordination includes activities such as planning, scheduling, assembling resources, managing resources, task allocation (roles), alignment, monitoring task and activity states, information sharing, and managing internal relationships (Neale, Carroll, & Rosson, 2004). This relates to the rules, community and division of labour that underpin the 'production' sub-system of Engeström's (1987) Activity Theory framework. In technology based learning environments the processes and procedures for managing these coordination tasks depend heavily on the tools available to the group (for instance, whiteboards, file sharing systems, chat tools).

2.5.3.1 Coordinating activity in technology based learning environments

Coordinating activity in technology based environment contains inherent difficulties above and beyond those experienced in face-to-face contexts. Neale, Carroll & Rosson (2004) define the collaborative overhead incurred while attempting to coordinate activity as 'process loss'. They also define 'distributed process loss' as the amount of coordination that is required to manage the main work of interest when students are operating remotely. Neale, Carroll & Rosson (2004) note that distributed process loss is much more costly than face-to-face, describing it as "so costly, in fact, that groups often do not recover from its effects" (p. 117).

On the other hand, the more aware people are the less need there is to coordinate activities. Maintaining awareness, like coordination, however, is a background process. And like maintaining background contextual information, distributed systems often fracture this type of process (Neale, Carroll, & Rosson, 2004). Their two year analysis of an online collaborative system showed how students attempted more tightly coupled work when they interacted face-to-face and during proximal interaction than during distributed interaction. They note that students struggled to understand what their remote partners were doing and why, which in some cases resulted in collaborative breakdowns. The use of collaborative technologies fractured the contextual information critical to the collaborative process. Neale, Carroll & Rosson (2004) propose that it is only if the proper levels of communication and coordination are supported, that groups can achieve common ground and acquire activity awareness critical for effective functioning.

Gilly Salmon (2000) proposes an approach to coordinating activity in technology based learning environments. In her content analysis of 3000 forum messages in an MBA course she derived a consolidated "Five-step model" of teaching and learning online (see Figure 9). This model focuses on the sociological and interactive aspects of teaching using Computer Mediated Communication, which was applied to manage learning using discussion forums.

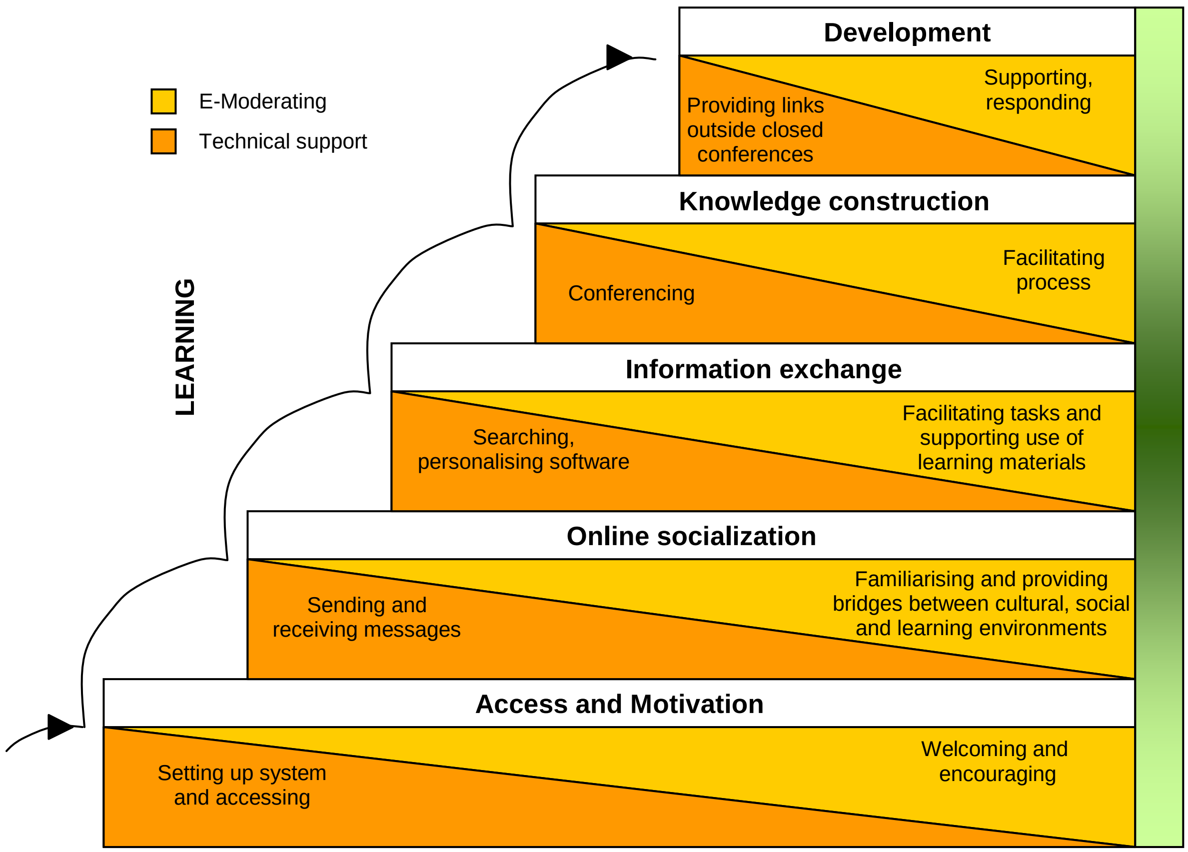

Figure 9 – Salmon's (2000) Five Step model of teaching and learning online

Salmon's (2000) model aligns with that proposed by Neale, Carroll & Rosson (2004) in the way higher levels of learning (collaborative knowledge construction and development processes) require greater levels of interactivity. Her research emphasizes that it is not the Computer Mediated Communication technologies in themselves that create effective interactive learning environments, but rather careful course design and management by the teacher. Salmon (2000) discusses the critical need for teachers to develop 'e-moderator' competencies in order to facilitate effective technology based learning activities.

> *Any significant initiative aimed at changing teaching methods or the introduction of technology into teaching and learning should include effective e-moderator support and training, otherwise its outcomes are likely to be meager and unsuccessful. Even where technological infrastructure and*

> *support are strong, and when worthwhile learning applications are developed, without staff development nothing is likely to happen beyond pilot schemes.*
>
> (p. 55)

It is important to note that Salmon (2000) bases her model on the analysis of asynchronous communication media, and that other approaches may be required to manage activity in e-learning environments based on synchronous tools. For instance, the need to train teachers how to use the web-conferencing environment may be substantially greater than for asynchronous technologies because of the much larger range of functionalities available, the increased choices for collaboration they afford, and the instantaneous and public contexts within which their skills will be required.

The level of students' technological competencies may impact upon students' ability to coordinate activity and hence tend to the conceptual content which is the focus of learning. In an experiment by Clarke, Ayres and Seller (2005), students with low-level spreadsheet capabilities learned mathematics more effectively if they learnt prerequisite spreadsheet skills prior to attempting mathematical tasks. Learning spreadsheet skills at the same time as the mathematical content decreased the cognitive resources available to attend to the mathematics. This indicates the cognitive load required to operate and understand a technology can negatively impact upon student understanding of the 'to be learned' subject matter. If this effect is extrapolated to the current context, the cognitive load caused by having to learn and operate the collaborative technologies may reduce the cognitive resources available to learn the curriculum. Thus developing students as well as teacher technological competencies may be critical to engaging effective interaction in the web-conferencing environment.

Having addressed the literature relating to technology design and activity design, attention now turns to content design.

2.6 Task Types in the Learning Domain and Their Design

2.6.1 Introduction

This section considers the subject matter to be learnt, which primarily includes the role of curriculum-based knowledge and processes in the overall learning design. This represents the "object" of the Activity System. First the abstraction process by which students form mental models is discussed, as this relates to the type of thinking that tasks need to engender. Then mental models and their types are described, representing the result of the abstraction process.The SOLO taxonomy is presented as a means of assessing the efficacy of student mental models, which is subsequently used throughout the study to evaluate the level of understanding that students evidence.

In order to differentiate between the different task (content) designs that may be applied in the web-conferencing environment, Anderson and Krathwohl's (2001) general Taxonomy of Learning, Teaching and Assessing is explained. This is supplemented by a hierarchy of task designs in the specific learning domain being considered (computer programming), which is then related back to Anderson and Krathwohl's (2001) general taxonomy. While some sections of the following discussion relates specifically to the teaching of computing, it is intended that the process of understanding and deconstructing a domain specific curriculum for the purposes of creating learning designs is the central concern.

2.6.2 Abstraction and mental models

Mental models are predictive internal representations of real world systems that allow people to reason about the world (Norman, 1983). Abstraction is the means by which students form mental models. Tasks should be designed and sequenced in a way that facilitates abstraction so that students may improve the accuracy and completeness of their mental models.

2.6.2.1 Abstraction

Hazzan (2003) has studied the process of abstraction in Mathematics and Computer Science. She defines abstraction levels in three ways:

> *1. abstraction level as the quality of the relationships between the object of thought and the thinking person (Wilensky, 1991);*
> *2. abstraction level as reflection of the process-object duality (Dubinsky, 1991; Sfard, 1991);*
> *3. abstraction level as the degree of complexity of the concept of thought.*
>
> (p. 97)

Thus the quality of an abstraction relates to how well it facilitates movement between generalized representation and its application in specific circumstances. Important in understanding teaching and learning in web-conferencing environments (or any environment) is appreciating how students perform the abstraction process to form mental models. Ahanori (2000) presents the cyclic Actions-Process-Object model that cognitive scientists use to describe how people abstract concepts. Under this model people build cognitive frameworks by transforming actions into processes and then into objects.

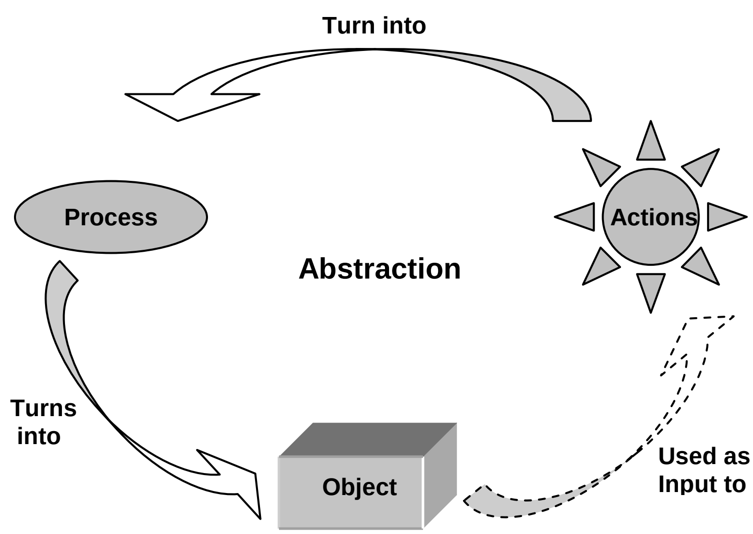

Figure 10 – A simplified version of the Actions-Process-Object model (ref: Ahanori, 2000)

The key idea is that when concepts are forming in the learner's mind they do so as a sequence of actions, or 'process'. However as the learner undergoes reflective abstraction the process becomes a notion captured as an 'object, i.e. a solid conceptual entity upon which other concepts can be built (Hazzan, 2003). The cycle explains how conceptual knowledge is found upon procedural knowledge, which is comprised of related pieces of declarative knowledge (Anderson & Krathwohl, 2001; Byrnes, 2001, elaborated later in this section). Through this abstraction process objects or 'chunks' of knowledge are built up in the minds of learners to develop their schema (Aharoni, 2000).

2.6.2.2 Mental models

Aligning with Norman (1983), Ramilingham et al. (2004) define mental models as follows:

> *[Mental models are] predictive representations of real world systems. That is to say, people create internal representations of objects and information in the world, and the use these mental representations to reason about, explain, and predict the behaviour of external systems.*
>
> (p. 172)

The critical aspect of models is that they allow the user to solve problems. Thus forming clear and accurate mental models is fundamental to the learning process.

Norman (1983) distinguishes between the target system (the system that the person is learning or using), the conceptual model of the target system (an accurate and appropriate representation of the target system), the user's mental model of the target system (which may or may not be accurate and suffice), the researcher's conceptualization of the learner's model (a model of a model). In these terms, teachers' conceptualizations of students' mental models should lead to the adjustment of instruction so as to best facilitate student development of complete conceptual models of target systems.

Often teachers attempt to provide students with a conceptual model of a system to support the formation of students' mental models. Effective representations are those that capture the essential elements of the system leaving out the rest, with the critical point being which aspects to include and which to omit (Norman, 1993). Successfully selecting and describing the poignant features of a system allows students to concentrate upon the critical aspects of the system with being distracted by irrelevancies. When acquired, such conceptual models enhance students' capacity to reason and think. However if critical features are omitted or represented in a way that students misunderstand, then students may not comprehend crucial aspects of the system and may subsequently form misguided conclusions (Norman, 1993).

Mental models are particularly important in computing, as explained by Ramilingham et al. (2004):

> *Programming is a highly cognitive activity that requires the programmer to develop abstract representations of process in the form of logical structures. Having a well-developed and accurate mental model may affect the success of a novice programmer in an introductory programming course. Such a model could include knowledge about how programs work in general, as well as knowledge about the syntax and semantics of a specific language [4]. Mental models (also referred to as schemas) play an important role in program comprehension [10, 14, 17] and correspondingly in comprehension related tasks, such as modification and debugging.*
>
> (p. 172)

Research in the field of computer science has led to an improved understanding of mental models and how they are and can be applied. For instance, in an ethnographic study involving 511 first year students at the University of the Witwatersrand, Gotschi, Sanders and Galpin (2003) conducted extensive analysis of students mental models of recursion. They found that without a viable mental model of recursion that correctly represents active flow (when control is passed forward to new instantiations) and passive flow (when control flows back from the terminated instantiations) students cannot reliably construct recursive algorithm traces.

Understanding students both well and ill-formed mental models has manifold utility. For instance the research by Gotschi, Sanders and Galpin (2003) exemplifies how identifying non-viable mental models that students may form (such as the looping, magic, and step models), allows teachers to pre-empt errors and provide tailored remediation. Secondly, the development of domain specific models can provide teachers with models (for instance in the area of recursion, the Kayney's 'copies' model), that have been demonstrated as successful at promoting understanding. Finally understanding models of thinking can inform educators' decisions about the required approach to learning – in the case of recursion a constructivist approach is required for students to form viable mental model adequate that can be applied to design and problem solving tasks.

One crucial mental model that has been identified in numerous studies (Robins, Roundtree, & Roundtree, 2003) is that of an abstract version of the computer, often called a 'notional machine'. The notional machine is "an idealized, conceptual computer whose properties are implied by the constructs in the programming language employed" (du Boulay, O'Shea, & Monk, 1989, p. 431). Robins et al (2003) state:

> *that the notional machine is defined with respect to the language is an important point, the notional machine underlying Pascal is very different from the one underlying Prolog. The purpose of the notional machine is to provide a foundation for understanding the behaviour of running programs.*
>
> (p. 149)

That the notional machine assists learning is not a hypothetical proposition. Mayer (1989) showed that students with a notional machine model were better at solving some kinds of problems than students without the model.

Du Boulay et al. (1989) suggest that in order for novice programmers to overcome comprehension problems caused by the hidden side effects of visually unmarked processes, the notional machine needs to be simple and supported with some kind of concrete tool which allows the model to be observed. They suggest that the visibility component of such models be supported through 'commentary' – a teacher delivered or automated expose of the state of the machine. On the other hand the simplicity component of the machine can be supported through:

1. *functional simplicity* (operations require minimal instructions to specify)
2. *logical simplicity* (problems posed to students are of contained scale)
3. *syntactic simplicity* (the rules for writing instructions are accessible and uniform).

They conclude that matching visibility and simplicity components of notional machines to different populations of novice learners leads to improved educational outcomes.

Another distinction made between the various cognitive representations in computer programming is that of 'schema' (static, 'program as text') versus 'plan' (action oriented, 'programming as activity') (Rogalski & Samurcay, 1990, cited in Robins, Roundtree, & Roundtree, 2003, p. 141). Although models that describe program comprehension (schema based) are much more common than those that describe program creation (plan based), Rist (1995) has constructed an elaborate model to explain how programs are generated. The synchronous tools offered in the web-conferencing environment provide the opportunity to not only support the development of students' static models, but also more complex dynamic mental models.

2.6.2.3 Structures and relationships in mental models

The SOLO taxonomy (Biggs & Collis, 1982) provides a framework for considering the structure and sophistication of student representations of their mental models. The taxonomy classifies the completeness of information that has been provided in a student's representation of their mental model and the extent to which it has been interrelated. The levels of the taxonomy are 'prestructural', 'unistructural', 'multistructural', 'relational', or 'extended abstract', with higher levels of cognition involve greater levels of interrelated knowledge (see Table 3 below).

SOLO description	Capacity	Relating operation	Consistency and closure	Response Structure
Prestructural	Minimal: cue and response confused	Denial, tautology, transduction. Bound to specifics	No felt need for consistency. Closure can occur without even seeing the problem.	Cue results in one incorrect response item
Unistructural	Low: cue + one relevant datum	Can 'generalize' only in terms of one aspect	No felt need for consistency, thus closes too quickly: conclusions are based on one aspect and so can be very inconsistent	Cue results in one correct response item
Multistructural	Medium: cue + isolated relevant data	Can 'generalize' only in terms of a few limited and independent aspects	Although a feeling for consistency, inconsistency can arise because closure occurs too soon on basis of isolated fixations on data, and so different conclusions with same data may be derived	Cues results in several correct response items (but not entire set and not interrelated)
Relational	High : cue + relevant data + interrelations	Induction: Can generalize within given or experienced context using related aspects	No inconsistency within the given system, but since closure is unique some inconsistencies may occur when going outside the system	Cue results in several correct and interrelated responses items representing a complete set
Extended Abstract	Maximal: cue + relevant data + interrelations + hypotheses	Deduction and induction. Can generalize to situations not experienced	Inconsistencies resolved. No felt need to give closed decisions – conclusions held open, or qualified to allow logically possible alternatives.	Cue results in several responses that both include the complete set of correct responses and information beyond that required. All information is interrelated.

Table 3 – Abridged version of Biggs and Collis' (1982) SOLO Taxonomy

It is important to note that educators cannot use the model to classify the formedness of student mental models, only attempt to classify the formedness of student representations of their models.

Biggs and Collis (1982) describe the levels of their SOLO Taxonomy can be described in terms of four attributes:

1. Capacity – the amount of working memory that the different levels of the taxonomy require. "One needs to think about more things at once in order to make a relational or extended abstract response than one does to make a unistructural response." (p. 26)
2. Relating operation – the way in which the cue (instructional prompt) and the response interrelate. "In the case of the prestructural response there is no logical interrelation" (p. 26)
3. Consistency and closure – the extent to which there are no contradictions between data and conclusion/s and the extent to which the learner needs to arrive at a conclusion. "a high level of need for consistency ensures the utilization of more information in making a decision, so that the decision is likely to be more open" (p. 28) on the other hand "the greater the felt need to come to a quick decision the fewer data will be utilized" (p. 27)
4. Structure – the way in which the knowledge units that comprise the concept and related concepts is interrelated.

The levels of the taxonomy are not absolute in so far as a student's mental model will unequivocally be classifiable into one of the categories, with Biggs and Collis (1982) referring to student responses that reach for a higher level but do not quite satisfy the conditions of that level as "transitional responses" (p. 29). The taxonomy is not an attempt to box responses into one level or another, rather, by defining levels of responses in terms of the features of the response educators are provided with a somewhat consistent means of describing different levels of mental model development.

The taxonomy has a precedent of being applied in computer science learning contexts. Thompson (2007) investigates the application of the SOLO taxonomy to programming projects in an attempt to provide more holistic assessment criteria. Lister et al. (2006) observe the SOLO levels in the responses of novice programmers to routine computer program interpretation problems. Whalley et al. (2006) apply the taxonomy to assess student program summarizations and discuss its relevance for code writing tasks.

The SOLO taxonomy is a constructivist model that focuses on the nature of information and its interrelatedness. It is also longstanding and well-renown model with a history of application in the learning domain being studied (computer science). For these reasons the SOLO taxonomy provides an appropriate framework to describe and assess the formedness of student mental model representations within this study.

Note that in some cases mental model representations are those of the individual (for instance in the case of text-chat responses to a teacher question). In other cases mental model representations are collaborative in a distributed cognition sense, allowing understanding of the group to be assessed. For instance, a group of students may collaboratively emulate the execution of a program by drawing output on the whiteboard.

2.6.3 The nature of knowledge and a general framework of learning tasks

Having identified how students form their mental models through the process of abstraction, and having identified how the efficacy of those mental models can be assessed, attention now turns to the types of tasks that may be applied to develop students' understanding. Different types of knowledge and processes may be represented differently in web-conferencing environments, and the capacity to distinguishing between tasks allows the differential effect on learning to be considered.

Anderson and Krathwohl's (2001) taxonomy of learning, teaching and assessing present a contemporary framework for classifying learning tasks. They classify educational objectives (and hence tasks) by two dimensions; the 'knowledge' dimension and the 'cognitive process' dimension. The knowledge dimension they present is useful for classifying the nature of the content that is being considered, and corresponds directly to those from cognitive psychology:

1. Factual (declarative) knowledge – discrete pieces of elementary information, required if people are to be acquainted with a discipline and solve problems within it
2. Procedural knowledge – the skills to perform processes, to execute algorithms and to know the criteria for their appropriate application
3. Conceptual knowledge – interrelated representations of more complex knowledge forms, including schemas, categorization hierarchies, and explanations
4. Metacognitive knowledge – knowledge and awareness of one's own cognition as well as that of other people.

Anderson and Krathwohl (2001, pp. 27-29)

Anderson and Krathwohl's (2001) also present a 'cognitive process' dimension in their taxonomy that is a revision of Bloom's (1956) taxonomy and incorporates the following categories:

1. *Remember* – retrieving relevant knowledge from long term memory
2. *Understand* – constructing meaning from instructional messages (oral, written, visual)
3. *Apply* – carrying out or using a procedure in a given situation
4. *Analyze* – breaking material into its constituent parts and determine how the parts relate to one another and to an overall structure or purpose
5. *Evaluate* – making judgments based on criteria or standards
6. *Create* – putting elements together to form a coherent or functional whole; reorganize elements into an original pattern or structure.

(pp. 67-68)

Anderson and Krathwohls' (2001) 'knowledge' dimension provides a framework for considering the type of information being addressed while the 'cognitive process' dimension identifies the type of processes which students apply when attempting the task. The Anderson and Krathwohl (2001) Taxonomy of Learning, Teaching, and Assessing has been selected as an appropriate framework to apply in this study because:

- The categories are based upon the underlying nature of the knowledge and processes being represented (based on cognitive science)

- It is a well recognized framework that has been referenced in other studies, thus allowing comparison and contrast to this study
- It is contemporary framework that incorporates recent advances in the understanding of teaching and learning.

As metacognitive knowledge is not a specific component of the mental models that students develop and can be applied to declarative, procedural and conceptual knowledge, it has not been used to differentiate task in this study.

2.6.4 Task types in computing

The general types of tasks that can be used to compose learning designs in the web-conferencing environments is complemented by an understanding of the domain specific tasks that may be utilized to help students form programming knowledge and skills. There are a wide range of computing tasks which can be used to develop students' mental models, including (Bower, in press):

1. Declarative tasks
2. Comprehension tasks
3. Debugging tasks
4. Prediction tasks
5. Provide-an-example tasks
6. Provide-a-model tasks
7. Evaluate tasks
8. Meet-a-design-specification tasks
9. Solve-a-problem tasks
10. Self-reflect tasks.

This hierarchy addresses the types of processes students perform. This allows the focus to be placed upon the way students develop towards expertise – by performing processes that allow them to abstract their mental models. Distinguishing task types based on the curriculum matter being addressed (for instance, variable types, 'while' loops, arrays) would fail to distill and group the educationally poignant aspects of the task – what sort of thinking skills and cognitive processes are being required. Classifying tasks by virtue of the processes students perform in relation to the curriculum matter allows effects of the task type upon collaboration and learning to be detected.

The hierarchy was developed based upon a systematic analysis of existing computer science curricula, consultation with academics from general education and computer science (both intra and extra institutional), and an analysis of education literature. Specifically, curricula from within our institution were deconstructed, not by conceptual content but by the task they expected students to perform. On this basis the various categories were formed. At the same time general education literature (Anderson & Krathwohl, 2001; Biggs & Collis, 1982; Bloom, 1956; Byrnes, 2001) and computer science education literature (Aharoni, 2000; du Boulay, O'Shea, & Monk, 1989; Novrat, 1994; Porter & Calder, 2004; Robins, Roundtree, & Roundtree, 2003) was reviewed to not only provide examples of other tasks, but also to offer insight into other approaches to classifying task types in computing. Finally, the hierarchy was presented to computer science and education academics for feedback and verification.

It is by no means proposed that the approach below is the only way that task types in computing could be classified. Instead, presenting such a hierarchy provides a framework for discussion and analysis. The levels of the hierarchy are now briefly described, along with the relationship between levels. An exemplar of each type is provided (based in essence from the introductory programming course being studied) to purvey the sort of task types that can fall within each category. For more information about the rationale underpinning this hierarchy and the range of tasks within each level, refer to Bower (in press).

2.6.4.1 Declarative tasks

Declarative knowledge is static, and usually involves at most one relationship between pieces of information. Declarative tasks work at the level of recognition and recollection.

Example:

- *True or false: To include a backslash character '\' in a string you need to 'escape' it by placing another backslash before it.*

Declarative tasks are the lowest level of tasks that students can be prescribed, and the knowledge that they embody underpins all tasks at higher levels.

2.6.4.2 Comprehension tasks

Typically comprehension tasks involve being presented with an artefact (such as a piece of code) or an item of declarative knowledge and providing an explanation (entire or part).

Example:

- *Explain the difference between the int 127 and the String "127".*

Comprehension tasks represent a movement away from straight recall of facts towards tasks requiring an understanding of underlying concepts. Comprehension tasks require students to generate solutions based on an underlying mental model of the concept or situation.

2.6.4.3 Debugging tasks

Debugging tasks require students to detect errors in programming code, often based upon an anticipation of what the program is trying to achieve.

Example:

- *What are the semantic errors within this program?*

```
int i;
int factorial = 1;
for (i = 1; i<=5; i++);
     {factorial = factorial * i;}
System.out.println(i+"! = "+ factorial);
```

Syntactic debugging tasks rely on well-formed declarative knowledge, whereas semantic debugging tasks rely more on well-formed comprehension type understanding. Also, debugging tasks incorporate a significantly greater process aspect than declarative or comprehension tasks.

2.6.4.4 Prediction tasks

Predictive tasks require students to emulate the output of the program.

Example:

- *What will be the effect of replacing the* `5` *with* `i+1` *in the following code?*

```
public class TwoDtester
{
  public static void main(String[] args)
  {
    int[][] steps = new int [4][];
    for (int i = 0; i<steps.length;i++)
    {
      steps[i] = new int[5];
      for (int j=0; j<steps[i].length; j++)
      {
         steps[i][j] = i+j;
        System.out.print(steps[i][j] + ",");
      }
    }
  }
}
```

Predictive tasks are central to computing because without the ability to predict the effect of the statements comprising a piece of code students cannot write programs. Accurate prediction relies on both accurate comprehension and declarative knowledge. Predictive are generally more cognitively demanding their debugging counterpart, because they rely more heavily on a student's notional machine. As well, predictive tasks require students to be generative and be able to interpret most all of the code in a program instead of merely identifying particular errors.

2.6.4.5 Provide-an-Example tasks

Provide-an-example tasks require students to represent their conceptions by supplying a concrete instance.

Example:

- *Create an original example of the "dangling else" problem.*

These are creative tasks that can be either declarative (factual and syntactic) or comprehensive (understanding or semantic) in nature. Note that these generative tasks often demand more intense cognitive engagement than those of previous levels (Robins, Roundtree, & Roundtree, 2003, p. 142). This is because they either provide smaller cues from which students can retrieve their knowledge (at a declarative level) or require students to synthesize existing pieces of knowledge to create an original representation.

2.6.4.6 Provide-a-Model tasks

Provide-a-model tasks require students to provide an abstract representation of a system.

Example:

- *Draw a diagram* to illustrate what happens in your computer's memory when you:
  - a) *create an object variable (define a new variable name and give its type)*
  - b) *initialize that object variable (by creating an object to which it refers).*

This advances beyond provide-an-example tasks to not only require students to demonstrate an understand examples that have been presented, but also to provide an abstract representation of an entire situation or process. This sort of task can be attempted at a fairly low level of cognitive demand if students simply represent models they have found elsewhere. On the other hand, if students are challenged (or challenge themselves) to synthesize their declarative and comprehensive knowledge to derive an original model, such tasks can be rich opportunities for relating and restructuring concepts, thus leading to deeper understanding. Provide an explanatory model can often improve students' debugging and predictive knowledge.

2.6.4.7 Evaluate tasks

Evaluate tasks require students to judge the quality of a particular approach.

Example:

- *Evaluate the following method as an approach to providing the value of the username field of the User class:*

```
public String getUserName ()
{
  System.out.println("The username is: " + username);
        return username;
}
```

Evaluation tasks have been associated with the higher order of thinking in taxonomies such as Bloom's (1956), but may be attempted at a variety of levels depending on the students' approach to the problem. For instance, the task "provide a list of the advantages of applets over applications" may either result in the reproduction of a text-book response or a critical and complex consideration of the approach to adopt when rolling out a particular tool to customers. Evaluation tasks may be performed upon the final solutions presented for provide-an-example and provide-a-model tasks, and are suitable for mixed ability and group-work because of their subjective or 'soft knowledge' nature.

2.6.4.8 Meet-a-Design-Specification tasks

Design tasks require students to combine their knowledge to present an original and creative solution.

Example:

- *Design a system to meet the following specif*ication:
  The system contains Lecturers, UnderGradStudents and PostGradStudents.
  a) *Every Person in the system has a name.*
  b) *The system also holds:*
     i) *whether a Lecturer is at a senior level 'S' or a normal level 'N'*
     ii) *the student number of each Student*
     iii) *The fee structure of each Student (assume "Full Fee" for PostGradStudent, "HECS" for UnderGradStudent)*

Design tasks can be pitched at an implementation level (e.g. write the code), or a conceptual level (e.g. provide a UML class diagram). Implementation level design requires the underlying cognitive skills developed through the declarative, comprehension, debugging, prediction, and providing example tasks. Conceptual level design requires only declarative and comprehension knowledge, however good conceptual design will also require the pragmatic understanding developed in debugging, prediction, example creation and evaluation tasks. Whereas evaluation of provide-an-example and provide-a model tasks is more summative (subsumes these tasks), evaluation should be an ongoing process that occurs during meet-a-design-specification tasks (is contained within such tasks).

2.6.4.9 Solve-a-Problem tasks

Solve-a-problem tasks are more authentic, ill structured tasks that require students to apply a full range of problem solving skills.

Example:

- *Diana wants to check whether her students' test scores seem consistent with their assignment marks. Create a system that aids her attempts to do so.*

Solve-a-problem tasks could be considered another way of framing design tasks, however because they require the student to respond to more ill-structured task requirements they have been classified as a separate category. Some students may be able to design systems to meet specifications, but less capable at solving problems where the approach is not well defined. Solve a problem tasks promote the development of context scoping, critical thinking, and cognitive flexibility, which are in the realm of more expert behaviours (Agnew, Ford, & Hayes, 1997; Spiro, Coulson, Feltovich, & Anderson, 1988).

2.6.4.10 Self-Reflect tasks

Reflection tasks require students to evaluate the ways in which they learn (as opposed to evaluating subject matter content).

Example:

- *Reflect on the way that you have attempted to learn this body of knowledge, and the way in which you have inferacted with your peers to do so.*

Reflection can be based on one's own engagement with the content, with one's engagement with others, or both. Reflecting metacognitively upon one's engagement with the content aids the development of control skills – the capacity to self-monitor and evaluate decisions made during the problem solving process – which is a key determinant of problem solving performance (Ginat, 2001; Schoenfeld, 1985). Reflecting on one's engagement with others is may develop students' ability to learn from and with others in the future. While reflection does not necessarily incorporate skills required in all lower levels of tasks, it can be applied to all previous levels.

The hierarchy presented does not imply that higher level tasks should be left to the end of an undergraduate computing course and that tasks at lower levels should only occur at the beginning. It is important that students at early stages of learning computing are encouraged to perform tasks that foster higher order thinking, albeit on a smaller scale and focusing on less complex material than at later stages of their computing education. Nor is it proposed that that all tasks will neatly fall within one level of the hierarchy; often task types can be prescribed in combination (for example “Describe the dangling else problem and compose an original example that illustrates it”).

The hierarchy presented does however provide a mechanism for analysing and describing domain specific task designs applied in this study. The emphasis on task processes is a shift from traditional focus on static content. This aligns with the view of learning computing as a process of constructing understanding rather than receiving a body of knowledge.

The hierarchy of computer science tasks can be related to Anderson and Krathwohls’ (2001) knowledge and process dimensions as represented in Table 4. In considering this table it should be noted that only the central knowledge and process levels have been represented. For instance, “solve-a-problem” tasks obviously involve elements of declarative and conceptual knowledge, as well as all process levels.

Computer Science task	**Knowledge level**	**Process level**
Declarative tasks	Factual	Remember, Understand
Comprehension tasks	Factual, Conceptual	Remember, Understand
Debugging tasks	Procedural	Apply
Prediction tasks	Conceptual	Apply
Provide-an-example tasks	Factual	Apply, Create
Provide-a-model tasks	Conceptual	Apply, Create
Evaluate tasks	Conceptual	Evaluate
Meet a design specification tasks	Procedural	Create
Solve-a-problem tasks	Procedural	Create
Self-reflect tasks	Conceptual	Evaluate

Table 4 – Relationship between computer science specific tasks and Anderson and Krathwohls’ (2001) Knowledge and Process dimensions

Table 4 demonstrates the link between the domain specific and general frameworks for classifying and analysing task content that will be adopted in this study.

2.6.5 Task character

One final aspect of the content design that deserves attention for its reported influence on learning is that of task character. The ‘authenticity’ of tasks has been analyzed by Herrington, Oliver and Reeves (2002). They define 10 characteristics of authentic tasks:

1. Have real-world relevance
2. Are ill-defined, requiring students to define the tasks and sub-tasks needed to complete the activity
3. comprise complex tasks to be investigated by students over a sustained period of time
4. provide the opportunity for students to examine the task from different perspectives, using a variety of resources
5. provide the opportunity to collaborate
6. provide the opportunity to reflect
7. can be integrated and applied across different subject areas and lead beyond domain-specific outcomes
8. are seamlessly integrated with assessment

9. create polished products valuable in their own right rather than as preparation for something else
10. allow competing solutions and diversity of outcome.

Bellamy (1996) describes authenticity as one of the main implications of design learning environments using an Activity Theory approach, because Activity theory assumes an authentic context. Providing contextualized and holistic tasks not only promotes motivation but also allows students to embed their practice in scenarios that most resemble the situations in which that knowledge will be required (Herrington, Oliver, & Reeves, 2002).

Malcolm Knowles (1984) theory of Androgogy and Carroll's Minimalist approach to education (1998) similarly emphasize the importance of task relevance. If problems are framed in a context that students are likely to confront then they will be more motivated to learn the material, will be more likely to spend time reviewing and acquiring concepts from the learning domain and be prepared to drill further down into the content area. Brown, Collins and Duguid (1989) also ascribe the importance of relevance in their "Situated Cognition" approach.

The impact of the meaningfulness of a task upon collaborations is summarized by Jonassen et al. (2005):

> *Meaningful collaboration necessitates a meaningful task…The more difficult and complex the task, the more likely it is that group members will collaborate. Problem solving tasks, especially ill-structured problems such as policy analysis and design problems are the most authentic and complex and therefore the most in need of collaborative efforts (Jonassen, 2004). Therefore, our primary recommendation is to use online collaboration to support more complex, authentic, and meaningful tasks, such as problem solving.*
>
> (p. 257)

Because tasks attempted in this study occur within a two hour lesson, it is not possible for them to incorporate the third characteristic in Herrington, Oliver and Reeves' (2002) description of authentic tasks. However, in the tasks that are set within the web-conferencing environment some tasks possess more of these authentic characteristics than others, providing the opportunity to study whether content designs with more authentic characteristics produce different levels or types of collaboration or learning.

This section has addressed how students abstract their mental models and the sorts of tasks that can be prescribed to support the mental model development process. The task character, Anderson and Krathwohl's (2001) general taxonomy and the domain specific taxonomy of task types in computing provide a framework for classifying and analysing content design. These different approaches to considering content design of tasks along with the approaches to technology design and activity design presented in previous sections provide a framework for constructing and analyzing learning designs in this study.

2.7 Interactions between Technology Design, (inter)Activity Design and Content Design

In observing how the interface, activity design and task type affect collaboration and learning in the web-conferencing environment, this study will also pay careful attention to how these factors interact. This relates to the context specific relationships between the subjects, tools and objects of the Activity Theory framework.

Interactions between technology, (inter)activity and content have been implicitly woven into the preceding discussion. For instance, interface design (technology) considered approaches to enabling collaboration (interactivity) and the importance of being able to appropriately represent concepts (task content). The socio-constructivist approach to learning design adopted has generally emphasized the importance of negotiated (activity) approaches to addressing the subject matter (task content), as well as providing specific examples of how this has been performed in computing (for instance, pair programming).

However at this stage it may be appropriate to explicitly address these interactions and their importance for learning design in the web-conferencing environment by explicating the nature of these interrelations.

2.7.1 Interrelation between Technology and Task Type

Interactions between technology design and the task being completed have already been identified in a general sense. Several authors (Jonassen, 2000; Sedig, Klawe, & Westrom, 2001; Tu, 2005) emphasized the importance of designing technology to support knowledge construction in the task being undertaken. Hollan et al. (2000, p. 190) point out the way in which the interface forms part of students thinking structure, and Zhang's (1997) research indicates the utility of using external spaces to support distributed cognition while attempting tasks.

In integrating technology and task design, the current challenge is to align the design of the web-conferencing interface with the specific representational requirements of the task. Laurillard (2002) criticizes instructive approaches, such as Socratic dialogue, for not providing students with adequate opportunity to engage with representational forms. She points out that a requirement for developing understanding in any field is an understanding of the semiotic protocols that are used:

> *Students need explicit practice in the representation of knowledge of their subject, in language, symbols, graphs, diagrams, and in the manipulation and interpretation of those representations.*
>
> (Laurillard, 2002, p. 40)

This means when facilitating learning through the web-conferencing system, students need to not only observe representational forms provided by the teacher, but also attempt to contribute and exchange those representations through the interface provided. This may entail students not only developing an understanding of those representational forms, but also how to use the interface to most effectively contribute those representations. This adds a layer of complexity in attempting to mediate learning through the technology.

However, allowing students to communicate, present and evaluate representational forms and approaches during problems solving tasks is important as it can develop their sense of criticism towards quality of solutions, thus increasing their capacity and tendency to engage in constructive self-reflection (Or-Bach & Lavy, 2004). While effective approaches to implementing this in the web-conferencing environment are undetermined, Or-Bach and Lavy (2004) propose that student learning may be accelerated by being presented with existing abstractions in order to provide a basis upon which to design their own abstractions.

2.7.2 Interrelations between Technology and (inter)Activity

The interaction between technology design and (inter)activity design focuses on how a technology such as the web-conferencing environment should support different types of collaborations. Once again, to some extent this has been addressed previously. The importance of designing technology for intuitive collaboration (Lipponen & Lallimo, 2004), of providing context and orientation (Luff et al., 2003) and the capacity for expression of sentiment (Jonassen, Lee, Yang, & Laffey, 2005) have all been discussed. Neale, Carroll & Rosson (2004) forewarned of the distributed process loss that can occur during technology based collaborations. The possibility of moving beyond face-to-face patterns of collaboration to leverages the communication capacities afforded by the technology has also been raised (Hollan, Hutchins, & Kirsh, 2000). In terms of managing activity in technology based learning environments, the importance of facilitating process, providing support and responding to students has been emphasized (Salmon, 2000).

Research by Simon, Anderson, Hoyer and Su (2004) provided specific examples of how the affordances of technologies can be applied to effectively manage activity. Their investigation of a Tablet PC based collaboration system in computer science classes Simon et al. (2004) allowed instructors to select either answers or students. The technology affords the capacity to filter out identities more easily than in a face-to-face classroom which could in turn encourage greater participation by alleviating the fear of embarrassment. As well, they note that sharing of different students (or groups of students) spontaneous attempts to solve problems provided an opportunity to point out common mistakes and allowed comparison of different approaches to the same problem to be compared and contrasted. The technology also enabled teachers to receive immediate feedback on whether students had understood concepts so that instruction could be adjusted accordingly.

Thus, consideration of how to best integrate technology and (inter)activity design in the web-conferencing environment incorporates some of the socio-constructivist principles that have already been identified:

i) providing an interface that offers students contextual and orienting information
ii) offering channels for non-content related communication
iii) combining tools that may enable communication patterns that transcend face-to-face possibilities
iv) providing an interface that intuitively and transparently facilitates collaboration.

As well, the research by Simon et al. (2004) demonstrates how designs should provide the teacher with the capacity to effectively support process and provide feedback.

2.7.3 Interrelations between Activity and Task Type

The activity design and the design of the task type interact in considering the field of collaborative learning of computing (not necessarily technology based). Literature relating to collaborative learning of computing provides a useful background understanding for this study, and some examples have been briefly discussed previously (Beck, Chizhik, & McElroy, 2005; Graciela, 2006; Waite, Jackson, & Diwan, 2003). However more immediately relevant to this study is literature relating to technology based collaborative learning of computing, which is discussed, and as such face-to-face collaborative approaches are not described here. For a review of approaches to collaborative teaching and learning of computing refer to Bower and Richards (2006).

2.7.4 Interrelations between Technology, Activity and Task Type

How to effectively aligning technology design, activity design and task type in a holistic sense to form an overall integrated learning design is the main point of inquiry of this study. In the current context, this requires that a designer leverages the affordances of the web-conferencing system to appropriately support interactive approaches to learning the concepts and processes at hand. Some literature relating to the collaborative learning in the domain of computing has already been discussed (Chase & Okie, 2000; McDowell, Werner, Bullock, & Fernald, 2002; Nagappan et al., 2003; Williams & Upchurch, 2001). However while these studies use computers as part of their collaborative learning design, they do not use computers to mediate communication.

There are, however, other studies that do examine the role of technology in mediating collaborative learning of computing. For instance, Cheng and Beaumont (2004) observe how different tools are naturally more appropriate for the levels of 'coupling' required at different phases of their Problem Based Learning computing tasks. During the initial stage of negotiating direction and goals the forum was the most popular tool as it allowed students to reflect upon the ideas of others and structure their own thoughts before they posted their contribution. On the other hand during the final stage of preparation of deliverables for submission the chat tool was popular for its ability to facilitate rapid collaboration between group members. The extent to which technologies satisfy the collaborative requirements of a task determines their utility.

Other researchers place emphasis on how their online collaborative tools can be more or less appropriate for different types of thinking. Hamer et al. (2007) present an asynchronous peer review tool (Aropä) for promoting reflective thinking on content. The authors contend that allowing students to inspect one another's code provides them with exposure to quality code as well as allowing them to learn from mistakes. Bower (2007a) describes how synchronous technologies supported group programming processes whereas wikis were more appropriate for developing abstract conceptual understandings.

Several other examples of how technology can be applied to engage the collaborative learning are provided in a recent review of learning computing online (Bower, 2007b). However much of such literature is anecdotal, not providing evidence upon which educators can found their practice, prompting the need for more methodological investigation into how representations mediated through online technologies interplay with cognition and formation of schema (Bower, 2007b). This study applies a methodological approach to exploring how different learning designs mediated through the web-conferencing environment affect collaboration and learning.

A final and defining characteristic of this study is that it explores the dynamic design potentials afforded by the web-conferencing environment. Previous technology-based educational design theories such as that by Laurillard (2002) and Salmon (2000) have been developed on assumption of a static technological design. The capacity to adjust the web-conferencing interface to meet changing collaborative and representational requirements of a learning episode allows the ways in which technology, activity and task interact to be explored from a dynamic design perspective. This in turn provides the opportunity for ontological innovation in the field of educational design.

2.8 Summary

This chapter has focused on underlying theory relating to how the design of the technology, (inter)activity and task type inform learning designs in web-conferencing environments. Activity Theory was selected as an overall framework for considering teaching and learning in the web-conferencing environment on the basis of the holistic, contextual perspective it could provide. Constructivism has been selected as the most appropriate view of learning for its ability to integrate associationist, cognitive and situated perspectives in a way that supports socially mediated approaches to construction of understanding in web-conferencing environments.

Analysis of literature related to learning technologies suggested an emphasis upon affordances rather than media. Cognitive science, Multimedia Learning Principles, social learning theory and previous attempts at educational technology design were all considered to derive an integrated framework for designing educational user interfaces. This provides a principled basis for designing the web-conferencing environment to meet the needs of learning episodes.

The (inter)activity design was distinguished from the task as the way students were expected to engage with the task and each other. A core characteristic in defining the possible activity designs was the degree of task ownership, either teacher-centred, teacher-led (mediated), or student-centred. The potentially critical impact of distributed process loss and of appropriate teacher management to support activity in technology based learning environments was identified.

A hierarchy of task types in computing was presented. Tasks were classified by the processes in which students engaged rather than the particular computing concepts that were being addressed. This approach was selected as it differentiated tasks by the way they supported students in abstracting their mental models, i.e. by how students learn rather than what they are learning. Anderson and Krathwohls' (2001) Taxonomy of Teaching, Learning and Assessing was selected as a more general framework by which tasks could be considered. The authenticity of the task was also identified as another characteristic by which the content design could vary and hence be analyzed in this study.

The importance of interactions between technology design, activity design and the design of tasks was recognized, and research and literature relating to these interactions were presented. The next chapter explains how the methodology underpinning this study has been constructed to investigate the influence of the technology, activity and task design upon collaboration and learning in the web-conferencing environment.

Chapter 3 - Methodology

This chapter explains how a design-based research methodology incorporating both traditional case study approaches as well as a multimodal discourse analysis was applied to conduct a mixed method analysis of collaboration, teaching and learning in the web-conferencing environment. First mixed methods, their utility and application in this context are explained. Then the design-based research methodology is described. Finally the approach to the ex-post facto multimodal discourse analysis is presented. The way in which the reliability, validity and rigor of analysis (i.e., criteria for interpreting findings) have been addressed is woven throughout the discussion.

3.1 Mixed Methods

3.1.1 Introduction to Mixed Methods research

Some authors have recently called for researchers to a move beyond a stance of 'incompatibility' of quantitative and qualitative research (Creswell, 2003; Johnson & Onwuegbuzie, 2004; Lister, 2005). The 'mixed methods' research they advocate recognizes that both positivist and interpretivist research methods are important and useful, and that by utilizing both approaches the strengths of each can be maximized and the weaknesses minimized. Proponents of mixed methods research argue that "research methods should follow research questions in a way that offers the best chance to obtain useful answers…many research questions and combinations of questions are best and most fully answered through mixed research solutions" (Johnson & Onwuegbuzie, 2004, pp. 17-18).

Mixed methods research can be defined as "the class of research where the research mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study" (Johnson & Onwuegbuzie, 2004, p. 17). There are many advocates of mixing qualitative and quantitative methods as a means of developing more complete understandings of datasets (Brown, 1992; Eisenhardt, 2002; Gunawardena, Lowe, & Carabajal, 2000; Hmelo-Silver, 2003; Martinez, Dimitriadis, Rubia, Gomez, & de la Fuente, 2003; Neale, Carroll, & Rosson, 2004; Suthers, 2006).

While quantitative research focuses on deduction, confirmation, standardized data collection and statistical analysis, qualitative research emphasizes induction, exploration, theory generation, and the researcher as the primary instrument of data collection (Johnson & Onwuegbuzie, 2004). Positivist purists believe that science involves confirmation and falsification and hence requires objective methods, whereas the unqualified relativism of interpretivist purism hinders the development of systematic standards for judging research quality. In the 'quantitative' approach to analyzing collaborative learning the communications are coded, summarized and frequencies are used for comparison and hypothesis testing, thus providing a more prospective foundation for analysis (Strijbos, Martens, Prins, & Jochems, 2006).

On the other hand qualitative researchers apply approaches such as participant observation, case summaries, and ethnomethodology, thereby assuming a more retrospective approach to analysis (Strijbos, Martens, Prins, & Jochems, 2006). Qualitative purists argue that time- and context-free generalizations are neither desirable nor possible and that research is invariably value bound because the subjective knower is the only source of reality (Johnson & Onwuegbuzie, 2004).

Mixed methods research provides an expansive and pragmatic technique for synthesizing the insights provided by qualitative and quantitative research rather than constraining the researcher to one approach. The mixed methods paradigm is "inclusive, pluralistic, and complementary, and it suggests that researchers take an eclectic approach to method selection and the thinking about and conduct of research" (Johnson & Onwuegbuzie, 2004, p. 17).

3.1.2 Advantages of using a Mixed Methods research approach

Mixed methods research can answer research questions that the other methodologies cannot, enable stronger inferences to be made, and provide the opportunity for presenting a greater diversity of divergent views (Teddlie & Tashakkori, 2003). It allows the best of both quantitative and qualitative approaches to be captured, for instance by developing a detailed and descriptive view of a situation at the same time as generalizing about a population (Creswell, 2003).

For example, in an analysis of knowledge building interactions in two different contexts, Hmelo-Silver (2003) demonstrated how qualitative and quantitative approaches can compliment one another in the study of collaborative learning. Combining fine-grained verbal data analysis along with qualitative analysis of larger units of dialogue allowed a more complete characterization of collaborative knowledge construction processes. The quantitative data (category frequencies) of the verbal analysis served to provide one type of representation of the knowledge construction process, but did not fully address how students constructed a joint public space. The qualitative analysis was able to illuminate how the space was co-constructed using negotiated planning and collaborative explanations. Hmelo-Silver (2003) argues that mixed methods are particularly useful for documenting collaborative knowledge construction in computer supported collaborative learning contexts because of the multifaceted nature of interactions in those environments.

In mixed methods research:

- Words, pictures and narrative can be used to add meaning to numbers, and numbers can add precision to words pictures and narrative (complimentarity)
- A broader and more complex range of research questions can be addressed (expansion)
- The strengths of qualitative and quantitative research can be combined and used to overcoming weaknesses in each approach (optimization)
- Convergence and corroboration of findings provides stronger evidence for a conclusions (triangulation)

- Insights and understanding can be provided that might otherwise be missed (thoroughness)
- By forming a more complete understanding of the situation being scrutinized theory and practice can be more confidently serviced (generalisability).

(Johnson & Onwuegbuzie, 2004)

Of these, Eisenhardt (2002) emphasizes the synergies that can occur by combining quantitative and qualitative methods. Quantitative evidence can indicate relationships that may not have otherwise been evident to the researcher, at the same time as preventing researchers from being carried away by their subjective impressions of qualitative data. On the other hand the qualitative data is useful for understanding the underlying reasons for relationships occurring in the study. The cross-validation of qualitative and quantitative data in a mixed methods design can then provide greater internal consistency (Eisenhardt, 2002).

3.1.3 Issues relating to mixed methods research

Care needs to be applied when adopting mixed method research, most importantly with how the methodologies are mixed (Johnson & Onwuegbuzie, 2004). The interpretivist and postpositivist paradigms should be deliberately integrated so that they cancel rather than compound each others' weaknesses (Rocco et al., 2003). Johnson and Turner (2003) refer to mixing methods for complementary strengths and non-overlapping weaknesses as the 'fundamental principle of mixed methods research'. The compatibility of methods used should be justified by the researcher (Creswell, 2003).

The mixing of methods also raises an issue as to how reliability and validity between studies should be addressed. Reliability is a concern in both approaches, but treated and reported differently. In quantitative approaches to studying online collaborations reliability is expressed as numeric values indicating level of agreement between coders, whereas in qualitative approaches reliability (credibility) is often established through internal or external triangulation (Strijbos, Martens, Prins, & Jochems, 2006). As well, the nomenclature for qualitative and quantitative research is also different (Teddlie & Tashakkori, 2003), with different possibilities for terms relating to the truth value, applicability, consistency and neutrality of the research (Lincoln & Guba, 1985). The researcher needs to decide how these differences between methodologies should be synthesized.

When constructing a mixed method design the researcher is required to make two primary decisions: (a) whether the research operates largely within one dominant paradigm or not, and (b) whether the phases of research are conducted concurrently or sequentially (Johnson & Onwuegbuzie, 2004). As well, the researcher needs to decide at what stage the qualitative and quantitative findings will be integrated (Creswell, 2003). The result of these decisions will determine the type of mixed method strategy that is applied.

3.1.4 Mixed methods applied in this study

3.1.4.1 Defining the methodology

As previously identified, the purpose of this study was to develop an understanding of collaboration and learning in web-conferencing environments by analyzing three semesters of an introductory computing subject. In order to address this purpose a "concurrent triangulation" (Creswell, 2003) mixed methods design has been adopted. This approach separates the quantitative and qualitative methods as a deliberate means of offsetting the weaknesses inherent within one method with the strengths of the other. Under a concurrent triangulation method quantitative and qualitative data collection occurs at the same time and in the one phase of the research study. The results of the two methods are then integrated during the interpretation phase.

The diagram below pictorializes the concurrent triangulation strategy using the conventional notation for representing mixed methods research design (Creswell, 2003).

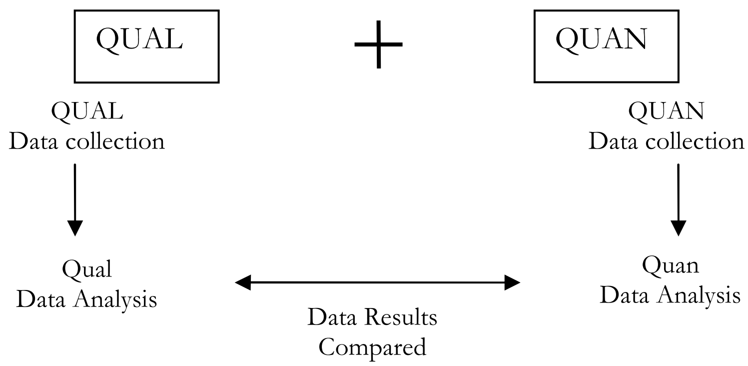

Figure 11 – Concurrent Triangulation Mixed Methods Research Design

The qualitative design-based research study analyzed the entirety of the three semesters of lessons conducted through the web-conferencing environment. For the design-based research study the unit of analysis was the semester (iteration). This is the same unit of analysis used in other design-based research projects (for instance, see Barab, Hay, Barnett, & Keating, 2000; Hickey, Kruger, Frederick, Schafer, & Zuiker, 2003) allowing broad patterns of interactions that occurred during each iteration to be characterized. The way in which different strategic approaches influenced collaboration and learning are investigated by observing effects across each entire semester. The influence of the approaches to interface design, activity design and the content identified in the research questions could be gauged using interpretivistic approaches. Descriptive techniques such as "vignettes" are used to exemplify the effects observed during the cycles of the design-based research process.

Using a sample of the data collected during the design-based research study, a multimodal discourse analysis was also conducted. For this quantitative strand of research the unit of analysis was a 'learning episode'. A learning episode represents a series of collaborations focused on addressing a discrete problem or activity covering a specified item of content. For instance, a learning episode might be the context and interactions associated with the task "explain the difference between a shallow copy and a deep copy". The multimodal discourse analysis examined 24 learning episodes that occurred in the web-conferencing environment in order to provide a detailed characterization of discursive interaction. The coding scheme was able to focus directly on curriculum content, activity coordination and technology, to provide a framework for understanding of how these three components of the research question influenced learning.

3.1.4.2 Justification of the methods selected

The design-based research study and the multimodal discourse analysis have been selected as the two methods for this study on the grounds of their complementariness on three levels, as follows:

- **Broad versus Detailed –** The study of entire iterations (semesters) in the design-based research provides a broad overview of behaviours, whereas the multimodal discourse analysis provides more detailed examination of individual learning episodes. In this way the relationship between the specific factors at play when teaching and the overall trends they cause can be perceived.
- **Emic versus Etic –** The descriptive approaches adopted in the design-based research methodology provides an emic view, offering a rich, contextualized representation of how collaboration and learning occurred in the web-conferencing environment. This allowed perceptions and insights collected by the researcher to be incorporated into the analysis, addressing the key issue of 'how' critical factors influenced one another. The positivist paradigm underlying the multimodal discourse analysis used constructions brought to the inquiry *a priori*, thus offering a more etic, objective view.
- **Process versus product –** The design-based research emphasized the process of inquiry; how designs changed and the evolving effects they produced. The multimodal discourse analysis provided a more detailed understanding of resulting collaborations, the nature of interactions and the range of variation that can occur between them.

Applying the concurrent triangulation methodology to two complimentary methods meant that inferences could be formed based on a more holistic understanding of the phenomena being studied.

3.1.4.3 Justifying the approach to mixing

Both the design-based research study and the multimodal discourse analysis were given equal weighting in the study. This meant that no preference was given to either in the analysis stage, allowing a balanced perspective that integrated the relative merits of each approach to be applied in the interpretation stage. On a pragmatic level, the amount of time spent on the multimodal discourse analysis was commensurate with the design-based research study, as was the extent of reporting. This supported a balanced use of results in the interpretation phase.

Note that in this study although the data for the two methods were collected simultaneously, the analysis was performed at different times. This was so the researcher could maintain continuity and consistency of thought during analysis, as well as maximize the autonomy of the two phases of analysis. First design-based research observations were recorded during each of the three semesters, not only in the form of web conference lesson recordings but also in the form of reflective journal notes that summarized the rationale behind and effect of different learning designs. Then after all three semesters had been completed the multimodal discourse analysis was conducted, based on transcriptions of the web conference lesson recordings. Finally, the design-based research data was analyzed in entirety by reviewing journal notes and recordings.

An effort was made to minimize the interaction between phases of analysis so that greater reliability of results could stem from between method agreements observed during triangulation of the data. This autonomy was preserved by deliberately attempting to avoid findings from one study influencing the search for findings in another during the analysis (but not integration of results) phase. Conducting the two strands of research using a high degree of autonomy served two purposes:

1. it allowed the overall reliability of the study to be improved through results found in both studies confirming one another
2. it allowed the relative merits of the two approaches to be more fairly compared and contrasted, providing a specific case to which the research methodology community can refer.

The extent to which the two strands of the study are autonomous is as hard to guarantee as it is to measure. However conflicting findings between the two approaches would be as interesting as confirmatory findings, meaning that there is little incentive for not retaining autonomy between the phases of analysis. As well, findings found in one study but not the other would also be valuable in comparing and contrasting the qualitative and quantitative approaches. The lack of requirement to achieve specific results dissipates the motivation to allow findings from one study to bias the other.

Reliability and validity issues have been addressed by drawing upon the established knowledge of each research paradigm individually. As a concurrent triangulation approach defers the integration of results until after analysis has occurred, both the design-based research study and the multimodal discourse analysis could be conducted independently using the pre-established quality control measures associated with each method. This avoided the need to invent untested integrated approaches to addressing reliability and validity). Correspondingly, the nomenclature associated with each paradigm has been preserved within each strand of study, which also serves to distinguish between the different ways quality of research is measured in the quantitative and qualitative paradigm (Guba & Lincoln, 1982).

The specific approaches to the design-based research and multimodal discourse analysis adopted in this study provide a mix of analysis that covers the qualitative-quantitative spectrum as follows:

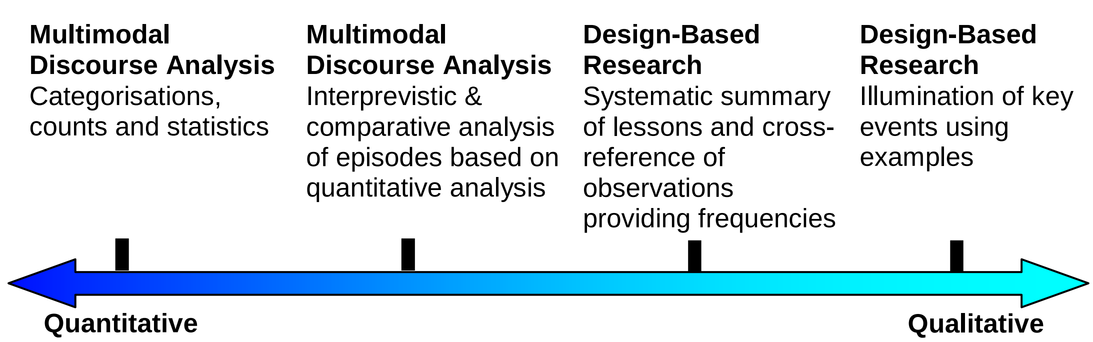

Figure 12 – Mix of methods covering the qualitative-quantitative spectrum

Note that the methodological approach to summarizing observations and key incidents from all learning episodes in the design-based research strand of this study allowed quantitative observations to be drawn in so far as frequencies of occurrence were recorded. At the same time the multimodal discourse analysis was used as a tool to highlight pertinent aspects of particular learning episodes, from which qualitative observations were drawn. Using the quantitative data to support qualitative (interpretivistic) analysis in the multimodal discourse analysis, as well as using frequency of observations (positivistic) approaches during the design-based research study allowed a more integrated mergence of qualitative and quantitative approaches. This supported the triangulation and integration of the results that are provided in the "Discussion" chapter.

The methods applied to conduct both the design-based research investigation and the multimodal discourse analysis are now introduced. First the design-based research approach to analysis, design, enactment, and reporting is described. Second the approach to multimodal discourse analysis is explained, providing details of the sampling, transcribing, coding and reporting techniques used. Each case is introduced with a general description of the methodology, followed by a rationale for adopting the approach in this study, and concludes by describing the methods applied.

3.2 Design-Based Research Method

3.2.1 About Design-Based Research

3.2.1.1 Introduction

There has been general acknowledgement amongst contemporary researchers that learning (student, group, organization) does not occur in-vacuum, but rather is affected by a complex set of interrelating factors (Lesh, 2003). Dealing with that complexity in a disciplined way is the essence of research design (Lesh, 2003). Design-based research (also called 'development research', 'design research' or 'design experimentation') methods integrate design and empirical research methods with an aim to develop models and an understanding of learning in naturalistic intentional learning environments (Tabak, 2004).

Design research represents a reconceptualization of learning theory as something that can be shaped by researchers and practitioners in context (Reeves, Herrington, & Oliver, 2004). The difference between predictive and developmental research approaches is summarized in Figure 13.

Design research occurs at a level that allows 'embodied conjectures' to develop learning theory (Sandoval, 2004). As opposed to directly developing 'design principles' which are articulated at a general, untestable level, embodied conjectures are based on extant knowledge of learning in a particular domain that can be challenged by trial (Sandoval, 2004). The empirical refinement of embodied conjectures may not only lead to enhancement of particular learning environments but also to developments in learning theory itself (Sandoval, 2004). An example of one such type of learning theory development is 'ontological innovation' – the introduction and refinement of new categories of existence (diSessa & Cobb, 2004). Design-based research facilitates the development of theory that can be directly applied while involving elements of generalization (diSessa & Cobb, 2004).

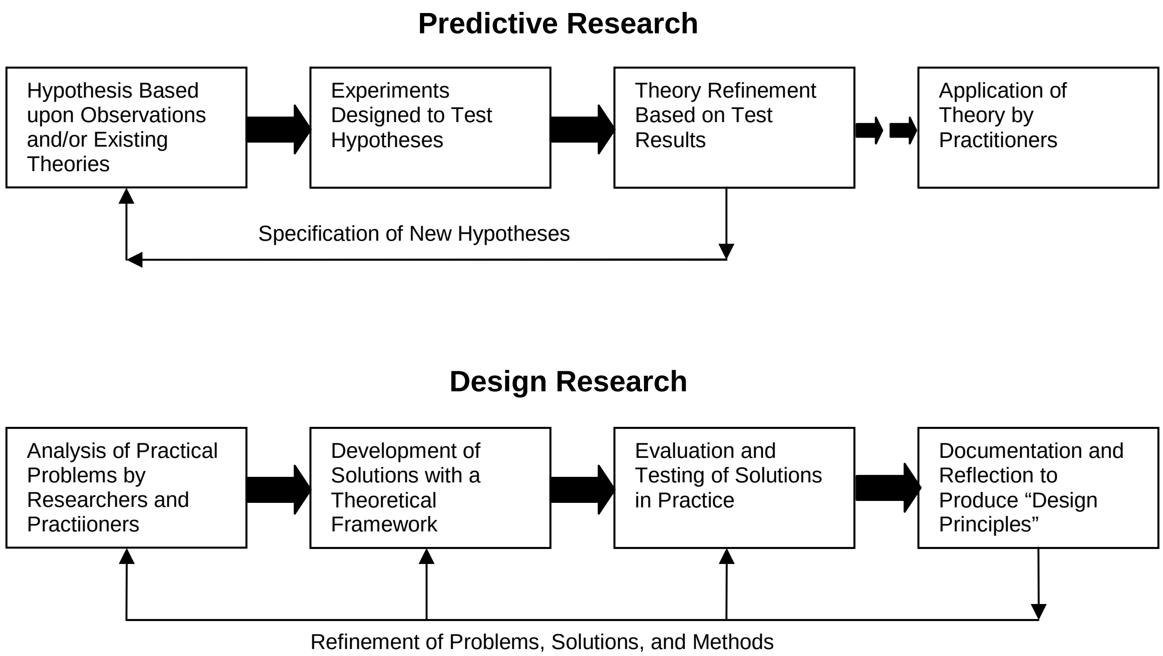

Figure 13 – Difference between predictive and design research approaches (Reeves & Hedberg, 2003)

Because design-based research is set in authentic learning environments there are many variables that cannot be controlled. Instead, design researchers attempt to optimize the design as far as possible and observe how different elements interact (Collins, Joseph, & Bielaczyc, 2004). Collins et al (2004) draw upon seven differences between laboratory studies and design-based research in their rationale for design experiment studies:

1. Laboratory settings vs messy situations
2. A single dependent variable vs multiple dependent variables
3. Controlling variables vs characterizing the situation
4. Fixed procedures vs flexible design revision
5. Social isolation vs social interaction
6. Testing hypotheses vs developing a profile
7. Experimenter vs co-participant design and analysis.

They argue that based on these differences design research is able to fill a gap between the case based focus on sociological and contextual factors provided by ethnography and large scale quantitative approaches that focus on the cause and effect of critical variables (Collins, Joseph, & Bielaczyc, 2004).

Cobb, Confrey, diSessa, Lehrer and Schauble (2004) suggest five features of design experiments that cut across the diverse range and types of research to embody the approach:

1. development of a class of theories about the process of learning and the means of supporting that learning
2. the highly interventionist nature of the methodology

3. the paradoxical use of theories to form conjectures that may form new (potentially contrary) theories
4. the iterative design to implement the prospective and reflective aspects of theory formulation
5. the development of theories that are applied in nature.

Because of its highly interventionist nature and developmental nature, a distinctive attribute of design-based research is that the research team deepens its understanding of the phenomenon under investigation as the study progresses (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2004). This necessitates comprehensive recording and documenting of the ongoing design process in order to evidence the rationale behind design decisions and provide a clear trail of evidence for findings that are reported (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2004).

Two other important aspect of design-based research relate to the structure of the method applied. Firstly, in design-based research the approach to redesigning environments should be both deliberate and well reasoned (Sandoval, 2004). Secondly, a systematic approach to analysis should be adopted (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2004; Sandoval, 2004).

3.2.1.2 Why use Design-Based Research in this study

Design-based research is a suitable method for investigating technology based learning approaches (Hickey, Kruger, Frederick, Schafer, & Zuiker, 2003; Reeves, Herrington, & Oliver, 2004; Sandoval, 2004). It is seen as a promising way to:

a. explore possibilities for creating novel learning environments
b. to develop theories of learning that are contextually based
c. advance and consolidate design knowledge
d. increase the educational community's capacity for educational innovation.

(The Design-Based Research Collective, 2003, p. 8)

The capacity to engineer the environment provides a measure of control when compared with purely naturalistic investigation, allowing effects to be detected (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2004). Being able to manipulate the learning designs enacted in the web-conferencing environment allows the impact of changes to be gauged. Furthermore, in attempting to support specified forms of learning (for instance, student-centred), relevant factors that contribute to the emergence of that form are more likely to be encountered which allows awareness of their interrelations to be developed (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2004).

The naturalistic basis of the design-based research approach closes the "credibility gap" between educational research and practice that exists in some methodologies (The Design-Based Research Collective, 2003). Design-based research operates at a level that constitutes a means of addressing complexity, which is a hallmark of educational settings (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2004). The multiplicity of tools availed by the web-conferencing system, the various types of content that can be addressed, and the choice of activity designs that can be used combine to create a complex environment for studying teaching and learning. Design-based research is able to incorporate the influence of authentic settings and the potentially multifaceted nature of outcomes, providing a more complete and realistic understanding than research conducted in impoverished contexts that only consider isolated variables (Barab & Squire, 2004; Lesh, 2003). This is particularly valuable in analyzing the dynamic design potentials of the web-conferencing environment, which may be less easily examined under more rigid methodological frameworks.

Because design-based research focuses on the process of learning it can provide insights into the complexity of developing knowledge and the role that the teacher plays in leveraging the affordances of learning resources, both of which may have gone unnoticed if solely more quantitative or summative foci had been adopted (The Design-Based Research Collective, 2003). Design-based research allows the more realistic possibility of teacher as reflective practitioner in educational development projects by not enforcing an artificial line between researcher and subjects (Lesh, 2003). The role of the teacher as both designer and manager in the web-conferencing environment becomes an important part of the authentic context of the study. A positive consequence of this dual role is that a greater degree of methodological alignment can be achieved by having the same person or people engage the theory, implement interventions and measure outcomes (Hoadley, 2004).

The cyclic and iterative processes involved in design-based research are more in alignment with the authentic design of learning environments (Lesh, 2003). However, design-based research goes beyond the design, implementation and testing of environments that subsumes most other approaches to developmental research, to necessarily attempt to generate theories about teaching and learning (The Design-Based Research Collective, 2003). Using a design-based research approach to study teaching and learning in the web-conferencing environment not only emulates the realistic process of teachers engaging in reflective practice to form understandings but also supports the distribution of understandings through a mandate for theory generation.

Design-based research permits the use of any and all types of data to arrive at an effective design, for instance the expertise of teachers and designers (Gorard, Roberts, & Taylor, 2004; Wilson, 2004). This enables the accumulated experience of the teacher-researcher with the web-conferencing system to inform descriptions so that relevant knowledge can be passed on to those unfamiliar with the environment. As well, design experiments value rather than discard ineffective designs as providing useful information regarding how users respond to particular approaches. This can then provide a more illuminating starting point for the next phase of the design process than if a semi-successful design had been implemented (Gorard, Roberts, & Taylor, 2004). Using all sources of data (including ineffective designs) when analyzing the influence of content, activity and technology upon teaching and learning enables more rapid design progress to be achieved than if this information had been discarded.

3.2.1.3 Issues in Design-Based Research

The Design-Based Research Collective (2003) discusses some of the issues involved in conducting design-based research:

> *Complications arise from sustained intervention in messy settings. A single, complex intervention (e.g., a 4-week curriculum sequence) might involve hundreds, if not thousands, of discrete designer, researcher, and teacher decisions-hopefully working in concert-in an attempt to promote innovative practice. In these situations, causality can be difficult to decipher and disambiguate; all possible factors cannot logistically be equally pursued; precise replication of an intervention is largely*

> *impossible; and emergent phenomena regularly lead to new lines of inquiry informed by current theories or models of the phenomena.*
>
> (p. 7)

Therefore design-based research relies on the researcher to identify potential confounding effects and provide their interpretations of interrelations based on their proximity to the context.

One issue that any research needs to consider is the extent to which a nomothetic (studying many subjects on fewer variables) versus idiographic (studying fewer cases in detail) approach is adopted (Brown, 1992). Nomothetic research provides quantitative support for principles of behaviour, while idiographic approaches allows in-depth understanding of contextualized cases to inform the field. Since design-based research aims to derive generalized principles for teaching from studies of specific contexts, a view that incorporates a degree of nomothetic and idiographic approaches is appropriate (Brown, 1992).

Design-based researchers need to also beware the Hawthorne effect, where every change results in an improvement in performance. One way that Brown's (1992) foundational design research study into developing communities of learners accounted for this was by noting that successive refinements resulted in specific and predicted changes in behaviour rather than general improvement. Brown (1992) also forewarns of romanticizing the novelty of findings. As this research relates to the relatively unexplored area of teaching and learning using computing the likelihood of this is reduced. However, it is the obligation of the researcher to identify cases where effects are enactments of principles observed elsewhere.

Another issue in design-based research relates to biases in data selection to demonstrate findings (Brown, 1992). When portions of transcripts are selected to illustrate theoretical point from a large array of possible examples, there is a high potential for misrepresenting the dataset. This can be addressed by using systematic approaches to representing the entire dataset, and then choosing specific cases to illustrate points from within the dataset. This approach has been adopted in this study with the prevalence of each point being represented indicated by cross-reference to all instances within an iteration. This allows the reviewer to ascertain the pervasiveness of the effect throughout the study, thus averting selection bias. As well, the attempts to make the research process as open and visible as possible allows other researchers to gauge the accuracy of claims (Brown, 1992).

While positivists may criticize design-based research for lacking rigor, Hoadley (2004) argues that design-based research is more rigorous than experimental research in connecting interventions to outcomes in complex and realistic settings. This, Hoadley claims, can lead to better real world alignment between theory, treatments, and measurement than experimental research.

3.2.2 The Design-Based Research process in this study

3.2.2.1 Enactment of the iterations

Before any of the Iterations considered in this study were implemented a pilot semester[3] of the ITEC100 introductory programming course was conducted (referred to as Iteration 0)

[3] Classes in 2005 Semester 1 were not recorded. This semester was seen as a familiarization opportunity with a small class of students (n=5).

during Semester 1 of 2005. This provided the opportunity to observe the features of the educational environment in operation, to form an elementary appreciation of its functioning, and based on these understandings to devise the research questions and strategies for the study. This period of time was also used to commence reviewing and synthesizing relevant literature so an awareness of the fields could be developed and hence the strategic redesigns in Iteration 2 could be developed on a principled basis.

Following this, three semesters (iterations) of classes were conducted as part of the design-based research process – Semester Two of 2005, Semester One of 2006, and Semester Two of 2006. These will be referred to as Iteration 1, Iteration 2, and Iteration 3, respectively. Twelve two-hour classes were conducted for each of the three semesters using the same curriculum materials. The same text-book, recorded lectures, and tutorial and practical sheets were used across the three semesters in order to provide a consistent curriculum across the three iterations and hence reduce the possibility of intervening environmental effects. While this meant the types of tasks (objects) being addressed across iterations was held constant, there was a great deal of variation of task types within each semester upon which basis the effect of different task types and their interaction with technology and (inter)activity designs could be observed.

The three iterations can be summarized as follows.

3.2.2.1.1 Iteration 1

In Iteration 1 (Semester 2 of 2005) the default layouts of the web-conferencing platform were applied, or minor variations thereof. The small changes that were made included making the chat pod larger so that students could see more text-chat at once, or making the attendance pod longer so that all student names could be seen. Changes to the layout were not premeditated or designed on a principled basis. The main way in which the interface was adjusted to meet the needs of the learning episode was by switching between the three default layouts.

The approach to teaching was predominantly transmission based, and to some extent teacher-led. Transmission approaches included long periods of teacher explanation and presentation of solutions relating to the tutorial and practical exercises. Teacher-led approaches usually involved the teacher using audio to ask students a question related to the exercises and having them respond using text-chat. As the teacher and student communication channels did not interfere with one another students could make contributions while the students were talking and vice versa.

While no major design changes were made during Iteration 1, continual reflection occurred regarding how micro-factors influenced the effective deployment of the web-conferencing system and how to engage student collaboration. This led to minor changes in teaching approaches and technology implementations, as documented in the lesson summaries that were recorded for Iteration 1. The technology, (inter)activity and task content observations of Iteration 1 provided a baseline for the study and a foundation upon which the major design revisions for Iteration 2 were based.

3.2.2.1.2 Iteration 2

Iteration 2 (Semester 1 of 2006) of the subject was characterized by the redesign of the environment to engage more effective collaboration. The web-conferencing interface was redesigned based on principles distilled from the analysis of literature relating to interface design (that has been outlined in Chapter 2). The "Approach to Redesign" subsection that follows provides an example of how these principles were applied, as well as the results of a micro-study examining the efficacy of the redesign approaches.

This semester incorporated the use of student-centred (inter)activity designs. This not only involved separate web-conferencing rooms for each group of students but also designing the interface of those rooms to meet the collaborative requirements of the learning episodes. During implementation of group-work episodes the teacher could "toggle" between browser windows containing the separate group-work rooms to observe progress and patterns of behaviour. Recordings of each group-work room could be analyzed in retrospect to provide a deeper understanding of the interactions that transpired. In order to avoid persistent effects of interactions between particular individuals, an effort was made to mix the membership of the groups as possible throughout the semester.

Teacher-centred and teacher-led approaches were still used in Iteration 2. The difference between the implementation of these approaches in Iteration 1 and Iteration 2 is that the interface had often been deliberately designed to meet the collaborative requirements of the learning episode. For teacher- centred approaches this may mean removing an obsolete file-share pod and extending the length of the chat-pod so that students could enter more substantial text-chat contributions if necessary. For teacher-led approaches this may mean designing an entirely new layout that provides a shared note-pod for collaborative program writing with a whiteboard to represent visual conceptions. Examples of such redesigns are provided in the Design-Based Research Results chapter (Chapter 4) and Appendix A – Design-Based Research Summary of Data.

While substantial amounts of time were spent considering and developing designs before classes in Iteration 2, the flexibility of the web-conferencing environment also allowed ad-hoc adjustments to the interface during lessons. This meant that improvements to interface designs could occur dynamically in class based on changes in the teachers' perceptions of interface requirements. As well, student feedback (either solicited or unsolicited) regarding the efficacy of interfaces could be (and was often) utilized to apply these dynamic redesigns.

By providing students with the access control they could themselves (and did at times) change the interfaces based on their perceived needs. In such cases the teacher could then question students as to the rationale for their changes, providing a more complete body of evidence for how interface designs in the web-conferencing environment affected learning.

In Iteration 2 student audio was trialled on two occasions. Observations drawn from piloting this approach led to its implementation throughout Iteration 3.

3.2.2.1.3 Iteration 3

Iteration 3 (Semester 2 of 2006) involved refining the major interface and (inter)activity design approaches applied in Iteration 2. Because similar learning designs were being utilized, the effects of small to medium scale changes could be investigated. As well, in cases where the learning design adopted in Iteration 2 was perceived successful and no redesigns were implemented, the consistency of collaborations with the same design across semesters could be gauged.

In this iteration of the subject the teacher encouraged pervasive use of audio by students, based on several cases in previous iterations where text-chat was observed to be deficient. The use of student audio was part of a deliberate attempt by the teacher to manifest a more conversational classroom environment (Laurillard, 2002; Waite, Jackson, & Diwan, 2003). This was easier to implement this semester than the other two semesters because there were fewer students (three), meaning that troubleshooting, setup and maintenance issues were less inhibiting.

Iteration 3 was also characterized by more spontaneous redesign of the interface by the teacher and students than had been applied in Iteration 2. These redesigns were based on the perceived collaborative requirements of the activity at hand and an understanding of how the affordances of the web-conferencing environment could satisfy those requirements.

Due to the extended duration of the Iterations (12 week semesters) different approaches to design could be observed on a number of different tasks. As the efficacy of approaches was gradually established there was less need to apply treatments (intended improvements), and instead the designs being implemented were monitored to check that they behaved as expected. Thus towards the end of the study less changes were being implemented as the number of open issues had been reduced.

Note that no redesigns occurred in the first week of Iteration 2 and Iteration 3. This consistency of approaches in the first week of all three semesters also provided a means of calibration between iterations, allowing the consistency of collaborations when the same learning designs were applied across different semesters to be gauged. This also allowed new students to develop a degree of familiarity with the web-conferencing environment and orient themselves to the course without the extra challenge of attempting group-work.

3.2.2.2 Approach to data collection

Recordings of lessons conducted in the web-conferencing environment formed the main primary source of data in this study. The capacity for these recordings to reconstruct all actions and contributions that occurred during each class (including voice, text-chat, whiteboard operations, screen-sharing episodes, file uploads and so on) allowed the process of learning to be scrutinized (not just the product). Other primary sources of data included all tutorial and practical sheets and solutions, all files that were uploaded to the file-share pod, and all remnant artifacts from the rooms (including text-chat, note-pod contributions, and whiteboard contributions). At the end of each lesson these primary data were archived in the project database.

Student feedback regarding teaching and learning in the web-conferencing environment was also harvested. The three means of collecting this feedback included:

- i) implicitly through unsolicited comments made during learning episodes
- ii) explicitly via in class teacher questioning regarding the efficacy of different approaches
- iii) explicitly through of an end of semester survey instrument.

These were also added to the project database.

3.2.2.3 Approach to analysis

In order to document the "process of enactment" (The Design-Based Research Collective, 2003, p. 7), a reflective journal was maintained. After each lesson between half and one day was spent reviewing the recording of the lesson, reviewing learning artifacts (such as text-chat transcripts and student solutions contributed to note-pods) and summarizing pertinent points into the journal. All observations related to identifying cause and effect relationships occurring within the learning episodes were noted, with a focus on how the interface, activity, content and teaching approaches affected collaboration and learning. Particular emphasis was placed upon documenting how different learning designs engaged different levels of interaction and enabled more effective representation of students' mental models.

Screenshots of rooms were often included in the journal notes if they illustrated important aspects of an environment design. Screenshots of recordings were used if it was necessary to capture aspects of an environment in use. Both successes and failures were documented, with the failures seen as making an as important contribution to understanding teaching and learning in the web-conferencing environment as successes. Documenting this information typically resulted in between ten and fifteen pages of reflective journal notes each week.

The observations contained in the reflective journal notes along with lesson artifacts and student feedback were then used as a basis for redesign. Particular attention was dedicated to the way in which theories of learning derived from the fields of cognitive science, multimedia learning, and distributed cognition could inform the redesign of the environment. Redesigns occurred at both a strategic and tactical level. Strategic redesigns occurred across iterations, as described in the "Enactment of Iterations" sub-section above. Tactical redesigns occurred within iterations, focusing incrementally improving the way in which the affordances of the web-conferencing environment were applied. The influence of both strategic and tactical redesigns on collaboration and learning were added to the project database through their inclusion in the reflective journal.

The continual cycles of design, enactment, analysis and redesign allowed the design of the learning environment to coincide with the development of theories regarding teaching and learning. The evolving nature of which is encapsulated in the term "prototheories" (The Design-Based Research Collective, 2003). The extended timeframe of this study allowed these theories to be retested in similar (but not identical) settings in order to ascertain their dependability.

3.2.2.4 Approach to redesign – an example and validation

3.2.2.4.1 An example

The screen shot shown in Figure 14 provides an illustration of how the web-conferencing system was being used in Iteration 1 to support the learning of computer science concepts relating to the use of 'if-else' statements. The teacher uses a standard interface design to broadcast the solution document. The teacher uses audio to explain how different if-else sequences result in different outputs, and students can respond using text-chat.

On the basis of the literature discussed in Chapter 2 and observations of using the web-conferencing system in previous iterations, the environment was redesigned in order to engage more collaborative and active learning. The considerations incorporated into the redesign are described below, to illustrate the ways in which the literature was applied. Note that the aspects of redesign are sectioned by cognitive stages of learning in order to provide structure for the description. However, the redesign itself synergistically drew upon a range of findings from the literature as well as from the observations drawn from previous learning episodes.

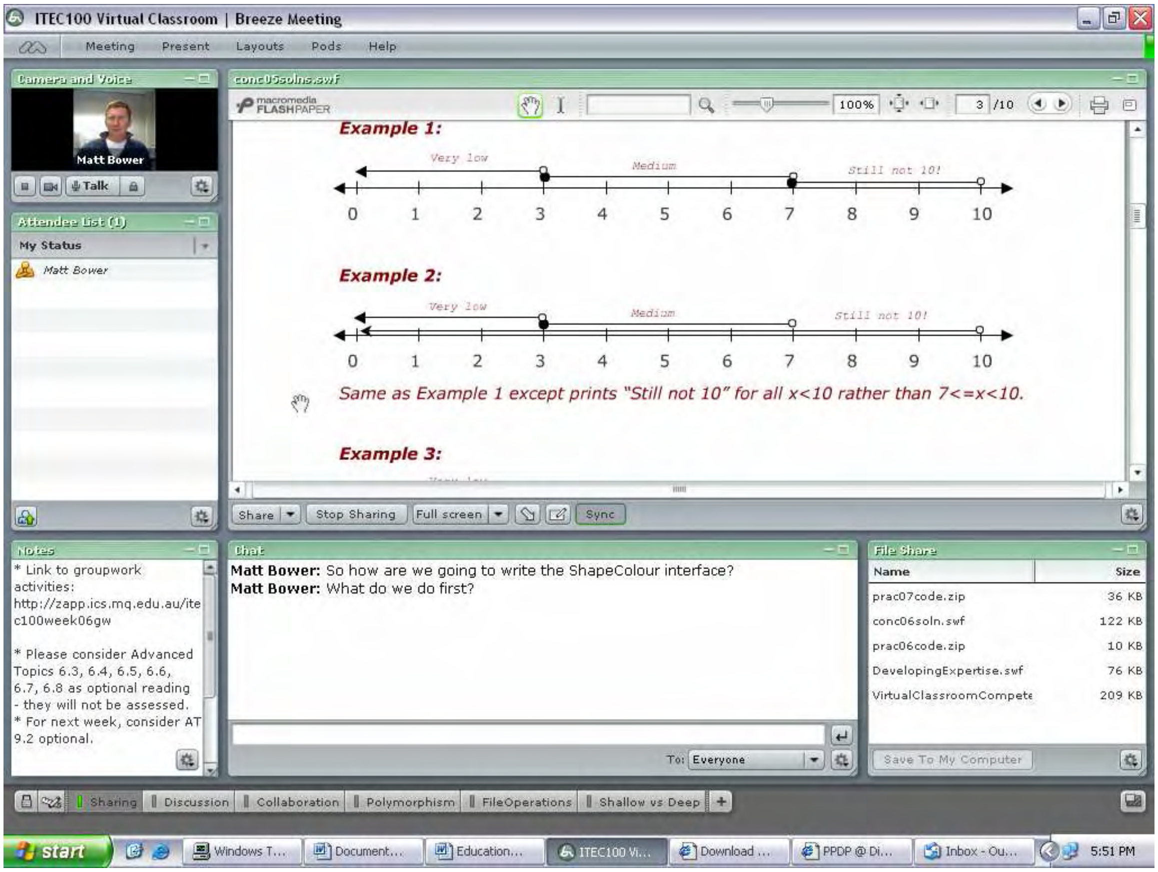

Figure 14 – An Iteration 1 design, showing (clockwise from top left) Camera and Voice, Document share, File-share, Chat, Notes and Attendee List Pods

3.2.2.4.2 Approach to redesign

Attention

The interface enabled the instructor to broadcast audio so that they could focus students' attention upon the task at hand (Mayer, 2005c). A more collaborative approach requiring students to provide a collaborative solution on the whiteboard was adopted, promoting increased engagement and thus greater attention (Mayer, 2005c).

Selection

The key diagram area was increased in size and placed centrally to signify its importance (Hollan, Hutchins, & Kirsh, 2000). Appropriate headings were placed on all pods to signal their purpose and to assist orientation. Students (and teacher) have access to a pointer tool so that they could dynamically signify parts of the question and solution space (Hatcher, 2003; Rouet & Potelle, 2005). The task description was placed in the main pod for easy selection.

Retrieval
Students were provided with audio and the opportunity to conduct discourse relating to the topic, facilitating retrieval of pertinent knowledge (Byrnes, 2001). Providing the task, description and the if-then-else statements within the interface also stimulates recall of relevant knowledge.

Comprehension
Placing the task description on the shared whiteboard space allowed students to visually represent their conceptions regarding the problem at hand and be provided with feedback from others (Vygotsky, 1978). The collaboration facilitated through the interface allows weaker students to learn vicariously through observation of their peers (Bandura, 1977). Having a visual task operating in conjunction with an audio communication channel allowed for complementary interaction between the modalities (Fletcher & Tobias, 2005; Low & Sweller, 2005). Students were granted highest level of privileges within the room so that they can create, place and resize other tools to support their cognition and better represent their ideas (Hollan, Hutchins, & Kirsh, 2000). Comprehension was also supported through collaborative tools that provided students the opportunity to ask questions of lecturer and peers (Vygotsky, 1978).

Synthesis
A public solution space provides the capacity for the different ranges within each part of the problem to be represented / integrated by different students, promoting the development of a shared understanding through distributed cognition (Hollan, Hutchins, & Kirsh, 2000). Audio technology allows tightly coupled interactions between students regarding approaches to solving the problem at hand (Engeström, 1987; Neale, Carroll, & Rosson, 2004).

Memory
The task required re-representation of existing understandings into a new (diagrammatic) form, requiring active processing and hence better commitment to memory (Byrnes, 2001; Sylwester, 1995). A shared and persistent space was provided for the representation of concepts, allowing them to be revisited (Zhang, 1997).

Abstraction
Multiple examples are posted in the same space for ease of comparison and contrast. The multiple examples and the diagrammatic representation of them engages students with the concept of ‘if-else’ rather than simply having them apply an ‘if-else’ statement upon an object (Sedig, Klawe, & Westrom, 2001). Students are provided with a space to summarize important points about if-else statements, documenting their abstractions and also supporting commitment to memory (Byrnes, 2001) . The diagrammatic approach to analyzing if-then-else statements provided students with a problem solving strategy that they could transfer out of the specific context in which they were operating (Salomon, 1992).

The redesign also employed several strategies to support the management of cognitive load. Examples were all posted in the close physical proximity and attempted in close temporal proximity, thus lowering extraneous cognitive load by reducing split attention (Ayers & Sweller, 2005). For the same reason, the question was situated close to the solution space. The capacity to offload information was provided through the both the number-lines on the whiteboard and the note-pod (Hollan, Hutchins, & Kirsh, 2000; Zhang, 1997). Students could use a range of colours to distinguish their whiteboard contributions from one another, providing them with greater environmental awareness and less extraneous cognitive load caused by coordinating activity (Luff et al., 2003).

An increase in germane cognitive load for more capable students is encouraged by requiring them to reflect upon and summarize the important points to remember about 'if-else' statements, requiring them to act upon the concept not just the object (Sedig, Klawe, & Westrom, 2001). Students were provided with prior experience with the tools and room, minimizing the cognitive load caused by having to learn the technology (Clarke, Ayres, & Sweller, 2005; Morrison & Anglin, 2005, p. 95). As well, the scope and complexity of activity provided within the interface was designed to suit the ability level of the learners (Vu, Hanley, Strybel, & Proctor, 2000).

Some of the elements that were included in the initial design were removed from the revised design to promote more effective use of working memory. The webcam was not broadcast as it added no informatory benefit to the learning episode (Mayer, 2005c). The file-share pod and unused note-pod were removed because they were considered extraneous in nature (van Merriënboer & Ayres, 2005). The text-chat pod was removed because it was considered as only being able to represent superfluous information in this case that could otherwise be represented in the note-pod, whereas the audio channel enabled dual processing when used in conjunction with the whiteboard (Low & Sweller, 2005; Mayer, 2005b, p. 184; Sweller, 2005b). The interface that resulted from the redesign is show in Figure 15 below.

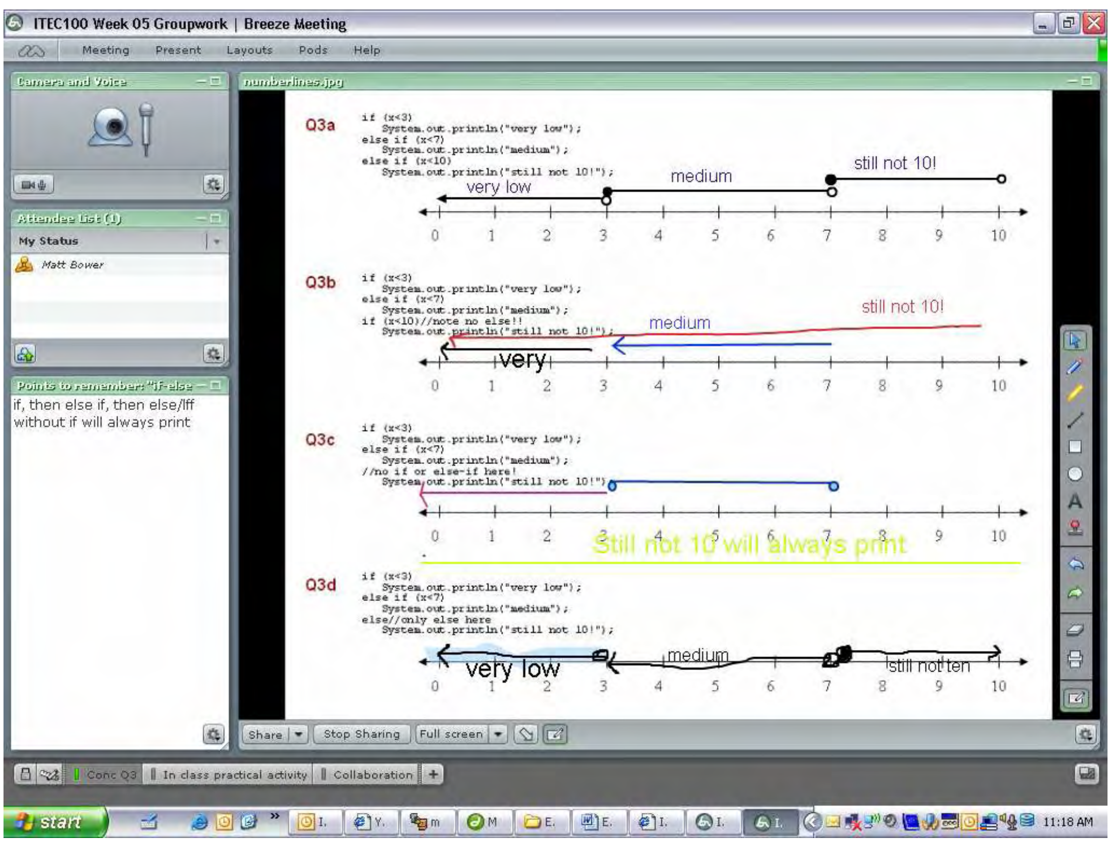

Figure 15 – Redesign of the if-else interface from Iteration 1

3.2.2.4.3 Validation of approach to redesign

A small scale study was conducted to gauge whether synergistically drawing upon the range of considerations identified in the literature and the experiences harvested during the design-based research process could result in environments that students deemed more effective. This was performed to provide a validation of the approach to redesign as well as to demonstrate a degree of methodological rigor. Prior to this the extra potential arising from the redesigned interface had been identified based on teacher observations, analysis, and anecdotal feedback from students.

Students from across all three iterations completed a survey during Semester 2 of 2006 (Iteration 3) to determine their perceptions of redesigned environments compared to those used in Iteration 1. Seventeen students who had been or were enrolled in the introductory programming course completed the survey. These students will be referred to as the "CS1" group. In order to provide a larger sample, twenty-six students from the university's Master of IT who had used the web-conferencing platform but not for the subject and topics being considered were also enlisted to complete the survey. These students will be referred to as the "non-CS1" group.

The online questionnaire presented the original interface and the redesign of the interface, as well as a brief description of how the interface was used to facilitate learning. They were then asked to respond to the statement "Interface 2 provides a more effective interface for learning about 'if-else' statements than Interface 1." A Likert scale was provided containing seven options from which they could choose (response choices included "Strongly Disagree", "Disagree", "Mildly Disagree", "Neutral", "Mildly Agree", "Agree", "Strongly Agree"). Students were also asked to "explain your answer providing as many reasons as you can".

Statistical analysis was performed upon student responses to Likert scale questions, based on a numeric allocation (of 0 through to 6) to the 7 possible response categories[4]. All tests performed on Likert scale question responses were one-tailed student T-tests, to test the hypothesis:

> H_0: the environment redesigns ***were not*** rated by students as significantly more effective for learning than the original designs.
>
> H_1: the environment redesigns ***were*** rated by students as significantly more effective for learning than the original designs.

For the 'if-else' learning activity described above, students in the CS1 group rated the redesigned environment as significantly more effective for learning than the original environment ($p < 0.001$). Students in the CS1 group also rated the redesigned environment as significantly more effective ($p = 0.013$).

A further three interface designs were tested using the same approach. These related to redesigns for a file input/output task, a polymorphism task, and a shallow/deep copy task (the redesigns of which are described in Appendix A – Summary of Design-Based Research Data).

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[4] While this approach is commonly used by researchers, it needs to be noted that performing such a transformation from descriptive to quantitative data is not without limitations and any results need to be considered in context.

A summary of results is represented in Table 5. Note that to avoid bias caused by the order in which the interfaces being compared were presented, two of the four questions placed the redesigned interface before the original interface. All p-values are reported to 3 significant figures, and represent one sided T-distribution probabilities that the rating of the redesigned environments were higher than the original designs.

Interfaces:	If-else	File input/output	Polymorphism	Shallow/deep copy
CS1 (d.f.=16)	p=0.000**	p=0.021*	p=0.648	p=0.001*
Non CS1 (d.f.=25)	p=0.013*	p=0.204	p=0.083	p=0.000**
Combined (d.f.=41)	p=0.000**	p=0.011*	p=0.486	p=0.000**

d.f.: degrees of freedom of t-distribution * $p<0.05$ ** $p < 0.01$

Table 5 – hypothesis test p-values for ratings of interfaces designed using the integrated framework

Table 5 indicates that students who had previously engaged in learning the sub-topics being considered deemed three out of the four environment redesigns significantly more effective for teaching the concepts. Students who had not previously engaged in learning the topics regarded two out of the four redesigns as significantly more effective. This data suggests that in some circumstances students are able to immediately perceive the qualitative improvement in environments that had been redesigned using the approaches adopted in this study.

Qualitative data solicited from students during the survey supported the results from the quantitative analysis. Students provided several reasons for preferring the re-designed interfaces that were as a direct result of applying the integrated design framework. Reasons included the size and placement of tools and information, the suitability of the type of tool provided for the task at hand, the degree of engagement facilitated, the use of highlighting (such as colour) and the modality employed (such as diagrams versus text).

This evaluation does not provide unequivocal evidence that all redesigned environments were more effective. Nor does it investigate cause and effect relationships regarding collaboration and learning, or develop any working theories. That is the focus of the broader design-based research study being performed. However, the results do indicate that applying the redesign approach as part of the design-based research process could result in environments that students perceived as superior for teaching and learning purposes, thus to some extent validating the methods that were applied.

3.2.2.5 Approach to reporting

3.2.2.5.1 Lesson summaries

In order to form a comprehensive representation of the situation being studied, a summary of all 36 lessons were constructed (refer to Appendix A). The lesson summaries were based upon all sources of data from the project database, which included the lesson recordings, primary artifacts from the lessons, student feedback, and the reflective journal. These week-by-week summaries and reflections aim to:

- Describe the lessons that occurred as a means of providing a concrete representation and archive of teaching and learning in a web-conferencing environment

- As a collective illustrate the nature of teaching and learning in a web-conferencing environment
- Provide insight into critical aspects of how the interface, activity and task type affected collaborations and learning.

The critical incidents, recurring themes and virtuoso moments that were incorporated into the week-by-week descriptions were selected for their capacity to demonstrate how the task, interface and activity design affect collaborations. From the ten to fifteen pages of reflective journal notes taken per week and the various other sources of data each lesson was distilled into between two and four pages for each week.

The lesson summaries included core observations, key incidents and reflective notes from the learning episodes. The following insignias were applied to the data:

- OB = “observation”. These are descriptions of the planned aspects of the lesson, with each observation representing a distinct learning episode or a sequence of related learning episodes.
- KI = “key incident”. These are occurrences in the lesson that had an impact upon or highlighted the quality of learning episodes.
- RN = “reflective note”. These are researcher evaluations (based on observations and key incidents that occurred throughout the lessons).

Observations represent raw data. Key incidents are specific events that have been selected for their contribution to the analysis of teaching and learning in web-conferencing environments. Reflective notes are subjective abstractions that have been made based on observations and key incidents. Reflective notes may also be based on the researcher’s teaching experience, for instance to provide suggestions for improvements in the next iteration of the subject (i.e., propose design refinements). The reflective notes also allow the evolution of the researchers’ understanding of teaching and learning in the web-conferencing environment to be traced.

The authenticity of the reporting is evidenced in the frequent reference to mistakes and poor designs. Problems with designs and implementations were seen as opportunities to better understand teaching and learning in the web-conferencing environment, upon which prototheories for more effective designs could based and tested. Accordingly they have been pervasively documented.

Only those observations, key incidents and reflective notes that contribute to the characterization of an iteration have been included in the week by week descriptions. As such, each observation, key incident and reflective note has been referenced in the Design-Based Research Results chapter.

3.2.2.5.2 Reporting of results

The results of the design-based research strand of this study are reported in Chapter 4. These contain a characterization and discussion of each iteration with relation to how technology, activity and task content (and combinations of these) impacted on collaboration and learning.

To characterize each iteration the observations and key incidents from the lesson summaries were reviewed and the aspects critical to designing and implementing learning episodes in the iteration distilled. Each aspect was cross-referenced back to the summaries to provide the chain of evidence. Themes that were repeated in several learning episodes were thus cross-referenced to each, providing an indication that they more strongly characterized the iteration.

The reflective notes from the lessons summaries were used to inform the discussion of each iteration, particularly with respect to the nature of how designs were influencing learning in the web-conferencing environments. As well, specific cases or "vignettes" have been included to demonstrate the effects being discussed. These are dispersed throughout the results section of Chapter 4.

3.2.2.5.3 Reporting of inferences

A measure of the quality of design-based research is the extent to which it leads to shareable theories that communicate relevant implications of the prototheories developed to the educational community (The Design-Based Research Collective, 2003). In order to accomplish this in a systematic and established way, the Discussion chapter (Chapter 6) uses a "pedagogical patterns" approach to describe learning designs. The Pedagogical Patterns Project (2006) home page explains pedagogical patterns as follows:

> *Pedagogical patterns try to capture expert knowledge of the practice of teaching and learning. The intent is to capture the essence of the practice in a compact form that can be easily communicated to those who need the knowledge.*

The Pedagogical Patterns Project (2006) and the E-LEN Project (2007) each have an extensive repository of general pedagogical patterns. There have also been pedagogical patterns proposed in the field of computer science (Bergin, 2002) as well as work in the field of e-learning (Retalis, Georgiakakis, & Dimitriadis, 2006).

The way in which pedagogical patterns are described is critically important if practitioners are to effectively find and successfully apply the knowledge that is being passed on (Haberman, 2006). Pedagogical pattern specifications describe the educational context, the forces contributing to the learning need such as the problem at hand, and the solution (Haberman, 2006; Pedagogical Patterns Project, 2006). In order to increase transferability, the consequences of applying the pattern should be explained, the limitations and advantages discussed, and specific examples provided (Derntl & Botturi, 2006; Haberman, 2006, p. 89).

Pedagogical patterns are a developed approach to capturing teaching knowledge that has been applied in the fields of computer science education and e-learning. To this extent they provide a potentially valuable link between past experience and future practice that is used in this study to harness and describe pedagogical knowledge acquired.

3.2.3 Issues of validity, reliability and objectivity

In order to promote objectivity, reliability and validity, design-based research relies on techniques used in other research paradigms, like "thick descriptive datasets, systematic analysis of data with carefully defined measures" (The Design-Based Research Collective, 2003, p. 7). This section describes the approaches adopted in the design-based research strand of this study that have been applied to address these research quality issues.

3.2.3.1 Construct validity

Construct validity can be defined as "establishing correct operational measures for the concepts being studied" (Yin, 2003, p. 34). Evidencing requires the researcher to select the specific changes that are of interest and relate them back to the original objectives of the study in a way that demonstrates that they provide adequate representation of the concepts being investigated.

In order to increase the construct validity in this study the following tactics have been employed, as recommended by Yin (2003):

1. *Multiple sources of data have been used*: this includes lesson recordings, teacher observations, pre-class learning artifacts, artifacts produced by students, and explicit student feedback, and allows constructs and effects to be observed on more than one evidential base.
2. *A chain of evidence has been established*: this chain extends from the primary artifacts being reviewed, to direct transcription of those artifacts (for instance, lesson recordings), to summaries and interpretations of those artifacts (analysis), to results (synthesis of findings from the analysis), allowing the basis for conclusions regarding constructs to be traced back to their original source. Establishing a chain of evidence also supports reliability of research, "as there can be no validity without reliability" (Lincoln & Guba, 1985, p. 316). A more in-depth description of the chain of evidence has been provided in the reliability sub-section to follow.
3. *This report has been reviewed by several experts*: as part of the authorship process this thesis was sent to a number of national and international experts from a range of fields to solicit constructive feedback, which resulted in refinement and validation of the report, including the construct validity.

3.2.3.2 Credibility

Lincoln and Guba (1985) refer to truth value of a qualitative study as its 'credibility'. This relates to the quantitative research concept of 'internal validity', or the extent to which a causal relationship between causes and conditions is established (Yin, 2003).

In order to address concerns of credibility, five strategies have been employed:

1. *Explanation building*: the iterative cycles of the design-based research process as well as the multiple instances of implementing designs within each iteration allowed explanations for effects to be constructed and be validated via repetition. Explanations could be incrementally built on the basis of observations from several episodes.
2. *Using logical models*: explanations for collaborations that transpire are deduced from previous understandings of teaching and learning in technology based collaborative environments (e.g., Multimedia Based Learning Principles, Mayer, 2005a) as well as previous observations in the context being considered, providing reasons for results being observed.
3. *Addressing rival explanations*: rival explanations have been deliberately considered and discussed throughout the summaries. This has meant that the conclusiveness of a perceived effect has often been qualified based on the possibility of another effect. In many cases this led to a repeated trial either in a following lesson or semester.

4. *Prolonged engagement and persistent observation*: three semesters provided an extensive duration over which to apply the design, enact, analyze and redesign cycle. The methodological approach to observation and documentation persisted throughout the study allowing a thorough capture of the designs and their effect on interactions and learning.
5. *Referential adequacy materials*: the project database provides an archive of all raw data (artifacts from the learning episodes), recordings, reflective journal notes and student feedback, allowing supervisors and other researchers to make assessments of credibility at any time.

Pattern matching was also used to promote internal validity. Pattern matching compares an empirically based pattern with one or more predicted patterns. Coincidence of empirical and predicted patterns serves to strengthen internal validity (Yin, 2003). In this study predicted patterns are often based upon relationships that have been observed in previous learning episodes, i.e. on the basis of emerging theory.

3.2.3.3 Transferability

Transferability relates to the quantitative concept of external validity, or the extent to which the results of a study can be applied to other domains (Guba & Lincoln, 1982). While explicitly extrapolating results is generally the most speculative component of a research study, it can be useful in helping others appreciate the significance of the analysis and transferring results to other contexts (Herring, 2004). Schofield (2002) discusses how the concept of 'fittingness' (the degree to which the situation studied matches other situations of interest) may provide a more realistic and workable way of thinking about the generalisability of research results.

Transferability in this study has been to some extent demonstrated by way of replication logic, where the approaches are tested and validated in more than one context (Yin, 2003). Some of the approaches adopted within this study are replicated across two dimensions:

i) learning episodes (either within a lesson or in different lessons of a semester)
ii) student cohorts (within a class across different student groupings, or across classes in the different semesters)

Observing replication of results in these ways provides an indication of their validity outside the specific case in which each was first observed. As well, reapplying treatments allows the nature of variance between applications to be gauged, providing a more comprehensive indication of the nature of teaching and learning in web-conferencing environments. That is to say, not only is the effect is gauged, but an indication of the strength and reliability of effects.

Providing thick (rich, empathic) description supports the transferability process by providing the data base that makes fittingness decisions possible (Lincoln & Guba, 1985). In this study thick description is provided throughout the lesson summaries in the Design-Based Research Data Appendix, which includes discussion of the context, the approaches being applied, and individual circumstances that are perceived to be important to collaborations and learning. Applying thick description across three semesters of lessons allows the varying impact of effects and the applicability to other contexts to be gauged.

3.2.3.4 Dependability

Dependability relates to the stability of effects uncovered in an analysis, which is analogous to the quantitative research concepts of reliability and replicability (Guba & Lincoln, 1982). Dependability in this study is promoted by:

1. *Use of multiple sources of evidence* (data triangulation)
2. *Creation of a project database* (containing raw artifacts, recordings, reflective journal notes, and other referential adequacy materials) allowing the process of reconstructing results to be traced. This allows the extent to which similar results would be achieved if the research were attempted by another party to be gauged.
3. *Maintain a chain of evidence* (from initial research questions to ultimate case study conclusions). This provides an audit trail through which others can interpret the strength of findings reported.

Each of these is addressed in turn below.

3.2.3.4.1 Multiple sources of evidence

The use of multiple sources of evidence in qualitative research allows investigators to form converging lines of inquiry, which provides more convincing and accurate evidence for conclusions (Yin, 2003). The term "triangulation" is used to describe this attempt to reduce the likelihood of misinterpretation, as Stake (1994) explains:

> *Triangulation has been generally considered a process of using multiple perceptions to clarify meaning, verifying the repeatability of an observation or interpretation. But, acknowledging that no observations or interpretations are perfectly repeatable, triangulation serves also to clarify meaning by identifying different ways the phenomenon is being seen.*
>
> (p. 241)

Three types of triangulation discussed by Yin (2003) have been utilized:

i) data triangulation – basing findings on analysis of multiple data sources
ii) theory triangulation – mapping and integrating different perspectives to the same data set
iii) methodological triangulation – applying and synthesizing different methodologies.

In this study data triangulation is drawn from the following sources:

a) recordings of student and teacher collaborations in the virtual classroom environment
b) learning artifacts constructed by the students
c) explicit feedback from students regarding both the efficacy of specific approaches adopted and the general utility of teaching and learning through web-conferencing systems.

Theory triangulation has been applied by regarding the data from multiple views, including:

a) the Activity Theory perspective (Engeström, 1987)
b) as a Conversational Framework (Laurillard, 2002)

c) theories relating to interface design and use, including the fields of cognitive science (Byrnes, 2001) multimedia learning principles (Mayer, 2005a) and distributed cognition (Hollan, Hutchins, & Kirsh, 2000)
d) planes of socio-constructivist learning environments, be they behavioural, cognitive and situated (Mayes & Freitas, 2007).

Analyzing and integrating these multiple views throughout this research seeks to reduce the possibility of results that are distorted or biased by virtue of being overly influenced by any one perspective.

Methodological triangulation allows the reliability of research to be enhanced by establishing alignment of results when different methodologies are applied to the same dataset (Cohen & Manion, 1994). Methodological triangulation has been applied by means of the mixed method approach involving design-based research and multimodal discourse analysis.

3.2.3.4.2 Project database

The project database for this study comprised the following elements:

a) The in-class curriculum for the introduction to programming subject (conceptual and practical exercises, fixed across semesters)
b) Recordings of the 2 hour lessons (across all three semesters)
c) Learning artifacts from the lessons (including all text-chat, file uploads, and contributions to note-pods)
d) Journal based summaries of each lesson and reflective notes (taken by the researcher following each lesson)
e) In-class student feedback regarding specific approaches to teaching and learning (both arising spontaneously and solicited by the teacher during class)
f) Post-semester student feedback and evaluation (of the subject and course as a whole).

The project database supports dependability by building a substantial and traceable body of evidence upon which findings and interpretations are drawn. It forms an essential part of maintaining a chain of evidence for this study.

3.2.3.4.3 Maintaining a chain of evidence

Reliability is enhanced by making "as many steps as operational as possible" (Yin, 2003, p. 38). Figure 16 illustrates the chain of evidence established in this study.

The extent of data that forms the Project Database has already been described. Dependability has also been promoted through the extensive efforts to provide a thorough and detailed description of the protocols and approaches to analysis applied in this research. This not only includes the application of concepts and approaches identified in the literature review but also the description of the process of redesigning. As well, throughout the study specific reference to evidentiary sources are continually drawn in order to substantiate claims. Thus the chain of evidence allows the conclusions of the study to be traced back to the original research questions via the evidential base.

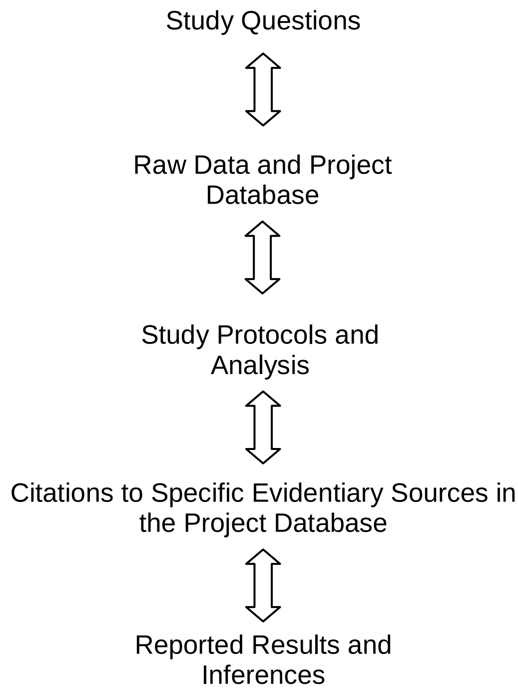

Figure 16 – Chain of Evidence to support dependability of research

Taken together the chain of evidence, project database and use of multiple sources promote descriptive validity (the extent to which accounts are factually accurate) and interpretative validity (the degree to which meanings derived from events are correct) in this study, in accordance with Maxwell (2002).

3.2.3.5 Confirmability – the role of the participant-researcher

Confirmability in qualitative research addresses the issue of researcher neutrality – the extent to which findings are not unduly influenced by the biases, motivations and interests of the inquirer (Guba & Lincoln, 1982). This relates to the rationalistic concept of objectivity (Lincoln & Guba, 1985).

In qualitative research the prior expertise of the researcher is valued in the analysis process (Yin, 2003, p. 137). A critical issue in design-based research is the nature of this joint role of the researcher as designer and potentially participant. Participant research involves active engagement of the researcher in the cases being studied to the extent that they influence the activities and discourse that transpires (Cohen & Manion, 1994, p. 107). In studies where the researcher is "intimately involved in the conceptualization, design, development, implementation, and researching of a pedagogical approach" ensuring that researchers make credible and trustworthy assertions can be a challenge (Barab & Squire, 2004, p. 10). The core criticism of the participant researcher is that proximity of the investigator to the situation being research causes biased collection, interpretation, analysis or reporting (Burns, 2000).

One approach to this tension is by drawing the researcher's perspective into the analysis by integrating it into existing theory (Barab & Squire, 2004). Through observing the recursive patterns of researchers' framing questions, developing goals, implementing interventions, and analyzing resultant activity understanding of the issues is promoted. To this extent, in design-based research the researcher can be encouraged to intervene wherever possible as a means to examine core theoretical issues and explore learning (Barab & Squire, 2004, p. 10).

Viewed from this perspective the fact that this research is that it is based upon real teaching from the field, conducted by the teacher who was attempting to improve their practice through methodological approach to research and development is a potentially valuable aspect of this study. The research is hedged in a real world context, attempting to derive practice-based heuristics from experience. In taking this position, it needs to be remembered that any claims being made are based on researcher influenced contexts and as such may not be generalizable to other contexts in which the researcher does not participate (Barab & Squire, 2004). However by using the aforementioned approaches to addressing validity and reliability in participant researcher contexts (such as establishing a chain of evidence and triangulation of data and results) claims of researcher bias are tempered.

3.3 Multimodal Discourse Analysis

3.3.1 Background to Multimodal Discourse Analysis

Texts can be defined as "meaning making events whose functions are defined by their use in particular contexts" (Baldry & Thibault, 2006, p. 4). Halliday elaborates:

> *We can define text, in the simplest way perhaps, by saying that it is language that is functional. By functional we simply mean language that is doing some job in some context, as opposed to isolated words or sentences that I might put up on the blackboard… So any instance of living language that is playing some part in a context of situation, we shall call a text. It may be either spoken or written…*
>
> (Halliday, 1989, p. 10)

Texts occur when participants utilize the modalities of different media to interact with each other. Jewitt (2006) defines 'modality' as "an organized set of resources for making meaning with: *semiotic* resources" (p. 17). Modalities inherent in new technologies include image, colour, speech and sound-effect, movement and gesture, and gaze (Jewitt, 2006). This is different to 'media' (such as printed books, CD-Roms, and computer applications), which is how texts are actually disseminated (Jewitt, 2004).

Texts are the results of discourses. Gee defines discourses as "sociohistorical coordinations of people, objects (props), ways of talking, acting, interacting, thinking, valuing, and (sometimes) writing and reading that allows for the display and recognition of socially significant identities" (Gee, 1997, pp. 255-256). Multimodal discourse analysis is particularly important because it attends to the multiplicity of modes of communication that are active in contemporary learning contexts (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001). Multimodal text analysis does not accept the notion that the meaning of the text can be divided into a number of separate and independent semiotic 'channels', preferring the notion that meaning is dependent on the way participants foreground and co-deploy selections of resources (Thibult, 2000, p. 321).

In their study of the science classroom, Kress et al. (2001) demonstrate how by offering equal attention to all modes of communication language (whether speech or writing) becomes but one of several modes of communication. They point out that when several modes are involved in a communication event then all of the modes can represent a significant aspect of the message's meaning. While the study by Kress et al. (2001) is applied in a face-to-face classroom where gesture is a possible, the other modalities of speech, image, gestures, writing and even action with models can all occur within the web-conferencing environment. As well, in the web-conferencing environment these channels are often more clearly and uniquely differentiated than in face-to-face research, making their separation and consequent re-assimilation a novel focus for research.

The open issues that Kress et al. (2001) suggest for their analysis are equally relevant in this study:

1. Do different modalities offer differing possibilities for representing?
2. What are the affordances of each mode (i.e. what are the potentials and limitations for representing in each mode)?
3. Are the modes specialized to function in particular ways (for instance, is speech best for one purpose as opposed to images being better for another)?

Jewitt (2006) extends upon the research by Kress et al. (2001) in her approach which combines both multimodality and Activity Theory. Her work focuses on the interplay between modes to look at how each mode interacts with and contributes to the others. Jewitt points out how at times the meaning realized by two modes can be 'equivalent' while at other times they may be complimentary or even contradictory.

In her study of face-to-face school contexts, Jewitt (2006) looks at three levels of meaning within the modes of communication she was examining: the ideational meaning, the interpersonal meaning and the textual meaning. She explains:

> *Semiotic resources of modes are shaped by how people use them to make meaning – the social functions that they are put to. Halliday (1978) classified these social functions into three metafunctions, three different kinds of meaning. Every sign simultaneously tells us something about 'the world' (ideational meaning), positions us in relation to someone or something (interpersonal meaning) and produces a structured text (textual meaning). Halliday and others explored how these three kinds of meaning are 'held-by' the grammar and elements of language.*
>
> (p. 18)

The interpersonal meaning is concerned with the interaction between speaker and addressee(s) – the way in which grammatical resources are used to facilitate social roles in general, and speech roles in particular, in dialogic interaction (Matthiessen & Halliday, 1997). The ideational meaning is concerned with 'ideation' – how grammatical resources are used to construe the world around us and inside us (Matthiessen & Halliday, 1997). The textual meaning is concerned with the creation of text – the way in which ideational and interpersonal meanings are presented as information that can be shared by the speaker and listener as part of an unfolding text (Matthiessen & Halliday, 1997). As resources the interpersonal, ideational and textual metafunctions form a system of meaning making that allow texts to be formed through the discursive flow they enable (Halliday, 1998, p. 189).

Modalities can represent all three types of meaning (Jewitt, 2006). For instance, in the visual mode ideational meaning is purveyed using narrative representations (that show the unfolding of actions, events, or processes of change) or conceptual representations (that relay the generalized, categorical and stable characteristics of elements). The visual mode can be used to deliver interpersonal meaning by depicting relationships between viewers. Finally, the placement of elements in a composition can affect the information value it has in the context, influencing the textual meaning (Jewitt, 2006).

The general 'metafunctional' types of meaning are realized differently by different semiotic systems (Baldry & Thibault, 2006). This then leads to resources being integrated into 'multimodal clusters' on the basis of the synergistic relations between the means by which metafunctions of modalities are realized (Baldry & Thibault, 2006, p. 31). The items in a multimodal cluster are spatially proximate so as to be easily functionally related to each other and to create effective semiotic combinations (Baldry & Thibault, 2006).

An advantage of multimodal analysis is that it not only facilitates a developing understanding of how the modes work together to realize the ideational, interpersonal and textual meaning, but also the cultural and cognitive issues associated with their use (Jewitt, 2006). To this extent Jewitt defines functional specialization and functional load:

- Functional specialization is a cultural valuation placed on modalities that determines the popular ways in which it is used
- Functional load refers to how information is distributed across modalities and the corresponding level of demand involved in processing that information.

(Jewitt, 2006, p. 51)

Functional load is useful for analyzing specific instances of learning, whereas functional specialization is an emergent and generalized trend in the way modalities are deployed. That is to say, functional load and functional specialization relate to the particular and conceptual approaches to multimodal design, respectively.

In order to develop clearer understandings of functional specialization and load during meaning making processes, intertextual analysis is required. Only through comparing and contrasting texts can systems of relations and shared principles of organization to be developed (Baldry & Thibault, 2006). Intertextuality is both the means by which typical metafunctional relations can be abstracted, as well as the way in which instantiations of typical meaning making patterns can be observed within specific texts. As such, intertextual analysis forms a foundational component of the research design applied in this study.

The highest level unit of sequencing within a text is the 'phase'. A phase can be defined as a "copatterned semiotic selection that are codeployed in a consistent way over a given stretch of text" (Baldry & Thibault, 2006, p. 47). Phases are characterized by a high level of metafunctional consistency, and provide suitable units by which a text can be segmented and analyzed. Within this study, phase transitions are most notably represented by switches between web-conferencing layouts, or spontaneous redesigns of the interface to meet the collaborative needs of the exercise.

Modal density refers to the intensity with which a specific mode or combination of modes is being used (Norris, 2004). This study allows the modal density inherent in different interface designs to be observed as well as their corresponding effect on collaboration and learning.

3.3.2 Strengths and issues relating to Discourse Analysis

Assessing the processes and effects surrounding online learning is a difficult undertaking (Jonassen, Lee, Yang, & Laffey, 2005). Analysis of communication transcripts is one approach to analyzing learning that has grown in popularity in the last decade (Strijbos, Martens, Prins, & Jochems, 2006). At the same time the CSCL field has evolved from applying approaches that simply counted messages to more advanced, interpretative approaches such as Computer-Mediated Discourse Analysis (Jonassen, Lee, Yang, & Laffey, 2005).

As a methodology, the Content Analysis approach has several strengths, including:

1. it is systematic and public
2. it mainly uses 'naturally' occurring raw data
3. it can deal with large amounts of data
4. it lends itself to historical data
5. and it offers a set of mature and well documented procedures.

(Bauer, 2000, p. 147)

While the design-based research process allowed observations to be interpreted and insights to be depicted, the discourse analysis approach provided a means of objective comparison that was not subject to personal inference or open to misinterpretation due to the phraseology of descriptions. Data could be portrayed in a less biased fashion. Quantitative conclusions regarding teaching and learning in a web-conferencing environment could be drawn.

Discourse analysis approaches allow coding schemes to be designed to address the specific research aims of a study. For instance, Henri (1992), Gunawardena, Lowe and Anderson (1997) and Herring (2004) all adapted the coding schemes to meet the particular educational technology research questions they were attempting to investigate. In this study the role of technology, activity, and content in teaching and learning using web-conferencing environments was able to be directly addressed by forming coding categories that aligned with these components of the research question.

In contrast to single channel discourse analysis techniques where one mode of communication (such as text-chat transcripts) is considered, multimodal discourse analysis allows all modes of communication to incorporated into the analysis (Jewitt, 2006). Where many channels of communication are being used, analyzing a subset suffers the risk of leaving out much of what is being communicated. It is only by considering all modes being used in the communication that meaning making be properly understood (Jewitt, 2006; Norris, 2004). Thus the multimodal discourse analysis allowed the activity system being studied in this case to be more completely characterized. Considering all channels of communication enabled a more complete understanding of teaching and learning in the web-conferencing environment to be formed, because it allowed the full range of ways that the different web-conferencing tools could be used to mediate activity and represent content to studied.

Performing the process of coding and analyzing data using discourse analysis techniques engenders a familiarity with the data that supports deep analysis. In this way the performing the multimodal discourse analysis also provided a foundation for qualitative analysis of learning episodes. The quantitative data that was derived could then both reveal and support explanations of how learning designs resulted in qualitatively different collaborations and learning.

However there are several potential issues to address when applying content analysis approaches:

1. segmenting units can lead to inaccuracies of interpretation
2. frequency distributions based on categorizations do not preserve the relationship between segmented text units
3. an over-emphasis on frequencies can neglect the rare and the absent.

(Bauer, 2000, p. 148)

In this research, all coding was applied in context in order to preserve the meaning of units as much as possible. That is to say, even though transcripts were segmented into units, if the meaning of a unit was inferred by other units then the context was taken into account when applying the coding frame. For instance, a student response of 'yes' to a teacher question could relate to different 'subject' codes based on the type of question to which the response related. Baldry & Thibult (2006) point out this approach has a longstanding basis in text analysis, citing Molinowski's (1923, p. 306) explanation: "the conception of context must be broadened beyond that of the utterance to the situation…the situation in which words are uttered can never be passed over as irrelevant to the linguistic expression" (p. 2). The approach to implementing this principle is explained in more detail in the "Multimodal Discourse Analysis Coding Frame" section to follow.

In multimodal discourse, communication acts often interweave different communication modes or 'resource systems' and can thus be interpreted as a single semantic unit (Norris, 2004; van Leeuwen, 2004). The coding scheme does not inherently unify contributions made using different communication modes and thus such instances must be captured during the qualitative analysis of transcripts. However, the familiarity with the transcripts that was developed through the intensity of the content analysis allowed relationships to be detected and reported. A deliberate search for trends in relationships between units occurred during the analysis phases, which were then elucidated in the qualitative descriptions of each learning episode.

In this study the interpretation of the coding frame attended to the rare and absent. This was supported by the intertextuality of the analysis; comparison and contrast allowed absent and rare events in a particular transcript to be more noticeable. If codes were absent then the reasons for the absence were discussed, especially if reasons for the absence revealed themselves. This is evidenced in the Multimodal Discourse Analysis Data Appendix (Appendix B).

3.3.3 The multimodal discourse analysis approach in this study

3.3.3.1 The sampling process

Transcribing all 72 hours of classes that were conducted (2 hour classes for 12 weeks over three semesters) was not feasible for time and cost reasons. In order to perform an in-depth analysis of how students collaborated in the virtual classroom environment, a sample of learning episodes was selected on the basis of its ability to enable an understanding of the underlying phenomena that were occurring (as recommended by Stake, 1994). Random sampling is often inappropriate for qualitative research (Ritchie, Lewis, & Elam, 2003). In discourse analysis random sampling is avoided because it sacrifices context, and context is important in interpreting discourse analysis results (Herring, 2004). Rather, data samples tend to be to some extent 'motivated'. Stake (1994) recommends selecting cases "of some typicality, but leaning towards those cases that seem to offer opportunity to learn".

Several considerations need to be taken into account when sampling from a population, including ensuring the sampling strategy is ethical, is feasible, stems logically from the conceptual framework and research questions being addressed, and provides adequate data for inferences to be drawn (Kemper, Stringfield, & Teddlie, 2003). The following criteria were identified to direct the selection of the sample, so that it could be both representative and as useful as possible:

1. Select samples relatively evenly across all three semesters
2. Select common tasks across semesters if possible so as to compare and contrast approaches and collaborations
3. Select a variety of task types (declarative knowledge, process based tasks, conceptual tasks)
4. Select a variety of activity designs (teacher-centred, teacher-led and student-centred)
5. Select a variety of interface designs employing different modalities
6. Select episodes that were of potential interest in so far as their analysis may contain pertinent information regarding teaching and learning in web-conferencing environments.

In order to perform the selection every task completed over the three semesters of classes were tabulated. Those tasks that were not attempted in all three semesters were eliminated from possible selection (Criteria 2). Then began the process of selecting a set of learning tasks that represented a variety of task types, activity designs, and interface designs.

Initially one tutorial style question and one practical style question were selected from each of the twelve weeks for transcription (based on satisfying Criteria 3, 4, 5 and 6). However the transcription process (as described below) took several times longer than anticipated, and for cost reasons transcriptions of one learning episode from weeks one to four and nine to twelve of each semester were selected. This approach allowed comparison and contrast between collaborations at the beginning of semester and the end of semester to be drawn. This resulted in a total of 24 learning episodes being analyzed. This provided a dataset sufficient to address the research question and of adequate magnitude so that statistical tests could be meaningfully conducted, as recommended by Herring (2004).

The levels of knowledge represented in the transcripts could generally be categorized as a declarative task (responding with factual information regarding programming), four procedural tasks (relating to performing programming processes) and three conceptual tasks (involving explaining conceptual knowledge relating to programming). The selection of tasks also represented the use of all the key collaborative tools of interest in the platform: text-chat, audio, presenting documents, screen-sharing, collaborative note-pods, and whiteboards. As well, a variety of activity designs were used (a mix of teacher-centred, teacher-led and student-centred). Table 6 provides a summary of the tasks that were selected, and details about those tasks.

Learning Episode	Task Description	Task Type	Interface Design	Activity Design	# Students	Time Taken	Script Pages
Topic 01 Iteration 1	Debug Cube Program	Debugging (procedural)	Presentational	Teacher-Led Programming	9	7	16
Topic 01 Iteration 2	Debug Cube Program	Debugging (procedural)	Presentational	Teacher-Led Programming	11	6.25	13
Topic 01 Iteration 3	Debug Cube Program	Debugging (procedural)	Presentational	Teacher-Led Programming	2	10.5	12
Topic 02 Iteration 1	Distinguish Program Features	Identification (declarative)	Presentational	Teacher-Led Question Response	8	7.25	9
Topic 02 Iteration 2	Distinguish Program Features	Identification (declarative)	Collaborative	Group-work Tutorial Answer	8	27.25	12
Topic 02 Iteration 2 Group 1	Distinguish Program Features	Identification (declarative)	Collaborative	Group-work Tutorial Answer	4	13.5	11
Topic 02 Iteration 2 Group 2	Distinguish Program Features	Identification (declarative)	Collaborative	Group-work Tutorial Answer	4	13.5	10
Topic 02 Iteration 3	Distinguish Program Features	Identification (declarative)	Collaborative	Group-work Tutorial Answer	3	27.5	18
Topic 03 Iteration 1	Write SoftDrinkCan Program	Meet design spec. (procedural)	Presentational	Teacher-Led Programming	8	18.5	19
Topic 03 Iteration 2	Write SoftDrinkCan Program	Meet design spec. (procedural)	Collaborative	Group Programming	9	19	8
Topic 03 Iteration 2 Group 1	Write SoftDrinkCan Program	Meet design spec. (procedural)	Collaborative	Group Programming	4	17.75	20
Topic 03 Iteration 2 Group 2	Write SoftDrinkCan Program	Meet design spec. (procedural)	Collaborative	Group Programming	5	17.75	8
Topic 03 Iteration 3	Write SoftDrinkCan Program	Meet design spec. (procedural)	Presentational	Teacher-Led Programming	3	17	16
Topic 04 Iteration 1	Applet Comprehension Questions	Comprehension (conceptual)	Presentational	Teacher-Led Question Response	9	8.75	10
Topic 04 Iteration 2	Applet Comprehension Questions	Comprehension (conceptual)	Collaborative	Group-work Tutorial Answer	8	17.25	4
Topic 04 Iteration 2 Group 1	Applet Comprehension Questions	Comprehension (conceptual)	Collaborative	Group-work Tutorial Answer	4	13	11
Topic 04 Iteration 2 Group 2	Applet Comprehension Questions	Comprehension (conceptual)	Collaborative	Group-work Tutorial Answer	4	13	7
Topic 04 Iteration 3	Applet Comprehension Questions	Comprehension (conceptual)	Collaborative	Group-work Tutorial Answer	3	7	6
Topic 09 Iteration 1	Shallow vs Deep Copies	Comprehension (conceptual)	Collaborative	Teacher-Centred Whiteboard Pres	9	11.75	14
Topic 09 Iteration 2	Shallow vs Deep Copies	Comprehension (conceptual)	Collaborative	Teacher-Centred Whiteboard Pres	7	8.5	7
Topic 09 Iteration 3	Shallow vs Deep Copies	Comprehension (conceptual)	Collaborative	Student-Centred Whiteboard Activity	4	6.75	6
Topic 10 Iteration 1	RadioButton to ComboBox	Meet design spec. (procedural)	Presentational	Teacher-Led Programming	8	21.5	33
Topic 10 Iteration 2	RadioButton to ComboBox	Meet design spec. (procedural)	Collaborative	Group Programming	7	32.75	20
Topic 10 Iteration 2 Group 1	RadioButton to ComboBox	Meet design spec. (procedural)	Collaborative	Group Programming	4	28	16
Topic 10 Iteration 2 Group 2	RadioButton to ComboBox	Meet design spec. (procedural)	Collaborative	Group Programming	3	27	14
Topic 10 Iteration 3	RadioButton to ComboBox	Meet design spec. (procedural)	Collaborative	Group Programming	3	36	36
Topic 11 Iteration 1	Nested Loop Array Output	Prediction (conceptual)	Presentational	Teacher-Centred Presentation	9	4.5	4
Topic 11 Iteration 2	Nested Loop Array Output	Prediction (conceptual)	Presentational	Teacher-Centred Presentation	6	10.5	22
Topic 11 Iteration 3	Nested Loop Array Output	Prediction (conceptual)	Collaborative	Teacher-Led Whiteboard Activity	2	27.75	36
Topic 12 Iteration 1	Adjust FileReader	Meet design spec. (procedural)	Presentational	Teacher-Centred Presentation	9	5	11
Topic 12 Iteration 2	Adjust FileReader	Meet design spec. (procedural)	Collaborative	Teacher-Led Whiteboard	7	11.5	15
Topic 12 Iteration 3	Adjust FileReader	Meet design spec. (procedural)	Collaborative	Group Programming	3	6.75	12
Totals						**500**	**456**

Table 6 – Summary of the 24 learning episodes sampled for the multimodal discourse analysis

Note that four of the tasks in Iteration 2 of the subject required splitting the class into two rooms in order to execute a student-centred group-work approach. This resulted in three transcriptions being required – two for the group-work rooms and one for the main room. In Iteration 3 this was not required because there were only three students completing the course – all group-work could be conducted in the one room. The sample of 24 learning episodes comprised 500 minutes of virtual classroom recordings, which resulted in 456 pages of transcriptions.

Adopting the approach of selecting the same task across three semesters in some way overcomes bias caused by inadvertent "cherry-picking" of learning episodes that suit the subconscious predispositions of the researcher – if a learning episode is selected from one semester then the corresponding learning episodes from other semesters must also be selected, and they may contain information that does not align with underlying preconceptions of the researcher.

The fact that the learning episodes were selected after the lessons were recorded means that more naturalistic data was obtained. This is data "in the wild" – recordings contain teacher errors, technical problems, moments of humour, expressions of student discontent and so on. In this way the data has not been affected by laboratory-style conditions, and thus provides a more accurate representation of the sort of discourse that occurs when teachers use conferencing software to conduct classes.

The fact that the samples chosen for the multimodal discourse analysis are drawn from the design-based research study allows their representativeness or otherwise to be ascertained to some degree. All of the episodes have a place in the descriptions of the three semesters of data contained in Appendix A, so the context from which they are drawn is apparent (promoting transparency of sampling).

The Task Type column in Table 6 contains both the computer science specific and Anderson and Krathwohl (2001) task classifications. It should be noted that this is a broad classification scheme and that many of the tasks involved a variety of computer science specific tasks and knowledge levels. As well, the Interface Design column classified interfaces as "presentational" (predominately designed for instructor presentation) or "collaborative" (shared access to tools and facilities between all participants). This provided a coarse way of differentiating between the wide variety of possible interface designs (but did *not* necessarily relate to how the interface was used). Finally, the Activity Design column is a general classification of the sort of (inter)activity design employed by the teacher in learning episode, with group-work approaches being "student-centred". Course-grain classification of the categories allowed statistical comparison and contrast to be performed. Finer distinctions were illuminated in the qualitative summaries of each learning episode.

3.3.3.2 The approach to transcription

A research assistant was hired to transcribe the audio from the lesson recordings. This was interleaved with the text-chat (that was able to be directly extracted from the recordings in plain text format). It was initially estimated that it would take 50 hours of work to transcribe the audio for 72 learning episodes, however after 100 hours of work the 24 episodes in the final pool had still not been transcribed and so had to be finished by the researcher (for budget reasons).

In cases where it was ambiguous whether or not a spoken sentence had been completed, the research assistant was advised to separate the discourse into two sentences. In this way the subject and nature of the discourse could be more easily classified when coding of the transcriptions was to occur, reducing the likelihood that several categories of statements would appear in the one sentence. This is elaborated in the Multimodal Discourse Coding Frame sub-section to follow.

The lead researcher then transcribed all actions that occurred in the episodes by reviewing the virtual classroom recordings. This included actions such as

- highlighting text with the cursor to focus attention upon it
- copying and pasting information between resources
- adjusting the virtual classroom interface to better facilitate communication
- broadcasting a document, such as those with questions or solutions
- screen-sharing (most commonly used when modelling how to program).

Semantic encoding of actions into textual form was necessary for the purposes of forming a transcript that could be coded and analyzed. These actions were inserted into their corresponding place in the audio and text-chat transcriptions.

Note that only observable actions were transcribed. That is to say actions that occurred outside the collaborative platform (such as a student attempting to write code on their own machine without sharing their screen with the rest of the class) were not considered to be an action for two reasons. Firstly, these occurred outside the collaborative environment and so could not be observed. Secondly, this research is concerned with interaction and collaboration in virtual classroom environments so it is reasonable to focus on those events that were observable by all participants.

An example of only recording observable actions is the moving of people between virtual rooms. If a person enters a room for the first time then their name and "entered room" will be recorded as part of the text-chat transcript – as such this is coded as an action. Or if the teacher's movement between rooms is recorded as part of their screen-share recording then this too is coded as a movement between rooms action. However, if students type some text in a group-work room for the first time a movement between rooms action is not recorded because they may have actually entered the room some time ago. In fact, participants can toggle between rooms at will without it being recorded. Only with explicit evidence of such movement is an action coded.

Due to two recording problems two of the learning episodes required some form of reconstruction. In Topic 2 Episode 2 groupwork room 2 the actions of the student programmer were not recorded. Based on the teacher's observations of this group's activity, the text-chat that was recorded, the final computer program that was created, and feedback from the student who constructed the program, the actions of the lead programmer were reconstructed. In Topic 9 Iteration 3 a problem with the group's recording meant that the activity was re-executed at the end of the semester with previous semesters' students. Because the Topic 2 Episode 2 reconstruction were estimated to make at most a 0.16% difference to the coding results and the Topic 9 Iteration 3 reconstruction was considered to be within the normal variation expected when conducted experimental study, these two limitations of the dataset were not considered to materially effect the results of this research. For further details refer to Appendix B Part B.

The "educational metafunction" of all teacher actions were also described in the transcripts, in order to explain the purpose of the teacher's actions. This educational meaning was interpreted on two different levels – the purpose of the action in the specific case that it occurred and the purpose of the action in a more general (abstract) sense. For instance, if the action recorded was the teacher typing into a computer program "System.out.print("The cube volume is " + cubeVolume);", then the specific metafunction was demonstrating how to print out the cube volume in the program, and the general metafunction was demonstrating how to output variable values. The metafunction of student actions were not interpreted as in many cases the intentions of their actions were ambiguous (which could have led to misinterpretations and thus false conclusions).

As well as the textual and action representations, screen shots of the recordings were also included in the transcripts in order to provide a more complete representation of the learning episodes. Screen shots were included (at least) at points where the interface changed substantially, notably at phase changes (transitions between layouts) or when the interface was redesigned to meet the collaborative needs of participants. Including these screenshots in the transcripts allowed changes to the ways in which semiotic resources were being co-deployed to be perceived. The transcript of the Iteration 1 Topic 1 learning episode has been included in the final section of Appendix B to provide an illustration of transcript composition.

A further 120 hours was required to complete this post-audio phase of the transcriptions, largely due to the number of playbacks needed to capture all actions, insert them chronologically into the transcripts, and to describe the educational metafunctions. During this time the audio transcriptions completed by the research assistant could be validated by the researcher, and adjustments made where necessary.

In the transcripts the names of all participants have been replaced by a two letter code in order to protect individual identities and to conform with the Macquarie University Human Ethics Committee requirements relating to this study. Note that in some cases the identity of the person making a particular contribution to a learning episode may not have been identifiable either explicitly through the virtual classroom recording or through the context of the collaborative activity. For instance, it was sometimes unclear which student had made a particular contribution to a note-pod. In these cases the identity of the contribution was recorded as "unidentified" (or "UnId" within the transcripts). In total there were 63 "unidentified" contributions throughout the entire dataset, (55 contributions to note-pods and 8 contributions to whiteboards), representing less than 1.4% of all contributions. This was not seen as significant in light of the fact that individual differences between students were not being examined in this study.

3.3.3.3 Considering approaches to coding

The nature of the data often influences the suitability of various analysis approaches (Herring, 2004). A wide variety of literature relating to content and discourse analysis was reviewed in an attempt to find the most appropriate approach. For instance, Henri's (1992) approach to content analysis of discussion forums and Gunawardena, Lowe, and Andersons' Interaction Analysis Model (1997) were both carefully considered. However these models and many others like them had been designed for interaction via discussion forums. Initial trials of these systems on the dataset being examined in this study indicated they were inadequate to capture aspects of the discourse relating to:

1. coordinating activity between participants
2. using the collaborative technology.

The asynchronous nature of the discussion forums analyzed in these earlier studies meant that coordinating who was to complete which task and how it was to be completed hardly entered the discourse and as such was not emphasized in the coding scheme. As well, because the collaborative technology underpinning discussion boards is far more limited than that being utilized in virtual classroom spaces, there was little or no discourse relating to the use of the collaborative technology.

However, aspects of these models were deemed valuable for the analysis of web-conference based learning being conducted, including:

- Henri's (1992) landmark emphasis on the meaning inherent within the online contributions (such as cognitive, metacognitive, interactive) rather than merely counting the frequency of postings (which Marra, Moore, & Klimczak, 2004 point out characterised previous efforts)
- the recognition of the interdependence of the individual and social construction of knowledge (Gunawardena, Lowe, & Anderson, 1997).

Thus, a coding scheme was developed to suit the nature of the discourse being analyzed in this study. The coding system was almost entirely developed *a priori*, based on a familiarity with the data but without having commenced the data analysis process. This avoided constructing the coding system in order to achieve specific results. However, refinements to the category definitions were made in some instances to clarify the boundaries of classification. As well, the action and pedagogical tactic categories were expanded during the coding process as different actions and tactics were observed. However, this was only to incorporate unanticipated actions and categories and did not in any way influence the inferences drawn from this study.

3.3.3.4 Designing the approach to coding

The coding scheme applied in this study was designed to not only capture aspects of the discussion relating to curriculum-based content, but also that relating to coordinating collaborative activity and using the collaborative technology. The rationale for this was that in a collaborative technology based environment, discussion regarding the coordination of activity and the use of the technology formed part of the learning process. Thus understanding the role and prevalence of activity and technology discourse in the collaborative knowledge construction process was useful from a pedagogical perspective.

In designing a coding scheme that differentiated the subject of discourse by whether it related to curriculum-based content, coordinating activity between people and the collaborative technology itself, the three aspects identified in the research question for this study have been addressed. They have been operationalized as follows:

1. **Content** – curriculum-based discussion (declarative, procedural, conceptual) for a topic of subject matter, relating to the learning of an idea in the learning domain.

2. **(inter)Activity** – discussion relating to coordinating interactions between people; what has/is/should be done and by whom.
3. **Technology** – discussion regarding the tools of the collaborative platform (web-conferencing environment).

Initially it was considered that the Technology, (inter)Activity and Content categories would be separated. However upon commencing coding it became immediately apparent that sentences often address more than one of these aspects at once, and that these intersections were potentially the most interesting aspects of the textual discourse. Thus the coding system was adjusted to allow for all combinations of Content, Activity and Technology was adopted, as illustrated in Figure 17.

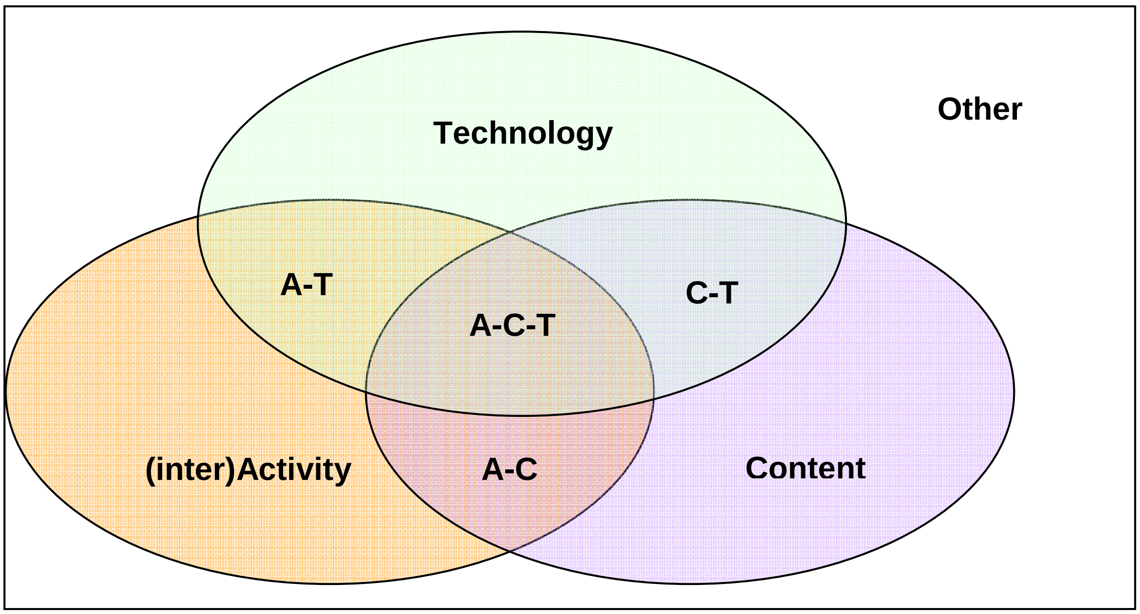

Figure 17 – Categorisation of discourse by Technology, Activity and Content

Identifying Technology, (inter)Activity and Content as the three aspects by which the subject matter of discourse is differentiated aligns directly with Production sub-system of the Activity Theory framework of analysis being applied to this study.

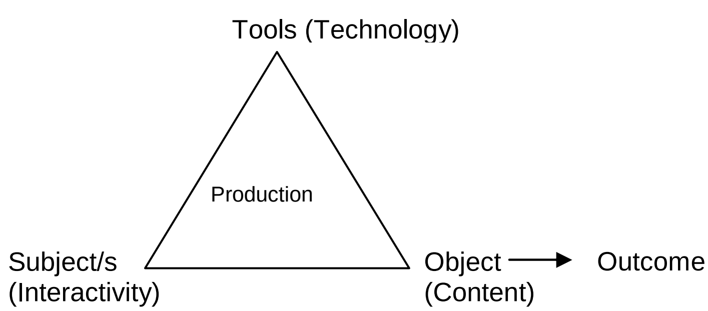

Figure 18 – Production Sub-system of the Activity Theory framework in relation to the coding scheme adopted in this study

The Technology discourse relates to the tools (web-conferencing affordances) being used. The (inter)Activity discussion relates to how the subjects (people) are coordinating with one another. The Content conversation relates to the object (curriculum matter) being addressed. Discourse on these levels leads to the learning outcomes (goals) being produced.

The Technology, (inter)Activity and Content classifications also correspond to the 'metafunctions' of textual discourse described by Matthiesson and Halliday (1997) and used by Jewitt (2006). Discourse relating to Technology is explicating the textual nature of the text – how the text is being structured and formed in the web-conferencing environment. Discourse relating to (inter)Activity explicates the interpersonal nature of the text – how it relates to others. Discourse relating to content explicates the ideational intention of the text – focusing on learning concepts about the world.

As well as investigating the subject of discourse, the coding scheme was designed to incorporate a dimension focusing upon patterns of interaction in the web-conferencing environment. Capturing information relating to the nature of collaboration between participants is an aspect that was not emphasized in many other popular coding systems. The coding layer recorded whether participant sentences were a statement or a question, whether they were independently initiated or responsive, and in the cases where they were responsive whether it was in response to statement, question or action.

A critical part of the multimodal discourse analysis was to examine ways in which participants leveraged the affordances offered in the web-conferencing environments to facilitate collaboration and share representations. Thus, all actions were coded according to the modality that was being used. The audio and text-chat were also differentiated in the coding system, meaning that the modality of all contributions (both words and actions) was recorded.

Two final aspects were of identified for coding. These were a) metacognitive discourse and b) pedagogic tactics specifically relating to teaching in the web-conferencing environment. Metacognitive discussion related to the way in which students were self aware of the knowledge development process. This was a dimension emphasized in other coding schemes and was included for its relevance to the mental model development focus of this study. Pedagogic tactics related to ways in which the teacher used the affordances of the web-conferencing environment to scaffold learning. This informed how implementation could influence collaboration and learning in the web-conferencing environment.

It should be noted that multimodal discourse analysis is a developing field and that while some excellent research has been performed in this area (Baldry & Thibault, 2006; Jewitt, 2006; Kress, Jewitt, Ogborn, & Tsatsarelis, 2001) this study extends upon and adapts the approaches presented in previous work to conduct a large scale quantitative analysis of teaching and learning in an online multi-modal environment. The methodology not only draws upon concepts and techniques applied in previous multimodal research, but also incorporates valuable principles and approaches identified in other content analysis studies (Gunawardena, Lowe, & Anderson, 1997; Henri, 1992). This is in accordance with the "pragmatist" approach typically associated with mixed methods research, which combines methods, techniques and procedures in a way that facilitates "the best understanding of a research problem" (Creswell, 2003, p. 12).

The coding frame outlined in the next section describes in detail (operationalizes) the approach to coding adopted in this study. The coding scheme used in this multimodal discourse analysis intends to be sufficiently broad so as to be easily understood and applied to a range of technology based learning contexts (at the same time as it captures aspects relevant to collaborative learning in web-conferencing environments).

3.3.4 Multimodal Discourse Analysis Coding Frame

3.3.4.1 Distinguishing Textual Discourse and Actions

In the web-conferencing environment there were many channels through which participants could contribute. Participants could explicitly contribute (textual) discourse using audio, the text-chat pod, the note-pods, or even by typing into the BlueJ Integrated Development Environment while sharing their screen. Participants could also perform non-language based collaborative *actions* in the environment, such as clicking on buttons, highlighting and deleting text, closing windows, drawing on the whiteboard and so on. As a multimodal discourse analysis, all channels of communication were transcribed.

For the purposes of this study, the following definitions apply:

- **Textual discourse** – any written or spoken contribution to the web-conferencing environment as part of a discussion, in effect, "what is said". This relates to the use of words to hold discourse.

- **Actions** – any recorded contribution to the web-conferencing environment that is non-textual, such as clicking on buttons, drawing on the whiteboard, modelling programming, and so on.

In this study, all textual discourse has been classified by its *subject* and its *interactive nature*. All *actions* were classified by the media through which they occur and sometimes further categorized by the collaborative function being performed. The details of these approaches to coding are described in later sub-sections.

Two other thin layers of coding applied to the transcripts. Firstly, any *discourse* that was *metacognitive* has been noted. Secondly, any *discourse* or *actions* that relate to virtual classroom pedagogical tactics (or "*techno-pedagogic tactics*") were coded as such. These layers are thin in so far as codes under each category were not applied to all discourse or actions, but only when they occurred. The details of these approaches to coding are also described in later sub-sections.

3.3.4.2 Segmenting Textual Discourse

Determining an approach to segmentation and establishing the reliability of that approach is a critical aspect of any Content Analysis (Naidu & Jarvela, 2006, p. 98). Content analysis of CSCL data has often suffered from general vagueness of definitions of units of analysis (Strijbos, Martens, Prins, & Jochems, 2006). Strijbos et al argue for more rigor regarding reliability in quantitative approaches in order to defend the apparent "accuracy" of conclusions drawn.

- Strijbos et al. (2006, p. 31) describe five types of units into which the data can be segmented. From large to small they are the message (e-mail or forum contribution), paragraph (section), 'unit of meaning' (or thematic unit), sentence (or syntactical unit) and illocution. For all textual discourse in this study the 'sentence' has been chosen as the unit of analysis, for the following reasons:

- It is a commonly accepted and applied unit of analysis (Strijbos, Martens, Prins, & Jochems, 2006).
- It is fine-grained, providing greater frequencies through which to determine patterns of collaboration.
- Its boundaries are often defined by the participants, allowing the data to remain in more pristine condition than when the researcher defines the 'units of meaning'.
- Its size is more consistent than the 'unit of meaning' approach and less exposed to unreliable segmentation issues such as unit boundary overlap (Strijbos, Martens, Prins, & Jochems, 2006).

Having a fine-grained unit such as the sentence also made it possible to gauge how much of the different types of textual discourse occurred in each episode. Using more course grained approaches such as "contiguous comments of the same type" could have distorted the composition of different types of contributions. For instance, a conceptual explanation may be comprised of several contiguous conceptual statements. If this was coded as one conceptual statement the extent of conceptual statements in the discourse would be under-represented.

In the case of audio contributions the beginning and end of a sentence were often obvious from analyzing the recording. In cases where sentence boundaries were ambiguous, sentences breaks were made. This prevented the subject of the discourse from running into one another, thus allowing for less ambiguous categorization of sentences under the coding scheme. Aspects such as timing of the spoken words determined where sentence breaks were placed. The researcher was able to review and adjust the positioning of the sentence breaks placed by the research assistant while transcribing the actions.

Because the contributor determines the bounds of a text-chat sentence the problem of determining the demarcation points was resolved. Participants would normally complete a sentence by pressing the return key. In some (very few) cases participants would include two sentences in a single text-chat entry separated by punctuation. For these text-chat contributions, end of sentence punctuation ("full stop", "question mark", "exclamation mark") was considered to denote the end of a sentence, just as a capital letter denoted the beginning of a new sentence.

Each text-chat contribution by an individual was considered to be at least one sentence, even if it was followed immediately by more related text. It was observed that in the large majority of such cases contributors were augmenting previous information in much the same way that people augment information from previous sentences when speaking. To this extent the approach to coding between the audio and text modalities was consistent. It should be noted that in some cases text-chat sentences were very short. For instance, students may respond to an audio question by the teacher with a simple "no".

3.3.4.3 Coding Textual Discourse

For the purposes of this study, textual discourse was considered to be any discourse:

1. spoken through the Voice over IP audio facility inbuilt within the virtual classroom

2. contributed through the text-chat pod
3. entered into note-pods as part of forming a written solution to a tutorial question (but not a computer program)
4. typed into the source code file of a program while screen-sharing was on for the specific purposes of conversing with others (which was used as a workaround in one learning episode).

On occasions students used emoticons such as ":-)" as the entirety of a text-chat contribution. If the meaning of the emoticon could obviously be interpreted as aligning with one of the Subject categories described below then it was classified accordingly, otherwise it was considered to be an "unclassifiable" contribution.

Computer programming code contributed to the IDE, whiteboard, or note-pods as part of a programming activity has not been considered to be textual discourse. Programming code is fundamentally different from other interactions in the virtual classroom. It is not an interpretation of an artefact, it is the actual artefact. If a person contributes programming code during a programming activity, it is not a conceptual representation or description of an object, but rather the actual object itself. To this extent it is not conversational or textually discursive in the traditional sense described by Halliday (1989).

Note that if computer code contributed as part of programming activities would have been included as textual discourse it would substantially increase the amount of discourse to these learning episodes (especially if a student copies and pastes a large, multi-lined segment of program code) without actually representing discussion based interaction, and thus would have led to a distortion in the amount of conversation that has occurred. Throughout the transcripts the contribution of program code as part of a programming activity has been represented as an action. However, there is one exception to this. If students contribute programming code as part of a text-chat contribution then it has been considered a part of the discussion about how to program and as such has been included as a textual discourse contribution.

As a matter of definition a decision needed to be made as to whether textual contributions to a whiteboard (such as diagram labels) should be classified as textual discourse. These were not considered to be sentences arising as part of a discourse but rather part of a labelling act, and as such were classified only as actions. On the other hand contributions of sentences to a note-pod as part of forming a collaborative solution to a conceptual exercise were classified as textual discourse. Such contributions were seen as (English) language exchanges of peoples' conceptions.

Only textual discourse comments were classified as to their Subject-Interaction profile.

3.3.4.3.1 Coding the Subject of Textual Discourse

The purpose of coding the subject was to determine the extent to which the discourse in the web-conferencing environment related to the actual task-based curriculum matter of the course (Content), coordinating interactions between people (Activity), or working with the collaborative platform (Technology).

All textual discourse that occurred in the web-conferencing environment was classified as to its subject matter, either Content, Activity or Technology, or a combination of these. The following three questions provided guidance in coding the subject of discourse for a sentence:

1. **Does the sentence relate to curriculum-based concepts? (Content)**
2. **Does the sentence relate to who should be doing what and/or when? (Activity)**
3. **Does the sentence relate to the use of the collaborative software? (Technology)**

Note that the answer may be yes to more than one of these questions, or no to all. The following section provides some examples of each of the possible Subject layer categories of sentences, as well as some associated commentary to help clarify the category boundaries.

It is necessary to apply all codes in context in order to categorize utterances according to their semantic intention. For instance, a student response of "yes" needs to be classified as to its Content-Activity-Technology profile based upon the utterance to which it is responding. If students are asked whether they know which group they are in and they respond "yes", this would be an Activity statement, whereas if they were asked whether the Java programming language is case-sensitive their response of "yes" would be a Content statement.

Activity

Activity sentences explicitly relating to what will be done and/or by whom in the current learning situation, in an attempt to coordinate activity between people. This also relates to setting up a task description. Examples include:

> *"Let's have a look at task number 3."*
>
> *"So in a moment I'm going to ask you all to give me your ideas."*
>
> *"We can see that someone is already adding to the list so I'll go next."*

Note that an individual's description of what they are doing without reference to other people is not considered coordinating activity – for instance when the teacher is describing how they are going about a programming or problem solving process. This is not adding to the collaborative overhead of coordinating activity between people and is thus not considered to fall under the Activity category – it is using the strategy of expert modelling (explaining underlying thought processes) to discuss Content.

If a person uses textual discourse to make their presence known when moving to a new room (by making a comment like "hi") then the first such comment has been coded as "Activity" since they are doing so to support the collaborative process. If they made further comments like "so what did you do on the weekend" it would be classified as "unrelated discussion" (as described below).

Content

Content sentences relate to curriculum-based subject matter, i.e. the content being learned. For instance:

> *"What is the problem with this piece of code?"*
>
> *"When I tried a value of 10 it didn't work."*

> *"Now I'm going to compile the program."*

Note that the latter statement may seem like it relates to Activity, however Activity involves coordinating activity between people. When the teacher is describing what he is doing while screen-sharing (for instance) this is a form of describing process related content.

A simple way to detect a Content sentence is to see if a computing term such as "variable" is being used. However, it is possible to have Content sentences that do not contain any computing terms. For instance, if one student asks "Is a local variable the same as an instance field?" and a second student replies "No", the response from the second student is a Content statement.

Technology
Technology sentences relate to the functionality and properties of the virtual classroom web-conferencing system.

> *"So when we're using the notes pod we can all scroll to different points"*

> *"The screen-share can take a while to come through depending on your bandwidth."*

> *"How do you rub out using this whiteboard?"*

If the sentence contains a word relating to the collaborative technology (such as 'whiteboard', 'note-pod' or 'group-work-room') then it indicates the sentence has a technological component. Note, however, that in these cases the sentence may not exclusively relate to technology. For instance, a sentence which relates to who should be performing a task using the technology would be Activity-Technology sentence. As well, statements relating to copying and pasting alone are not considered Technology statements, nor is merely working with the IDE while programming, since these do not relate directly to the collaborative technology (collaborating through the Virtual Classroom).

Activity-Content
Activity-Content sentences relate to who should perform a task during collaborative problem solving and contributions that coordinate curriculum-based discussions between people.

> *"Please add aCompany to the list of parameters in this program."*

> *"You need to change the class name"*

> *"Any questions?"*

Note that any time the lecturer asks whether students have any questions relating to the conceptual material of a task it has been coded as Activity-Content. Considerable thought was dedicated to this decision. It was considered that statements ranging from "If people have any questions about this concept could they please ask them now" to "questions?" had the same intention, and they both relate to the conceptual material (content) and explicitly requesting input from students (activity). Note that a student response of yes/no to such a question or the asking of a question in return is coded as Content only, because it does not *explicitly* request any activity on the part of the teacher or peers.

Activity-Technology

Activity-Technology sentences relate to how to perform and coordinate a task between people in the virtual classroom using the web-conferencing technologies.

> *"People can just copy and paste their solutions directly into the text-chat pod."*
>
> *"Could the first three students on the attendee list click on the Group-work Room 1 link."*
>
> *"Can you hear my audio?"*

Note that if people are talking about copying and pasting in general without reference to a component of the virtual classroom then it was not considered Activity-Technology, but rather Activity.

Content-Technology

Content Technology sentences relate to using technologies to address content.

> *"You can see I'm using the pointer tool to highlight the instance field declarations in this program."*
>
> *"So could we use another box on the whiteboard to represent the second value in the array?"*
>
> *"The first diagram on the whiteboard represents a shallow copy of an object."*

Activity-Content-Technology

Activity-Content-Technology sentences relating to how to use the technology to perform an activity while demonstrating content based knowledge.

> *"Can you see that I've created a new Tin Can object on the whiteboard?"*
>
> *"So in the chat window can you all be discussing what you think the difference between an instance field and a local variable is."*
>
> *"If everyone can scroll right to the bottom of the notes pod and let me know when you've found the createControlPanel method."*

Other

A fundamental aspect of a coding frames for content analysis is that each text unit must fit a code and none can be left over (Bauer, 2000). To this extent the category "other" has been included to code the subject of textual discourse that does not relate to either Content, Activity, or Technology. These have been broken into two sub-categories:

General sentiments and attitudes regarding a task

These involve personal expressions of feelings or subjective judgments, not specifically related to explicitly discussing an aspect of content, activity, or technology.

> *"Yeah, I really enjoyed that exercise."*
>
> *"I'm finding this whole computing thing hard."*
>
> *"Thank you for your positive energy and excellent questions."*

Personal thanks regarding responses have been classified as general sentiments and attitudes because they have been considered more interpersonal than related to the content, activity or technology.

Personal, unrelated, or unclassifiable discussion
These do not relate to teaching, coordinating activity or technology – off task textual discourse.

> *"Nice desktop pattern dude."*
>
> *"Where did you go to school?"*
>
> *"Hmmm, ok, whoops"*

All sentences classified in this category cannot be classified into any other category. Note that sometimes it is possible to tell the subject to which a statement like "Hmmm, ok, whoops" is referring, based on the context of other actions occurring in the lesson. In these cases the statement would not be included in this category. However, if the subject of a statement cannot at all be classified into another Subject category then it has been placed under this category.

3.3.4.3.2 Coding the Nature of Interactions

Every textual discourse contribution (written and speech) was also coded based on its interactive nature in the following manner. All textual discourse contributions were classified as either statements or questions. This distinction was made in order to analyze whether particular learning designs or pedagogical strategies led to more questions being posed or answered. Statements do not generally invite response whereas questions indicate to others that responses are required, thus impacting on the expectation to interact. Where a question was rhetorical, it was coded as a statement. All textual discourse sentences were also coded as to whether they were independently initiated or responsive. If they were responsive, the contribution to which they were responding was noted, either a Question, Statement, or non-discursive contribution (Action).

This categorization scheme resulted in an eight point coding system for nature of interactions:

1. Independent Question
2. Independent Statement
3. Question Response to an Action
4. Question Response to a Question
5. Question Response to a Statement
6. Statement Response to an Action
7. Statement Response to a Question
8. Statement Response to a Statement.

In some ways every comment could be considered responsive to the task. However, the purpose of the independent versus dependent sentences is to ascertain cause and effect – the extent to which contributions inspire further contributions. To this extent, only comments that were responding directly to a specific action or comment were considered to be a "response".

It was often difficult to determine when an elaborative comment was a response or an independent comment. If the comment directly relates to the specific concept that was being addressed by the previous comment (even if it is elaborative) then it is considered a Response. If it is elaborating beyond the scope of the original concept then it was an Independent comment.

One question was whether question or statement responses to one's own actions, questions or statements should be considered responsive. Because interaction and collaboration between people is the focus of this research only questions and statements to other people's contributions are considered to be responsive.

Sometimes the interactive nature of an utterance is difficult to classify – for instance when someone is making a direct response to a compilation message returned by the IDE or output from a program. If the response is directly relating to output from compiling or running a program it has been classified as a "statement response to an action" because it is a direct response to the result of the action of clicking on the compile button.

There are a range of possibilities for what constitutes a "question". This study was interested in investigating the flow of conversation, how ambiguities identified in the collective knowledge base (either student raised or teacher posed) inspired further conversation. A decision needed to be made about what constituted a question, and then have that applied consistently in the coding scheme. For these purposes a question has been defined as any sentence intended as a question and phrased in the manner typically associated with a question.

For instance, "What does that line of code mean?" is both phrased as a question and intended as a question. On the other hand, rhetorical questions like "I'm just going to share my screen OK?" are not categorized as questions. That is, questions must ask for a response.

As well, in order to clarify this layer of the coding scheme (especially to differentiate it from other coding schemes that classify the interactive nature of discourse) the following points have been added:

- When a new topic is raised without being prompted it is considered "independent".
- When a sentence explicitly refers to what was said in another sentence (for instance a judgment, evaluation or answer) then it is a "response".
- If a sentence involves a question (even though it may also be conjoined with another part statement) it is considered a question.

As such, this layer coding scheme emphasizes how conversation flows and is inspired – where the stimulus for collaboration lies and how it is streamed together.

3.3.4.3.3 Thin coding layers applied to Textual Discourse

Coding Techno-Pedagogic Tactics

Any sentences that related to pedagogic tactics specific to teaching in virtual classrooms were noted. The categories of these "*techno-pedagogic*" tactics were derived as coding occurred. The following four textual discourse techno-pedagogic tactics were coded:

1. Audio describing student actions to emphasize and focus attention upon them
2. Audio repeating student audio to emphasize/clarify it
3. Audio repeating student text-chat to emphasize and focus attention upon them
4. Repeating own audio using text-chat to emphasize and place a marker in chat transcript.

Note that a fifth non-textual discourse (action) based techno-pedagogic tactic was also observed and coded, namely, "highlighting text with the cursor in order to emphasize". This is outlined in the Action section that follows this section.

It should be pointed out that techno-pedagogic tactics are technology based instantiations of face-to-face teaching tactics.

Coding Metacognitive sentences

Any sentences relating to *metacognition* were also coded into two categories, namely:

1. Reflection on others' understanding and thinking
2. Reflection on own understanding and thinking.

A broad definition of metacognition was adopted, so that a question from the teacher such as "Do you think you understand?" would be considered as a question "reflecting on others' understanding and thinking", and the student response "I understand" would be a "reflection on own understanding and thinking".

Note that all textual-discourse contributions were coded relating to their Content-Activity-Technology category, whereas techno-pedagogic and metacognitive comments were only coded when they occurred. This superimposition of techno-pedagogic and metacognitive comments upon the Subject and Nature of Interaction layers meant that it was possible to classify techno-pedagogic and metacognitive statements as to their Subject and Interactive Nature profile.

3.3.4.4 Coding Actions

All actions recorded in the transcripts were classified into the following categories:

1. adjusting the virtual classroom interface to better facilitate communication (for instance adjusting the size of pods or turning screen-sharing on)
2. broadcasting a document with questions, answers or content (for instance, showing the model solution to a conceptual question)
3. highlighting text with the cursor to emphasize (for instance, selecting a line of computing code that is being discussed in order to draw students' attention to it)
4. moving information between resources and pods (such as copying computer code from a Word document in order to move it to a note-pod)
5. moving of people between layouts and rooms (people entering a group-work room)
6. note-pod non-textual discourse contributions (such as deleting a line of text or adding a line of computing code as part of a collaborative programming effort)
7. recording lesson (selecting record lesson from the virtual classroom functions menu)
8. screen-share modelling programming (broadcasting an individual's desktop while the IDE is running, including related activities such as navigating file system)

9. unrelated task (actions not related to the present task, for instance, setting up the next task)
10. whiteboard adding to and editing (for instance drawing a line, adding a label, or deleting a shape).

These categories not only differentiate the type of action being performed but also implicitly and immediately indicate the modality being used.

The meaning unit for all actions was any distinct semantic collaborative contribution involving some component of spatial selection. For instance, clicking on the share screen button within the virtual classroom environment, drawing a rectangle on a whiteboard, or pasting a line of computer code into a program are all distinct action units. In terms of modelling programming while screen-sharing is on, the following were all classified as distinct action units: clicking save on the file menu and typing file name (saving a file), double clicking on a source code file icon (opening source code file), clicking on the compile button (compiling), clicking on the project window icon on the task bar (navigating to the project window), right clicking on the source code file, selecting the main method from the popup menu and clicking on OK (running the program).

3.3.5 Analysis of data

3.3.5.1 The Qualitative Data Analysis System

All data were coded and analyzed using the NVivo7 Qualitative Data Analysis System (QSR International, 2008). This system allowed transcription documents to be imported, codes to be assigned, and queries to be run against the data (see Figure 19).

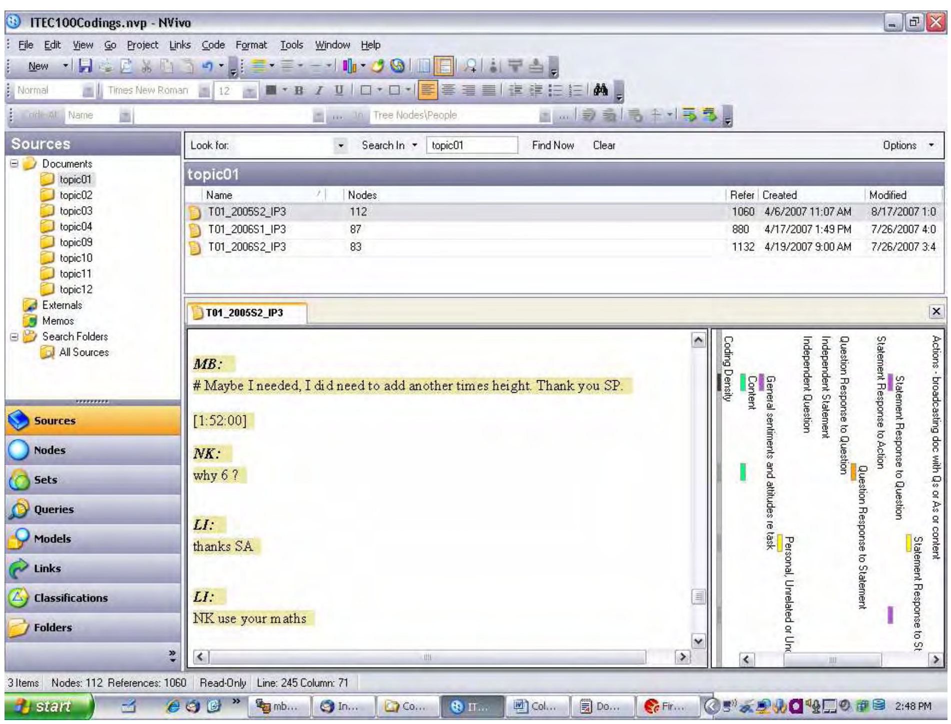

Figure 19 – Screenshot of the NVivo7 Qualitative Data Analysis System

Using a Computer Assisted Qualitative Data Analysis System (CAQDAS) was deemed useful for its potential to allow analysis to remain grounded in the data, permit captured synthesis, facilitate and display ordering, permits within and between case searches, allows systematic and comprehensive coverage of the dataset, and allow transparency to and sharing with others (Spencer, Ritchie, & O'Connor, 2003).

3.3.5.2 Analysis conducted

The observations made for each learning episode were based upon an integrated analysis of lesson recordings, the transcripts of those recordings, and the quantitative and qualitative data derived from performing the coding of the transcripts. For each of the 24 learning episodes two matrices summarizing the Subject of textual discourse and the Nature of Interactions were calculated using the CAQDAS. The first matrix summarized the teacher discourse and the second summarized the student discourse as an entire class. The actions (and thus the corresponding modalities to invoke actions) for each episode were also summarized, once again separated by teacher and students. The separation of teacher and student contributions was performed so that the influence of the teacher discourse and activity upon student discourse and activity could be observed.

On the basis of this quantitative information and with reference to the original transcript and recordings, qualitative analysis of the learning episodes was conducted to explain how collaboration and learning had been affected by the task type, interface design, and activity design. When considering the quantitative information textual discourse and actions were not directly compared. For instance, forming a combined count of the number of actions and textual contributions during a learning episode is an irrelevant measure since the visual information purveyed with actions may speak much more (or less) than words.

Lesson recordings were always utilized when performing qualitative analysis. Transcripts were appropriate for determining the types of information that were delivered, but could not be used determine the utility of particular approaches to communication. Effectiveness of interaction is a subjective matter that depend on a multitude of factors (such as rhythm, pace and intonation) which were not captured by transcriptions. Thus the lesson recordings were always referenced to form the qualitative summaries of each learning episode presented in Appendix B.

In several circumstances statistical analysis was performed to compare and contrast collaborations across implementation of the same task in the different Iterations. In most cases this resulted in Student T-tests or Chi-square tests being performed in order to detect significant differences between episodes. Note that for Chi-square tests grouping of categories of discourse occurred in some cases where there were small category numbers so as to preserve the adequacy of the tests. For instance, Koopmans' (1987, p. 420) recommendation that in order to preserve adequacy all cells should have an expected frequencies of at least one and 20% of all cells should have expected frequencies of at least five was often applied.

The fact that redesigns did not occur in the first lesson of Iteration 2 and Iteration 3 allowed the consistency of collaborations when a similar task, interface and activity design was applied to be gauged. Comparing and contrasting learning episodes across all other topics (topics 2, 3, 4, 9, 10, 11, 12) allowed the effect of redesigns to be analyzed.

The temptation to perform statistical tests between all learning episodes within each topic was generally resisted in favour of more descriptive approaches that interpreted the quantitative data. This was because of limitations relating to validity (different students and circumstances in each learning episode challenges the notion of causality) and generalisability (the context dependence of such results would limit their applicability in other educational settings). As well, by observing and describing the causes of efficient and inefficient implementations using qualitative rather than stochastic approaches engenders an understanding 'how' (rather than 'whether' or 'how much') educational designs affect learning. Descriptive approaches also facilitate transferability decisions regarding the applicability of the findings to other contexts (Guba & Lincoln, 1982).

Results for the entire dataset were also calculated. These included:

- a summary of the textual discourse contributions (Subject and Nature of Interactions) for both the teacher and the students (as a class).
- interactions between the Subject and the Nature of Interaction for both the teacher and the students.
- a summary of the types of actions that transpired in the learning episode analyzed
- a summary of the metacognitive contributions and the techno-pedagogic tactics that were applied throughout the dataset.

These descriptive statistics served to characterize the nature of teaching and learning in the web-conferencing environment. They also formed a basis for analyzing the effect of the interface design, task type and activity design upon collaborations. Quantitative (statistical) approaches as well as qualitative (reflective) analyses of this data were applied.

In cases where statistical analysis was performed to detect multiple effects, Bonferroni adjustments were applied to the significance level. This accounted for the fact that conducting multiple tests increases the likelihood of Type I error (erroneously rejecting the null hypothesis to accept the experimental hypothesis).

Finally, based on the results of the quantitative and qualitative analysis conducted, observations relating to teaching and learning in web-conferencing environments were consolidated.

3.3.6 Reporting of results

The analysis of the 24 learning episodes is provided in Appendix B – "Multimodal Discourse Analysis Data". Matrix summarizing textual discourse in terms of the subject and nature of interaction are provided for each episode (for both the teacher and the students). This is complimented by the qualitative analysis of each learning episode, which not only draws upon the quantitative data of the learning episode in question, but also observations and data from other iterations of the same task. The qualitative reporting also incorporates and discusses results of statistical analysis performed. Screen-shots of the interfaces have been provided in all episode descriptions to illustrate the specific designs that were applied.

Appendix B also contains:

- a description of all statistical tests including the null and alternative hypotheses, approach adopted, results of calculations and corresponding statistical implications.

- a discussion of the limitations of the dataset (which includes the learning episode where a particular student's textual contributions needed to be reconstructed and the post semester implementation of a learning episode to account for a recording error).
- an example transcript from Iteration 1 Topic 1, provided for illustrative purposes.

The consolidated results derived from the quantitative data, statistical tests and qualitative analysis across the entire dataset is included in Chapter 5 – "Multimodal Discourse Analysis Results". Global results for all 24 learning episodes are provided that serve to characterize teaching and learning in the web-conferencing environment. The impact of task, activity and technology design are also reported. Consolidated findings based on the qualitative analysis that occurred for each learning episode are provided. The quantitative and qualitative analysis for all three iterations of Topic 10 are presented towards the beginning of Chapter 5 in order to provide an example of the within episode analysis process that occurred.

Note that for ease of interpretation throughout this report, table cells representing counts of between 1 and 4 occurrences have been marked with a light colour, while cells with counts of 5 or more have been coloured in a darker shade. Teacher tables have been shaded using orange, student tables in blue.

As previously mentioned, these results are then integrated with the results to the Design-Based Research study in Chapter 6 – "Discussion and Inferences" to provide overall implications for teaching and learning in the web-conferencing environment.

3.3.7 Issues of validity, reliability and objectivity

3.3.7.1 Validity

Fundamental to quality transcript analysis is operationalizing the key concepts being applied (Herring, 2004). Murphy (2004) identifies three threats to construct validity based on the operationalization of constructs:

- construct under-representation – the inability of an instrument to adequately define or encompass important aspects of the construct
- construct irrelevance – the tendency to include irrelevant constructs distinct from, or surplus to the intended construct to be measured
- lack of discriminant capability – the inability of an instrument to readily and unambiguously place content into discrete and useful categories.

(Murphy, 2004, p. 348)

The main instrument to promote validity of the multimodal discourse analysis is the coding frame. For the subject codes (the dimension pre-identified as having a high potential for ambiguity) three examples of each coding category have been provided. This has been done to support the construct validity of the coding frame by clearly encompassing the range of possibilities for each code and distinguishing them from one another (addresses issues of construct under-representation and lack of discriminant capability). Negative cases have also been described in cases where codes could be seen to (incorrectly) incorporate aspects of another category as a way to circumvent construct irrelevance. Explanations of all coding categories were also provided (subject, nature of interaction, metacognitive, techno-pedagogic, actions). Examples and negative cases are included in these explanations where ambiguities in boundaries were observed.

The internal validity (or extent to which the proposed cause-effect relationships accurately represent the operation of a system) has been upheld in part through the intervention of the researcher in identifying situations where variables do not directly influence effects (even if statistical evidence may have indicated otherwise). For instance, statistical analysis on the effect of interface design and task type on collaborations was discounted in Chapter 5 on the grounds of intervening variables (namely, the activity design). Internal validity is also supported by the amount of data sampled.

The external validity of any findings is a subjective matter (Herring, 2004). An attempt has been made to support the decision about whether findings from the multimodal discourse analysis can be transferred to other situations by providing a rich description of the context and methods of research. The applicability can to some extent be gauged by the similarity of other contexts to that being studied and the strength of findings presented.

3.3.7.2 Strategies to promote reliability

Bauer (2000) recommends two criteria for evaluating the quality of Content Analysis:

1. Coherence (how easily the coding frame can be comprehended, i.e., natural in relation to the data and easily defined)
2. Transparency (documenting the coding process in detail).

Attending to these can improve the reliability of the research (the extent to which the research can be replicated). In order to provide an easily interpreted and implemented (coherent) coding frame each of the codes has been described as succinctly as possible to convey the boundaries of each code. The coherency of the frame is indicated by the relative ease by which a greater than 80% inter-rater reliability score was achieved for allocating codes (as described in the "Objectivity" section that follows). All codes are naturally arising in so far as they are inspired by observing the multimodal discourse in the web-conferencing environment.

In order to promote reliability through transparency the coding framework defining all textual discourse and action codes was comprehensively explained (as outlined in the Multimodal Discourse Analysis Coding Frame section). As well, the coding framework was not only rigorously documented, but also carefully maintained and applied. Any textual discourse contribution whose classification required careful consideration was recorded, and the reasons for classification applied were explained. There were 680 such cases recorded throughout the coding phase. These could then be reviewed over time to promote consistency of coding approach throughout the coding phase, and were cross-checked once all 24 learning episodes had been coded to ensure reliability. If any adjustments to codebook definitions were deemed necessary at any stage of the transcription (in order to tighten or clarify category boundaries) then the entire dataset coded to that point was reviewed to ensure conformity with the new definitions.

Mechanical techniques were also used to promote reliability of coding. After each transcript had been coded the query tools within the CAQDAS were used to check that all textual discourse units were coded once and only once by both their Subject and Interactive nature. This ensured that all sentences had been coded and that the boundaries of those sentences were identical. The same approach was used across the entire dataset after all transcriptions had been performed to check that there had been no alterations to this aspect of consistency.

After all transcriptions had been coded, the entire dataset was once reviewed from beginning to end to ensure no shift in the coders' conception of category definitions had occurred. Adjustments were made where necessary. Since adjustments were made to less than 2% of the codes, a third scan was deemed unnecessary.

Techniques were also employed to promote reliability of statistical analysis. In order to avoid errors in calculation, test-statistics and p-values have been calculated in two ways wherever possible to provide a means of validation. For instance, for Chi-square tests it was possible to calculate the test statistic using the inbuilt functionality of the statistical tool (Excel) as well as by manually calculating the sum of squared Z-values. For 2x2 Chi-square tests it was possible to validate p-values using standardized tests of differences in proportions (which is an equivalent test).

Other techniques for promoting reliability of the multimodal discourse analysis include:

1. describing the transcription and coding process (facilitating emulation)
2. provision of the inter-rater reliability process and results (below)
3. presentation of all coding results in the Multimodal Discourse Analysis Data Appendix
4. providing a complete description of all statistical tests which, in conjunction with the data, allows them to be repeated.

As well, all recordings, transcripts, codings and statistical calculations have been kept as a part of the overall project database for this study, allowing reliability audits to be conducted at any stage.

3.3.7.3 Measuring reliability – objectivity of coding scheme application

In order to address the reliability of a coding scheme the use of other raters is recommended (Herring, 2004). In this study a second rater was used to gauge the consistency with which the coding methods could be applied. Generally speaking there are two reliability issues inherent in content analysis research – the demarcation (segmentation) of units within the sequence of materials, and then the corresponding coding of those units (Bauer, 2000, p. 143).

The Kappa statistic is common measure of inter-rater reliability. However several claims have been levelled against using the Kappa statistic for this purpose, including:

- the common statement that kappa is a "chance-corrected measure of agreement" is misleading. As a test statistic, kappa can verify that agreement exceeds chance levels. But as a measure of the level of agreement, kappa is not "chance-corrected"; indeed, in the absence of some explicit model of rater decision making, it is by no means clear how chance affects the decisions of actual raters and how one might correct for it." (Uebersax, 2002)
- The Kappa statistic is dramatically affected by the trait prevalence (distribution) in the population under consideration (Gwet, 2002).

These characteristics have led many scientists to recommend qualified use of the statistic at best (Uebersax, 2002), and in some cases abandonment of the statistic altogether (Gwet, 2002). Accordingly, the traditional percentage agreement statistic has been used in this study. When using this approach "reliability is generally considered to be very high at $r > 0.90$, high at $r > 0.8$, and acceptable in the range $0.66 < r < 0.79$" (Bauer, 2000, p. 144).

Note that unlike psychometrics, in content analysis low reliability does not invalidate an interpretation, as Bauer (2000) describes:

> *…the ambiguities of the material are part of the analysis. A simplistic coding may yield reliable but uninformative results. On the other hand, a high reliability is difficult to achieve for a complex coding, while the results are more likely to be relevant for theory and the practical context.*
>
> (p. 146)

To provide dataset upon which measures of inter-rater reliability could be drawn, four learning episodes from the sample of 24 were selected. The episodes were selected so that a range of topics, iterations, task types, interface designs, activity designs, and modalities were represented, as described in Table 7.

Topic – Iteration	Task Description	Task Type	Interface Design	Activity Design	Modality
Topic 1 Iteration 2	Debug Cube Program	procedural	presentational	teacher-led	screen-sharing
Topic 9 Iteration 3	Shallow vs Deep Copies	conceptual	collaborative	student-centred	communal whiteboard
Topic 11 Iteration 1	Nested Loop Array Output	conceptual	presentational	teacher-centred	document broadcast
Topic 12 Iteration 3	Adjust File Reader	procedural	collaborative	student-centred	communal note-pod

Table 7 – Learning episodes used for inter-rater reliability measurements

3.3.7.3.1 Reliability of segmentation

In order to provide a measure of segmentation reliability the demarcation of sentences applied by the transcriber was compared to demarcation performed by the researcher. There is a variety of approaches to measuring reliability of segmentation, the selection of which can significantly affect the proportion of agreement calculated (Strijbos, Martens, Prins, & Jochems, 2006). In this study a "disagreement" in segmentation was recorded every time the transcriber and researcher marked a different end of "sentence" position (i.e. one person felt a sentence had been completed and the other did not), and an "agreement" in segmentation was when the transcriber and researcher agreed on the end of a sentence position.

Inter-rater reliability thresholds for segmentation are equivocal:

> *A proportion agreement reliability of segmentation does not exist in CSCL research nor in the domain of content analysis (see Neuendorf, 2002; Riffe, Lacy & Fico, 1998; Rourke et al., 2001). Thus, the proportion agreement threshold for coding used in content analysis is the most applicable where "a minimum level of 80% is usually the standard" (Riffe et al., 1998, p. 128).*
>
> (Strijbos, Martens, Prins, & Jochems, 2006, p. 34)

For the transcripts analyzed there was 134 agreements and 30 disagreements, leading to an overall segmentation agreement of 81.7%. This is acceptable according to Strijbos et al. (2006). Note that Topic 9 Iteration 3 was not included in this analysis because it was transcribed by the researcher.

3.3.7.3.2 Reliability of coding

In order to calculate measures of coding reliability a second rater was employed to code the four transcripts identified for inter-rater reliability analysis. The rater was selected by one of the supervisors of this research as someone who was familiar with technology based learning and the coding of transcripts.

The rater was provided with the codebook and instructions about the coding process. Both the Subject of textual discourse and the Nature of Interaction were coded. First the transcript from Topic 9 Iteration 3 was coded and percentage agreement calculated using the formula:

$$Percentage\ Ageement = \frac{Sentences\ Coded\ Identically}{Number\ of\ Sentences\ Coded}$$

This resulted in a percentage agreement for the Topic 9 Iteration 3 transcript of 83.9% for the Subject of textual discourse but only a percentage agreement of 68.8% for the Nature of Interaction. When results were reviewed it became clear that the rater had been biased by a previous coding system that he had used which influence his conception sentences that were a "response". This led to a discussion regarding what was meant by "response", and an adjustment to the codebook to emphasize these differences.

Following this the other three transcripts identified for inter-rater reliability analysis were coded. This resulted in a percentage agreement for the Subject of textual discourse in the four transcripts of 80.2%, and a percentage agreement for the Nature of Interaction of 82.3%. These once again indicate an acceptable level of agreement between raters for reliability of coding purposes (Strijbos, Martens, Prins, & Jochems, 2006).

3.4 Ethical Considerations

All aspects of this research were conducted with the approval and conforming with the requirements of the Macquarie University Human Ethics Committee. Students were informed that their contributions during class may be used for teaching and learning research purposes, but that all such contributions would be de-identified (anonymized). Throughout the project students had the right to have data relating to their participation in classes withheld at any time during or after the study. Care was taken to ensure that data collection could in no way harm or interfere with student progress or assessment. All data collected during this study is to be kept for five years following the last publication relating to the research.

3.5 Synthesis of Studies

In alignment with the concurrent triangulation approach to research selected for mixing methods in this study, analysis of data for the multimodal discourse analysis and the design-based research were performed separately and integrated at a later stage. In the next chapter (Chapter 4) the design-based research results are presented, followed by the presentation of the multimodal discourse analysis results in Chapter 5. The data upon which these two chapters are based are provided in "Appendix A – Design-Based Research Data" and "Appendix B – Multimodal Discourse Analysis Data", respectively. Triangulation of the design-based research and multimodal discourse analysis occurs in the "Discussion" chapter

(Chapter 6). This is where findings for the overall study are discussed and implications for teaching and learning in web-conferencing environments are presented.

Chapter 4 - Design-Based Research Results

This chapter presents the results of the design-based research that occurred over the three iterations of teaching and learning in the web-conferencing environment. The effect of strategic refinements to learning designs is described, iteration by iteration. Observations for each iteration are summarized in terms of the ways in which the interface, activity design and task type (and interactions of these) influenced collaboration and learning.

4.1 Introduction

This chapter describes how interface designs, activity designs, and tasks applied as part of the design-based research affected collaboration and learning in each of the three iterations of the introductory programming subject. The impact of teaching tactics and approaches to implementation in the web-conferencing environment are also described. Claims made are referenced back to the learning episode summaries contained in "Appendix A – Design-Based Research Summary of Data" in order to provide a "chain of evidence" (Yin, 2003) from the effects being described to their occurrences in the lessons. Cross referencing allows concrete examples of the effects to be traced, as well as the prevalence of the effects throughout the dataset to be gauged. This aligns with calls for design-based research approaches to applying systematic analysis and reporting in order to promote validity and reliability (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2004; Sandoval, 2004; The Design-Based Research Collective, 2003).

The results have been derived by organizing and describing the observations from Appendix A in order to form a characterization of each of the three semesters. Effects are classified by technology, activity and content (and combinations of these), in accordance with the research question and approach adopted in this study. The observations provide a macro level overview of each iteration. In some cases vignettes have been provided to illustrate observations and findings. Detailed analysis of the discourse that occurs in individual learning episodes is deferred until the multimodal discourse analysis.

Note that all student identities have been kept anonymous to preserve the privacy of the participants and to adhere to the ethical requirements underpinning this study. This has been achieved by using a two letter code to denote each student in transcripts and by censoring all student names that appear on screenshots. As well, it should be noted that within classes student privacy was respected by only sharing student code with other students after receiving their express permission (or anonymizing the code before sharing).

4.2 Results

4.2.1 Iteration 1 results

Because Iteration 1 occurred before substantial redesigns were implemented, it provided the baseline with which to compare and contrast the effect of design strategies implemented in Iteration 2 and Iteration 3. Observations collected during this iteration were used to identify potential weaknesses in learning designs and hence provide the initial foundation for strategic redesign.

4.2.1.1 Iteration 1 technology designs and their use

In the first iteration the standard interface layouts were used, or minor variations thereof. For instance, the 'Sharing' layout was often deployed in order to present documents and solicit short solutions from students. The fact that all students were using text-chat to respond in this iteration allowed several contributions to be made simultaneously, which could then be compared and contrasted [ref. Appendix A I1T1OB2, I1T1OB3, I1T1OB4, I1T2OB1, I1T5OB4, I1T11OB1]. For instance, see Vignette 1.

Vignette 1 [I2T1OB2]

The default sharing layout is used to cover the preliminary conceptual questions.

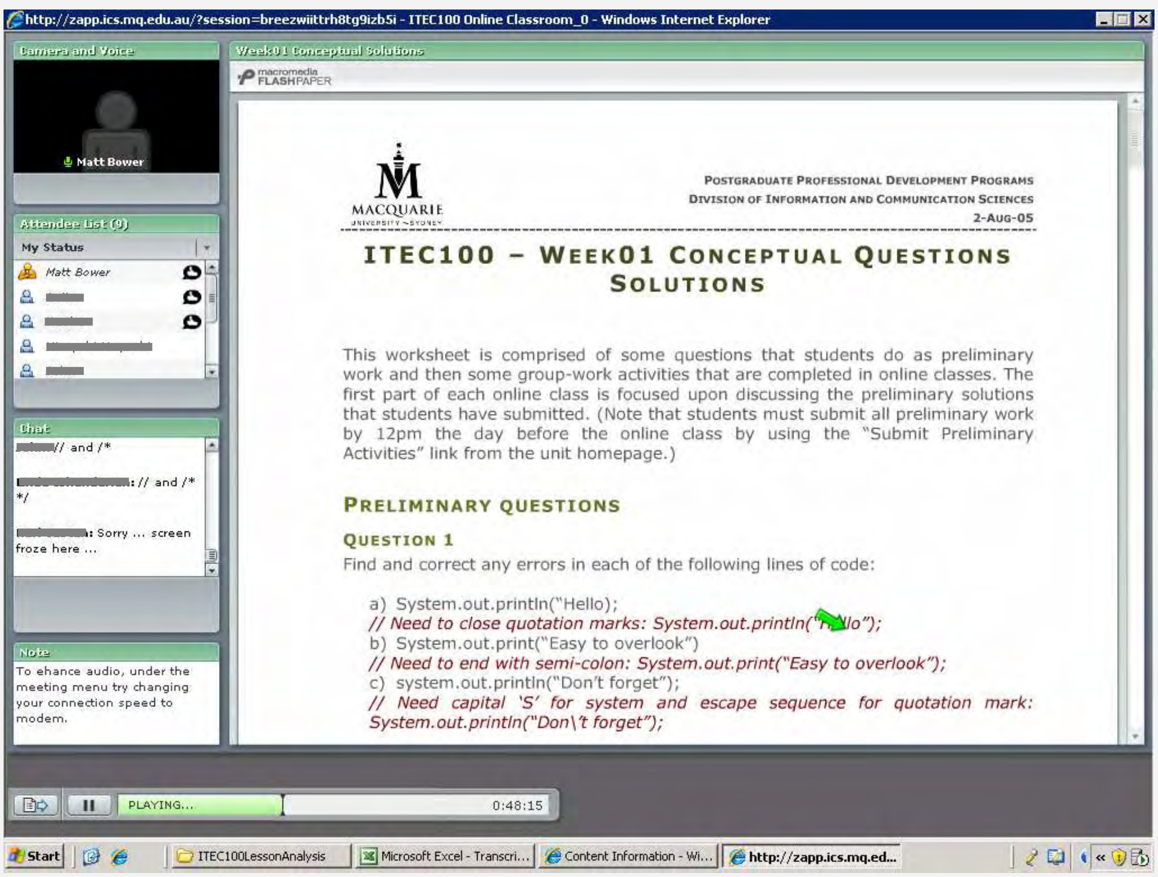

Figure 20 – Iteration 1 Topic 1 "Sharing" interface

The solution document is broadcast and students are asked to respond to the teacher's questions by typing answers in the chat-pod. Using this type of "question-response" approach allowed several students to contribute short textual answers simultaneously. In response to the teacher's audio question asking the meaning of "syntax error", the students provide the following responses within 14 seconds [I1T1OB2]:

NK: wording error
KC: Bad Java grammar ...
LI: violation of language
SP: error in programming language
NK: misspelling
JR: The compiler will not accept it

Then when asked for the meaning of the term "logical error" [I1T1OB3], students provide the following responses within 24 seconds:

JR: errors are not detected by the compiler as they are syntactically correct
AB: when you get a result you dont expect
KC: That is where the computer did not know what I wanted it to do ...
LI: bad programmer
NK: not easy to find
SP: code works but result is wrong
JR: programmer must test the program to find logical errors
SA: The syntax is ok but the results are not in accordance

Some other advantages of using text-chat throughout this semester included:

- students could ask questions and make comments without interfering with the audio of the presenter [I1T1OB2, I1T1OB3, I1T1OB4, I1T2OB1, I1T5OB4, I1T11OB1]
- students could answer other students' questions about a teacher presentation without interrupting the lesson [I1T8KI3]
- text-chat provided an archive that could easily be reviewed during or after the lesson.

The text-chat pod can allow a multistructural understanding to be shared by virtue of students contributing multiple pieces of information relating to the concept. However it cannot allow a relational understanding to be shared since students do not inter-relate all items of knowledge in the same way that they would if they were applying the information as part of a problem solving process [I1T2OB3, I1T12OB1].

It was noted that size of the text-chat pod affected the capacity of students to collaborate [I1T1OB6, I1T1KI8, I1T3KI2]. If the pod was too small for the size of the group and task at hand, the ability to review and monitor text-chat collaborations was compromised. Accordingly, the teacher on occasions chose to enlarge the chat pod and place it along the bottom section of the browser window [I1T1OB3], as illustrated in Vignette 2.

Vignette 2 [I1T1OB3]

During the coverage of the Week 1 Tutorial Questions the small size of the text-chat pod was compromising the amount of text that could be compared and contrasted on the screen at any one time. As such the teacher reduced the size of the screen-share and placed the text-chat pod along the bottom of the screen.

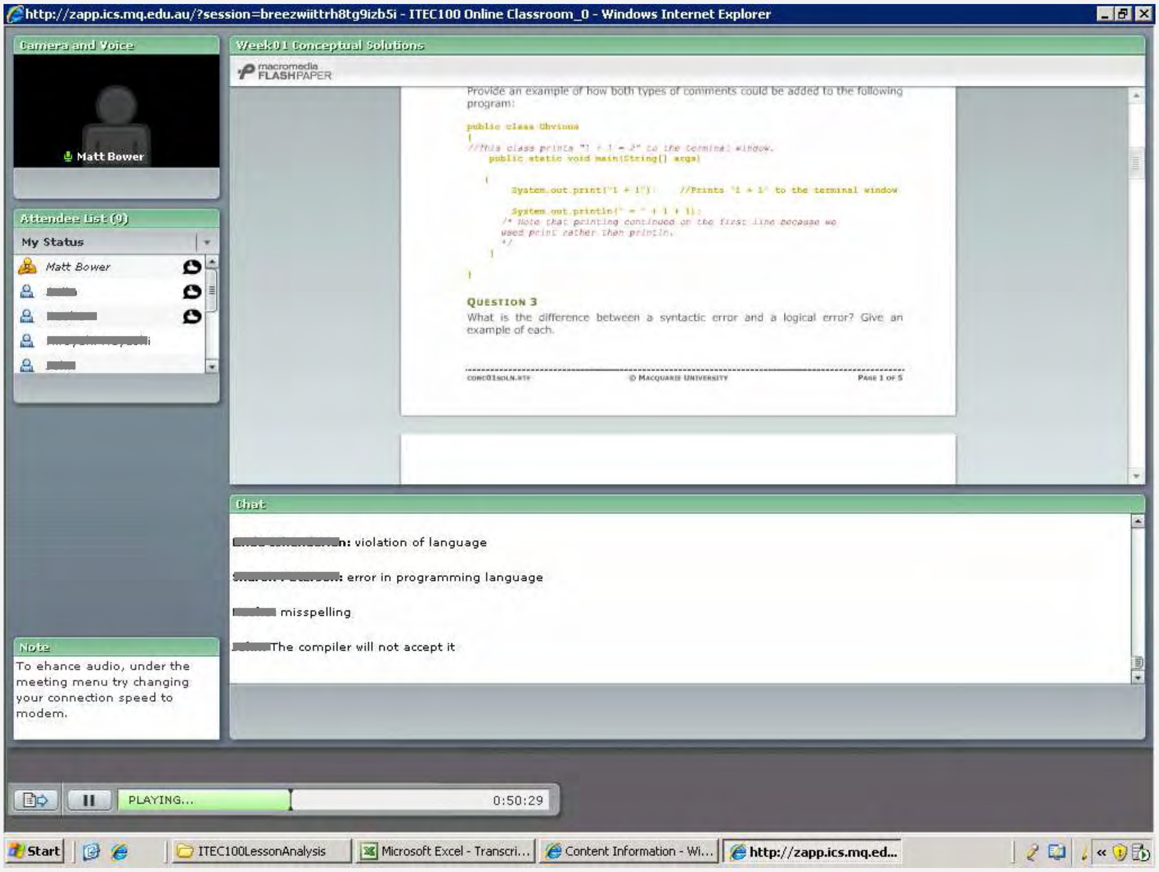

Figure 21 – Iteration 1 Topic 1 Text-chat pod enlarged

One student commented that this was an improvement. Another student then suggested that the attendee pod in the interface shown above should be elongated. This suggestion was subsequently applied because it enabled the empty space to be utilized to allow the students to immediately see who else was in the room [I1T1KI6].

Students (as the end-user of interfaces) are a critical source of design ideas regarding the interface design [I1T1OB6]. Student observations and design suggestions were derived from their actual attempts and experiences using the interface in-situ rather than from estimating the student experience in advance (as is the context of the designer).

An important factor in interface selection was correctly matching the collaborative technology to the type of contributions being made by students, in accordance with Salomon's (1994) Symbol System Theory. The chat-pod question-response approach being adopted in Vignette 1 and Vignette 2 was successful for eliciting shorter textual responses from students. However for the question "Describe the process of compiling and then running a program behind the scenes" the teacher provides the answer by broadcasting the solution document because the answer involved more elaborate descriptions and diagrams (which have been pre-prepared in the solutions). That is to say the text-chat medium which was been used to elicit student responses was diagnosed as an inappropriate modality to present more complex, conceptual models. Another example of using a diagram to represent large amounts of conceptual information is provided in Vignette 4 to follow.

To cover the practical activities, screen-sharing was often used from the default sharing layout so that the teacher could "model" programming processes (for example, Vignette 3). This allowed students to observe programming processes such as editing, compiling and debugging program code, offering them a "cognitive apprenticeship" (Brown, Collins, & Duguid, 1989). The screen-sharing provided a modality that was able to dynamically represent the process information being shared, again representing information in a "cognitively efficient" form (in accordance with Symbol System Theory, Salomon, 1994).

Vignette 3 [I1T3OB3]

The approach of broadcasting the screen to model programming processes was used from the first lesson of Iteration 1.

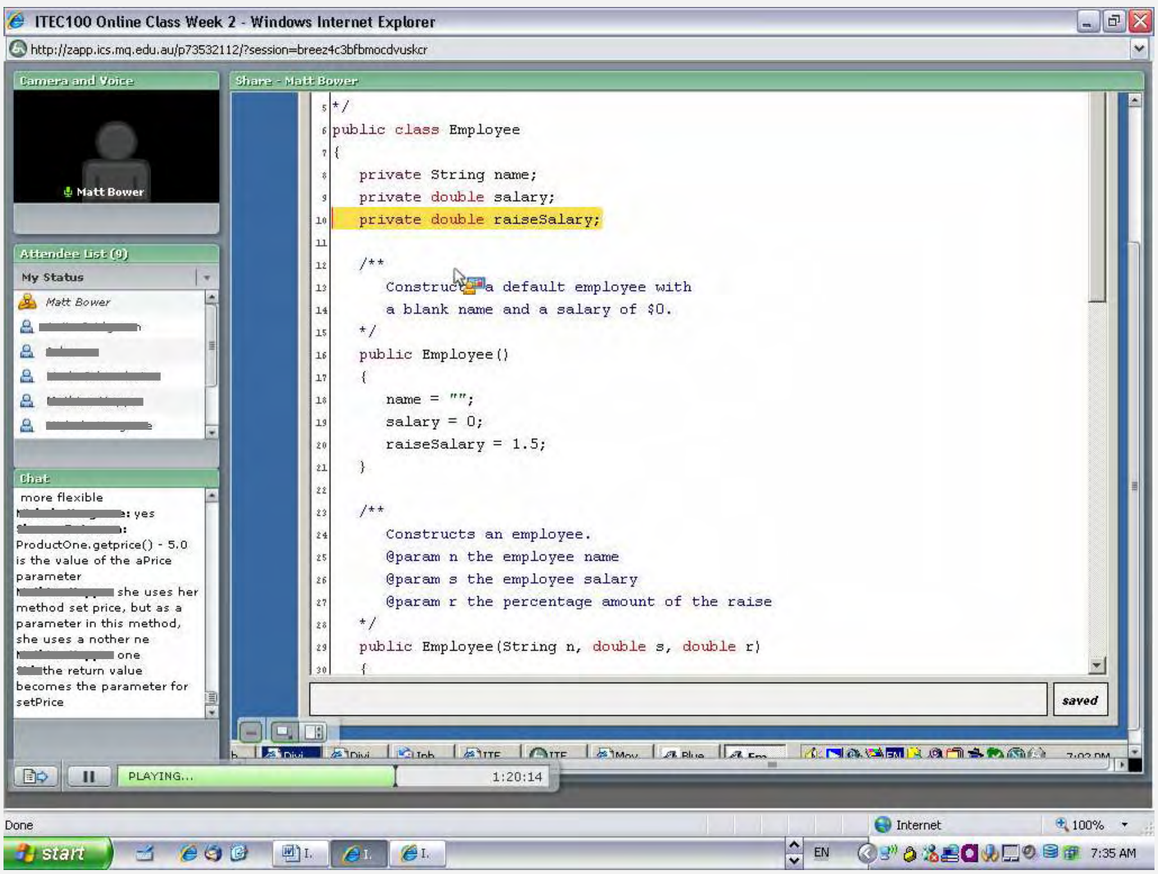

Figure 22 – Iteration 1 Topic 2 Using screen-sharing to communicate programming process knowledge

In the screen-share above the students are able to see how to open new projects, create new program source code files, and acquire a range of other skills relating to writing and running a computer program. This allowed students to efficiently develop process based knowledge in cases where they had little or no previous understanding of how to program. The teacher can use audio to provide insight into underlying thought processes being performed.

As a third example of the importance of matching the modality to the collaborative requirements of the episode, there were instances where students attempted to copy multi-line formatted contributions (for instance segments of program code) to the text-chat rather than using a note-pod. This resulted in all formatting being removed which reduced the comprehensibility of their contribution [I1T5KI1].

It was immediately apparent that broadcasting the webcam afforded no learning gains [I1T1OB10]. While it provided a degree of personalization in the lesson, it was to some extent distracting and redundant. The webcam broadcast also consumed bandwidth and required teacher monitoring. For this reason the webcam was often used for the first few moments of the lesson and then paused.

The reliability of the web-conferencing system and the network connection also had a direct impact on collaborations. The technology imposed a collaborative layer above that incurred in face-to-face classrooms, the quality which impacts upon the way in which users experience and decide to deploy the interface. Examples from Iteration 1 included:

- the reliability and quality of internet connections and the network had a critical impact upon the ability of users to participate in learning episodes [I1T1KI4, I1T1OB6, I1T3KI2, I1T4KI4, I1T5KI3, I1T6OB1, I1T6KI2, I1T8KI4, I1T11KI1]
- the jumpiness, slowness and resizing behaviours of the “green arrow” pointer tool led to it being rarely used [I1T1KI3, I1T3KI3]
- on one occasion a malfunction (inability to drag pods and contribute correctly) with the room led to it not being used for a learning activity [I1T4KI7].

Participants quickly learn the constraints of the web-conferencing system and devise strategies to circumvent them. Erratically behaving tools that were not necessary (such as the “green arrow” pointer tool) were abandoned. On the other hand the reliability and quality of the network connection was often due to the students’ Internet Service Providers and as such the teacher and students had no strategies to improve their experience, other than to suggest that they watch the recording.

4.2.1.2 Iteration 1 (inter)activity designs and their implementation

Transmissive (teacher-centred) approaches were used pervasively in Iteration 1 (for an example, see Vignette 4). Often this would take the form of the teacher explanation of a concept or solution to a problem while broadcasting a solution document. However, other transmissive approaches were also adopted. The “modelling programming” approach (where the teacher broadcasts their IDE and describes how to solve a programming problem, as previously described) allowed the teacher to demonstrate programming skills and articulate programming thinking in a time efficient manner [I1T6OB6, I1T6KI5]. The “debugger step-through” (whereby the teacher steps through a segment of code using the IDE’s debugger) allowed students to develop their understanding of how programs function by providing them with a working example of du Boulay et al’s (1989) notional machine [I1T6OB5, I1T6KI4]. That is to say, transmissive approaches were observed to have instructional utility in some circumstances.

Vignette 4 [I1T5OB1]

When the teacher broadcast their screen and uses audio to explain the output ranges for a series of "if-else" statements (see figure below), there was very little student input. Even though the visual representation of information accompanied by audio explanation is cognitively efficient, students have no space or reason to engage with the activity because the teacher dominates the space. Because they usually only contribute a single item of knowledge in the text-chat, they are only able to represent a unistructural level of understanding.

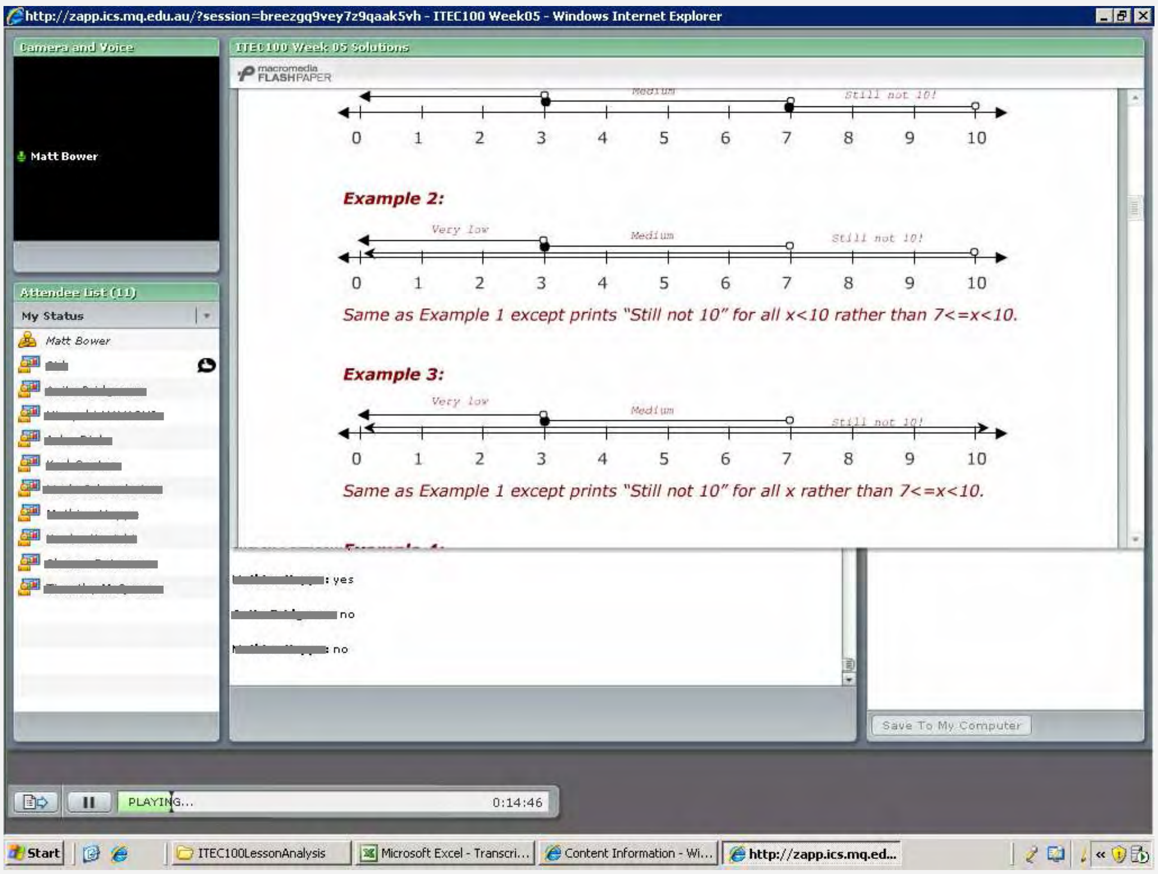

Figure 23 – Iteration 1 Topic 5 "if-else" output ranges using a transmissive approach

However lower amounts of student contribution were observed during more instructive approaches. There appeared to be a trade-off between the amount of teacher commentary and the amount of student contribution [I1T2OB4, I1T2RN3, I1T5OB1, I1T5OB2, I1T5OB4, I1T5OB3, I1T8OB5, I1T9OB5, I1T10OB2, I1T1OB3]. Teacher domination of solution spaces was observed to remove the opportunity for students' mental models to be revealed [I1T2OB3, I1T12OB2, I1T12KI3]. Increased levels of student contribution were observed to coincide with providing students with space to contribute (which could be as simple as the teacher pausing and waiting for students to respond) [I1T12KI2].

At other times throughout Iteration 1 more interactive "teacher-led" approaches were adopted, where students were required to participate in a discourse. For instance, the "question-response" approach to covering short tutorial questions was described in Vignette 2. This approach was observed to lead to moderate to high levels of student contribution [I1T4OB1], and appeared particularly suitable for responses involving short declarative descriptions [I1T10OB1, I1T10KI2, I1T12OB1]. This allowed students to evidence a multistructural level of understanding as they shared multiple items of knowledge relating to a concept.

Another teacher-led approach that appeared a consistently effective for engaging students in collaborations and developing their mental models was the "instructed teacher" approach [I1T2OB5, I1T7OB4, I1T10OB3, I1T12OB4]. Under this approach students provide the teacher with text-chat directions about how to solve a programming problem. The teacher implements the instructions on the IDE while broadcasting his screen. This approach could apply a similar layout to the "modelling programming" approach, but involved more student input by virtue of requiring students to suggest how to perform the problem solving process (see Vignette 5).

Vignette 5 [I1T1OB5]

Under this basic example of the "instructed teacher" approach the students make suggestions about how to solve a programming problem via text-chat. The teacher then implements those suggestions.

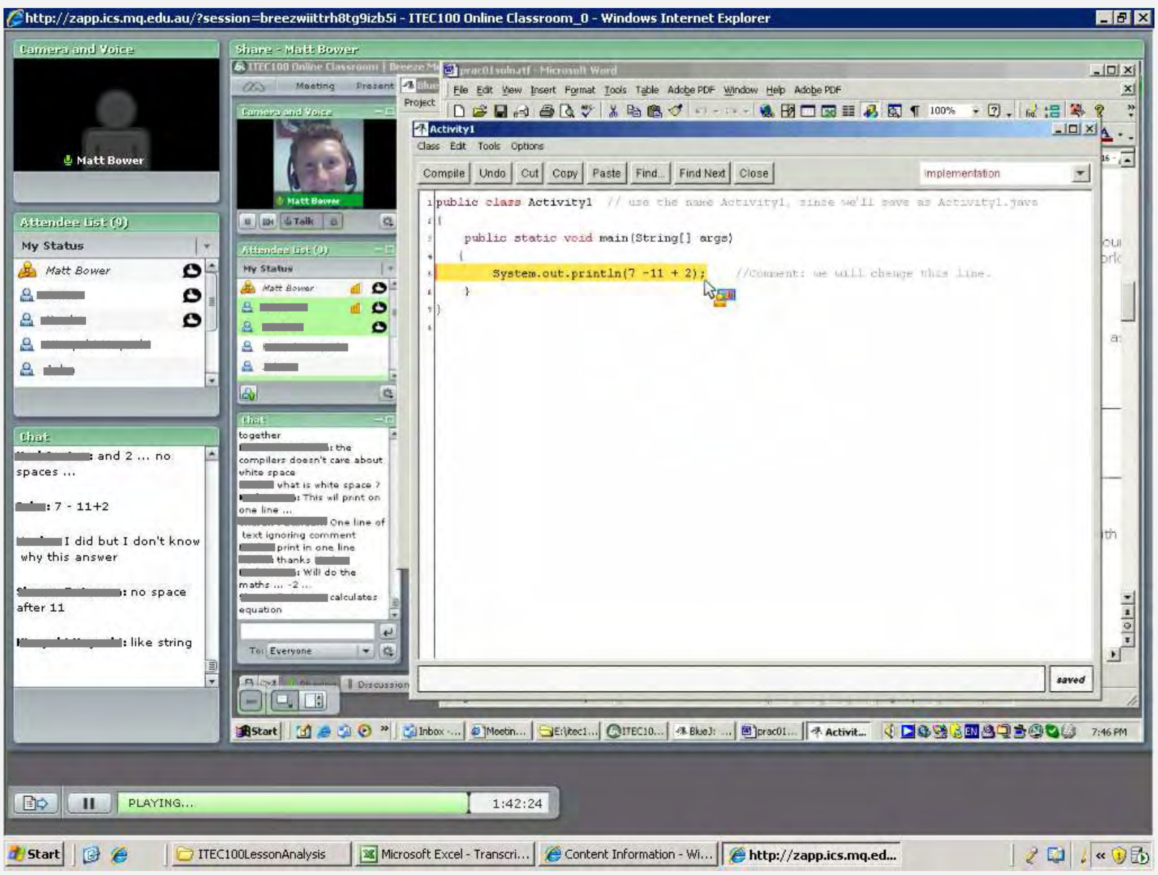

Figure 24 – Iteration 1 Topic 1 rudimentary "instructed teacher" approach where students suggest to the teacher how to solve a programming problem

This allowed students to demonstrate that they had a multistructural understanding by virtue of contributing several pieces of information related to solving the problem. However the approach did not allow a relational understanding to be evidenced because the teacher was completing procedural aspects and intermediary steps in the problem solving process.

Note that in the screenshot above the text-chat pod is being broadcast during the screen-share, causing it to appear twice. This was because the only way the teacher knew how to view student text-chat comments was by having the virtual classroom browser window open behind the IDE so that they were still visible. Later in the semester the teacher realized that student text-chat comments appeared in mini pop-up bubbles if the virtual classroom browser window was minimized during a screen-sharing session.

It should also be noted that in Iteration 1 attempts to use more student-centred approaches to learning were trialled, but these usually involved students simultaneously working on a problem at home in isolation. It was difficult or impossible for the teacher to effectively monitor their progress or for students to learn from one another while completing such activities [I1T4OB2, I1T5OB3, I1T7OB3, I1T10OB4]. In one instance group-work was attempted in separate group-work rooms, however students were not entirely sure about the task they were supposed to perform, lacked direction about how to interact with one another, and lacked the collaborative competencies to perform the task effectively [I1T3OB1]. This sub-optimal outcome led to no further group-work being trialled in Iteration 1.

Advising students how to collaborate during learning episodes resulted in more effective and efficient communications. Explicitly identifying the collaborative pattern to be used allows students to immediately and confidently focus on completing the activities at hand [I1T12OB1, I1T12KI1]. For instance, simply encouraging students to copy and paste text from their solution documents when using text-chat increased the pace with which information could be shared [I1T2KI3]. On the other hand, absence of collaborative patterns could detriment collaborations. Not having roles and approaches to contribution defined could lead to hesitation and unnecessary coordinating discussion [I1T3OB1].

The teacher was observed to be the major determinant of the collaborative pattern that was adopted (either through explicit instruction, modelling, or by dominating the collaborative space) [I1T8OB3]. For instance, if the teacher answered every student question posed during a lesson then students were less likely to contribute answers. Alternately, reflecting student questions back to the class resulted in increased student involvement, which in turn allowed their mental models to be revealed [I1T9OB4].

Aspects of pedagogy that affect face-to-face teaching were also observed when teaching in the web-conferencing environment:

- Spontaneous teacher attempts to perform an unplanned presentation often led to circular and unclear explanations [I1T6KI3, I1T8OB1, I1T9OB5].
- Teacher preparation in terms of having resources ready for use affected the quality of presentation. For instance, minutes were sometimes lost while the teacher set up the

next learning episode (e.g., performing tasks such as loading project files into the IDE and turning on screen-sharing) [I1T8OB2, I1T9OB5, I1T2KI7].
- Issues of scope and sequencing still required forethought. For instance running a program before inspecting the code enabled students to quickly develop a conception of the underlying program design, as opposed to covering the code first and then running the program [I1T6KI6, I1T8KI1].
- Asking probing questions that encourage students to deepen their understanding (for instance, the perennial question "why?") was observed to stimulate valuable discourse [I1T9OB1, I1T9OB4, I1T9KI1].
- General teaching strategies of encouraging questions, modelling enthusiasm, acknowledging student contributions, prompting elaboration were evidenced throughout the transcripts and appeared equally as important in engaging students as in face-to-face contexts [I1T1KI9, I1T2OB2, I1T2KI2].

However the general implementation of learning designs in web-conferencing environments differed from in face-to-face contexts in some ways. For instance, there were less cues from students (gestures and expressions, as noted by Jonassen, Lee, Yang, & Laffey, 2005), which meant that explicit requests for feedback were required to gauge student comprehension and the appropriateness of instruction [I1T5OB2]. The teacher implemented some virtual classroom pedagogical tactics to account for the different nature of teaching and learning in the web-conferencing environment, such as:

- repeating student text-chat using audio to emphasize [I1T1KI7, I1T9KI2, I1T11KI2]
- repeating own audio using text-chat to emphasize a point or to place a marker in the text-chat to assist later review [I1T2KI1, I1T6KI1].

These tactics serve as a form of highlighting (Mayer, 2005b) and demonstrate how modalities may interoperate in order to promote attention and selection. Teaching was adjusted to leverage the inherent affordances and circumvent the constraints of the web-conferencing environment.

Time available to cover the lesson material was observed to affect the teaching approach adopted. Throughout the semester a trade-off between the transmissiveness of the instruction and the duration of the learning episode, with more transmissive approaches reducing student opportunities for engagement and collaboration [I1T2RN3, I1T7OB2, I1T12OB3]. This meant direct instruction approaches were sometimes applied in the latter part of a lesson to accommodate for time lost while applying interactive approaches in the earlier part of a lesson. Time pressure also led to other compromises in instructional approaches, such as:

- skimming over complex questions [I1T4KI3]
- referring students to downloadable solutions rather than explaining programs or concepts [I1T7OB6, I1T11OB4].

The interface design and the technological competencies of users affected interactions in the web-conferencing environment. For instance, throughout Iteration 1 it was noted that the type and amount of collaboration students could perform was compromised by not having their audio set-up [I1T8OB1]. This theme is elaborated in a following section.

4.2.1.3 Iteration 1 task observations

There were indications that pitch (the extent to which the content was aimed at the appropriate level of difficulty for student ability levels) effected collaborations. For instance, the repetitive coverage of the preliminary conceptual questions in Topic 3 [I1T3OB2] resulted in lack of input and off-task behaviour. In contrast covering practical tasks addressing misconceptions that students had demonstrated corresponded with heightened levels of student engagement [I1T3OB3, I1T3KI4, I1T4OB3].

Tasks which addressed how to use the curriculum matter to solve real life "authentic and meaningful" (Herrington, Oliver, & Reeves, 2002) problems relating to students' jobs resulted in greater levels of interest, such as a how to create a file reading program that de-capitalized HTML tags [I1T12OB4]. Tasks relevant to completion of the students' programming assignments also corresponded with increased levels of student engagement [I1T10OB5].

The tasks that students were required to perform were observed to affect the extent to which abstractions were developed. For instance, the task requiring students to identify "inheritance", "dependency", and "association" relationships in a java source code file in Topic 12 supported the linkage of concrete examples to abstract concepts [I1T12OB2].

4.2.1.4 Iteration 1 representing content using technology [C-T]

In Iteration 1 the teacher was the main representer of knowledge. The way in which information was presented affected the understandability of the knowledge, as determined by multimedia learning principles. For instance, using diagrams as well as audio explanations was able to provide a clearer illustration of a concept than if audio alone had been used (multimedia principle, Fletcher & Tobias, 2005) [I1T9OB2, I1T9OB3, I1T9KI3].

Failure to apply multimedia learning principles was observed to reduce comprehensibility, for instance:

- not presenting visual representations (e.g. diagrams or code) with audio commentary compromised understandability [I1T5KI2, I1T5KI4, I1T5OB4, I1T7KI3]
- movement between several layouts and files during a single explanation resulted in split attention [I1T7KI1].

On occasion the teacher attempted to construct a diagram on the whiteboard to support verbal explanations. This invariably incurred a time overhead as compared to face-to-face whiteboards, in part due to the sub-optimal and limited interface provided by the web-conferencing whiteboard tool. On the other hand it was noted that the incorporating a diagram into an explanation generally contributed to student conceptions being clarified [I1T9OB2, I1T9OB3, I1T9KI3, I1T11OB5, I1T11KI4]. Refer to Vignette 6.

Vignette 6 [I1T9OB2]

At one point in the Topic 9 lesson, two students indicated that they did not understand why superclass variables can store references to subclass variables but not the other way around. The teacher spent approximately seven minutes drawing and discussing an example on the whiteboard to help clarify students understanding.

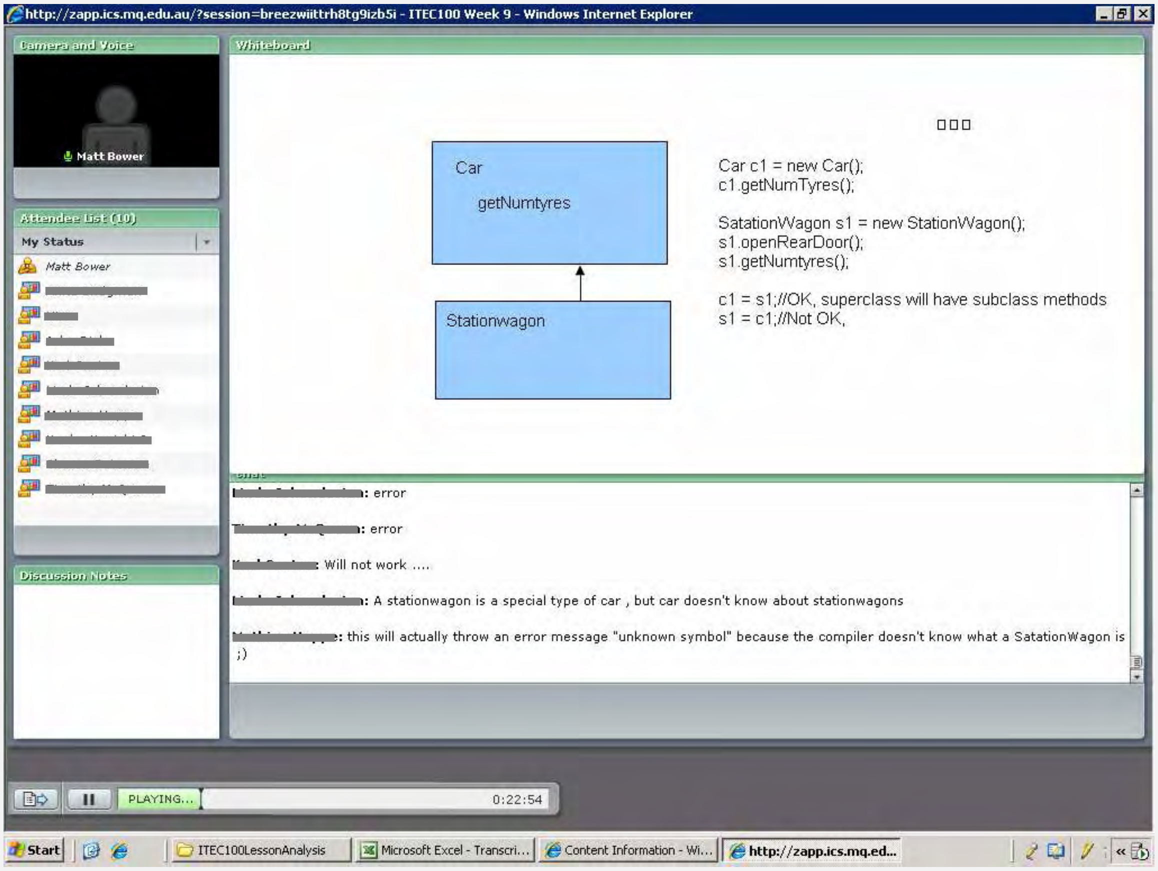

Figure 25 – Iteration 1 Topic 9 Teacher drawing a visual representation on the whiteboard to supplement audio explanations

Although this process was time consuming, it allowed the code to be related to a visual representation of how superclasses and subclasses operate, leveraging the multimedia principle (Fletcher & Tobias, 2005). This involved a lower level of cognitive load than would have been required if a purely verbal explanation was used because the whiteboard tool allowed some of the cognitive effort to be offloaded to the web-conferencing environment (Hollan, Hutchins, & Kirsh, 2000).

For explanations benefiting from diagrammatic representations, pre-prepared documents (either Microsoft Word documents converted to Macromedia FlashPaper format or whiteboard diagrams drawn prior to the lesson) provided the most time effective means for immediate illustration. However these conceptual representations required that the teacher pre-empt the diagrammatic requirements of the lesson, and in the case of Microsoft word documents converted to FlashPaper they could not depict the dynamic development of concepts (as is often useful to support an explanation) [I1T1OB4, I1T2OB3, I1T2KI4, I1T3KI3, I1T10OB1, I1T11OB2].

4.2.1.5 Iteration 1 interactions using the conferencing system [A-T]

The teacher's ability to use the virtual classroom technology (or "virtual classroom competences") impacted on the effectiveness of delivery and learning on several occasions in

Iteration 1. For instance, in the first weeks of Iteration 1 the teacher did not know that minimizing the web-conferencing browser window while screen-sharing would cause student messages to pop-up in mini-bubbles (windows). Thus in order to be able to see students' text comments the teacher often had the text-chat visible behind the IDE (as shown in Vignette 5). This resulted in a double representation of the text-chat pod to students, unnecessarily occupying space that could have been used to broadcast more educationally useful information (redundancy principle, Mayer, 2005b). This was an example of the teacher not understand how the collaborative technology operated. Other examples of this included:

- Not understanding ways in which the different levels of student permissions will allow students to access various features of the virtual classroom [I1T1KI1]
- Not being able to advise students on the operation of multiple rooms during group-work (logins, audio, etc) [I1T3KI1]
- Not understanding the critical effect of the "synch" button preventing the students from seeing the relevant parts of the solution or inadvertently allowing them to access all of the solutions [I1T4KI1, I1T5OB1, I1T6KI7, I1T9KI4]
- Not being able to provide students with the best advice to improve the view of the screen-share broadcast [I1T4KI5, I1T7OB5, I1T7KI4]
- Not understanding how full-screen mode prevents student from making text-chat contributions [I1T4KI6, I1T7KI1]
- Not appreciating that different screen sizes may cause more of the solution document to be revealed than intended [I1T7KI2].

An understanding of how the features of the web-conferencing software could be applied in different circumstances evolved throughout the semester as the teacher's experience increased.

Another way in which teacher virtual classroom competencies could influence collaboration and learning was when the teacher understood how the web-conferencing system operated but inadvertently misused the technology. Web-conferencing environments are different to face-to-face environments in that settings within the environment affect how others perceive collaborations in ways that may not be directly observable by the collaborator. For instance, having incorrectly set audio levels is difficult to self-detect but easily detected by others [I1T9KI4, I1T10KI1]. Other examples of the teacher misusing the technology despite understanding how it works include:

- Accidentally posting private messages instead of public messages through the text-chat [I1T10KI1]
- Forgetting to broadcast the desktop when attempting to perform a screen-sharing presentation [I1T9KI4, I1T11KI3]
- Forgetting to minimize the web-conferencing browser window during a screen-share so that student text messages will be provided in pop-up windows [I1T9KI4]
- Not appreciating the impact of the media upon collaboration, such as responding to audio technology problems using audio [I1T4KI2]
- Unintentionally leaving the microphone on during mid-lesson breaks [I1T1KI2, I1T2KI5].

Instances of misusing the interface occurred almost uniformly throughout the iteration, reducing in prevalence even more slowly than compromises caused by misunderstanding the interface.

There were also examples of underdeveloped student virtual classroom competencies affecting collaborations in Iteration 1. These included:

- not being aware of how to use the scroll or full-screen button to clarify the size of desktop broadcasts [I1T2KI8, I1T8KI2, I1T9KI5]
- not knowing how to upload files to broadcast documents [I1T3OB1]
- inadvertently communicating using private text-chat instead of public [I1T1KI5].

Students had been given an approximately 30 minute introduction to the virtual classroom in the first lesson; the various tools (text-chat, whiteboard, polling tool) had been used by students to introduce themselves to one another. This was seen as an effective way to simultaneously accomplish the two aims of developing technological competencies and a sense of community [I1T1OB1]. However there were several virtual classroom skills that had not been covered in the introductory session that were required later in the course, and others that were covered but that students forgot. Because students often required reminding of how to use unfamiliar tools at the time of use it was usually thought best to leave their explanation until that time. Adopting a gradual approach to developing virtual classroom competencies prevented cognitive overload in the first lesson.

4.2.1.6 Iteration 1 coordinating collaborative problem solving [A-C]

Few student-centred approaches to learning were adopted in this semester, which meant that the teacher coordinated problem solving tasks. Even though the teacher was leading most of these tasks, the quality of the task specification was noted to affect the success of learning episodes. Poor task specifications were observed to detriment collaborations and activity (for instance, task specifications that were incomplete, did not describe how students should interact using the technology, or contained content errors) [I1T4OB4, I1T4KI7].

4.2.2 Discussion – Iteration 1

Throughout Iteration 1 the technology imposed an extra communicative layer that could add a collaborative overhead to learning episodes. Overcoming distributed process loss (Neale, Carroll, & Rosson, 2004) by checking other people are receiving broadcasts, troubleshooting technological problems and discussing how the technologies work all required attention [I1T1RN3]. Observations from this iteration indicate that students need to be continually reminded about virtual classroom skills and approaches. Gradually incrementing the level of collaborative difficulty within and between lessons was observed to be an effective way to develop student virtual classroom competencies [I1T3RN1].

However, the technology afforded several new learning design possibilities not able to be enacted in regular face-to-face environments. The capacity for students to use text-chat to make contributions and ask questions while the teacher was speaking enabled the "Instructed Teacher" and the "Question-Response" approaches to be implemented. Students could compare and contrast information and respond to one another without interfering with the audio broadcast, allowing greater amounts of information to be processed than possible if the approach was applied in face-to-face environments.

The trade-off between teacher commentary and student contribution appeared to be relational rather than functional. That is, high levels of teacher commentary could lead to low levels of student commentary, but at other times low levels of student commentary could lead to higher levels of teacher commentary (as the teacher attempts to stimulate both collaboration and learning). The ability for the teacher to create a collaborative environment in which students feel comfortable responding to questions and initiating comments appears critical to the quality of discourse in the more interactive learning designs. However, approaches to achieving this did not become apparent by analyzing the data from Iteration 1.

Based upon observations and reflections from this Iteration, several strategic improvements to learning designs were proposed for Iteration 2:

- a movement towards more student-centred learning [I1T5RN5]
- a movement towards more collaborative learning [I1T5RN3]
- a movement towards problem based, situated cognition learning approaches focusing on more authentic and holistic tasks, in order to encourage student engagement [I1T8RN2, I1T12RN1]
- more extensive use of the debugger to demonstrate the operation and mechanics of programs (supporting the development of students' mental models, particularly of the notional machine) [I1T5RN1]
- adopting approaches that promote greater student contribution so that their understanding can be gauged [I1T5RN4, I1T5RN2, I1T11RN1]
- greater application of approaches that explicitly require students to demonstrate their mental models [I1T5RN3, I1T9RN1]
- encouraging deeper processing of concepts by designing tasks and spontaneously promoting discussion asking students to explain "why" [I1T7RN1, I1T7RN2]
- trialling the use of student audio to gauge its effect on collaborations[I1T5RN2]
- a movement away from the teacher dominating collaborative solution spaces to students controlling the solution space [I1T8RN1].

Often throughout Iteration 1 more student engagement was desired but not achieved. The group-work activity session trialled in Iteration 1 was sub-optimal because of the poor task design, specification and underdeveloped student virtual classroom competencies. Increasing the amount and quality of collaborative learning in Iteration 2 meant reflecting on the reasons for the lack of success with this, and other approaches to learning implemented in the previous Iteration and attempting to improve them. The design refinements applied in Iteration 2 as part of the design-based research were aimed at determining effective approaches to achieving collaborative learning in web-conferencing environments.

Iteration 2 also provided other opportunities:

- the opportunity to see whether the transmissive approaches that were applied in Iteration 1 could be improved (for instance, by providing clearer and more focused explanations) [I1T9RN2]
- validation of approaches that appeared successful in Iteration 1 (such as using the question-response approach to covering declarative questions)
- improvement of teacher virtual classroom competencies, and gauging the effect of this on the quality of learning episodes
- use of more effective interface designs to match the collaborative requirements of tasks and promote more successful communication [I1T12RN1].

These investigations were enacted in Iteration 2 as part of the next phase of the design-based research process.

4.2.3 Iteration 2 results

The nature of learning that occurred in Iteration 2 of the introductory programming subject in the web-conferencing environment is characterized below. Comparisons are drawn to Iteration 1 and the effects of attempting to apply more student-centred and collaborative learning approaches are described.

4.2.3.1 A calibration of Iteration 2 with Iteration 1

In the first lesson of Iteration 2 the same teaching approaches as Iteration 1 were deliberately used, in order to provide a means of calibrating collaborations between the two semesters. This included:

- The same content, same order of material coverage
- Posing of similar in class questions to students
- The same approach to using media to sharing diagrams and elicit student contributions [I2T1OB4, I2T1KI1]
- similar teaching tactics applied in the classroom such as repeating student text-chat to provide emphasis and typing audio comments in the text-chat pod to provide an additional cue and marker in the transcript [I2T1KI2].

Applying similar learning designs in Topic 1 of Iteration 1 and Iteration 2 appeared to produce similar collaborations, including:

- similar student responses to the preliminary conceptual questions under the "question-response" approach [I2T1OB2, I2T1OB3]
- the same student tendency to contribute less in response to periods of more dominant teacher contribution
- a similar capacity of students to use and learn the virtual classroom tools [I2T1OB1].

The similarity with Iteration 1 can be observed by comparing Vignette 1 with Vignette 7.

As well as similarities in collaborations between the first lesson of each of the two iterations, there were similarities noted between the types of collaboration in other Iteration 2 lessons when similar instructional approaches to Iteration 1 were applied. For instance, a similar type and amount of student discourse was observed when re-applying the teacher-led review of practical activity work in Topic 4 and Topic 5 [I2T4OB3, I2T5OB6].

Vignette 7 [I2T1OB2, I2T1OB3]

A similar interface design as Iteration 1 was used to elicit student responses to the preliminary tutorial questions for Topic 1 regarding the meaning of "syntax error" and "logical error". Note that the text-chat pod appeared is extended along the bottom of the screen, allowing more student text-chat discourse to be seen at one time. As well, a file-share pod is placed in the bottom right hand corner of the interface had been used to allow students to download course related files.

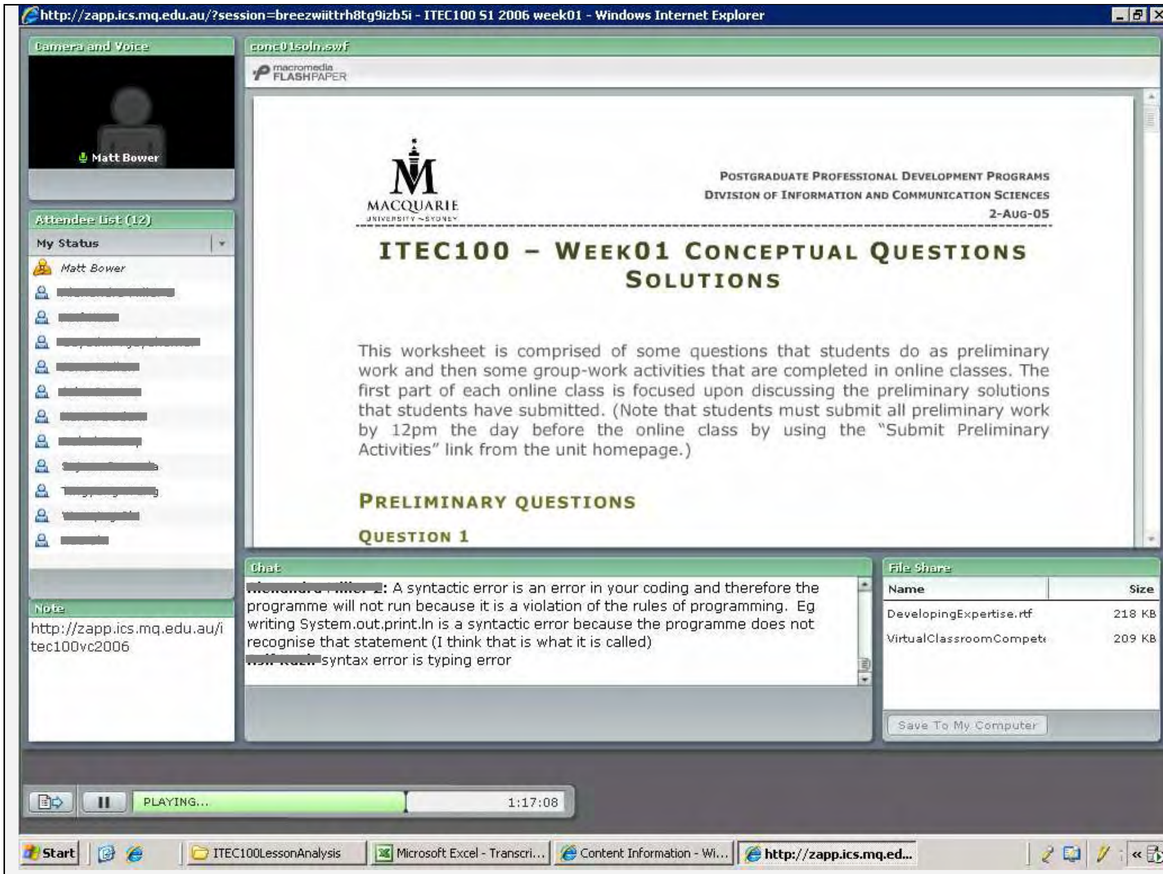

Figure 26 – Iteration 2 Topic 1 Question-response approach

In response to the question regarding the meaning of "syntax error" students replied:

XS: syntactiv error will stop program from running
JB: If the programmer has incorrectly used the programming language when writing their program, a syntactic (or compile-time) error will result. Each programming language has its own set of language (syntax) rules. If these rules are not strictly adhered to, the compiler will generate an error when it tries to convert the program to byte code. All syntactic errors must be rectified by the programmer before the compiler will successfully compile the program.
AM: A syntactic error is an error in your coding and therefore the programme will not run because it is a violation of the rules of programming. E.g. writing System.out.print.ln is a syntactic error because the programme does not recognise that statement (I think that is what it is called)
AK: syntax error is typing error
SR: A syntax error is a violation of the rules of the programming language. Can be detected by the compiler.
KD: something wrong wid format

When the teacher requests an explanation of the term "logical error" students contribute:

AK: logical error is runtime error
XS: logical error occurs while program could still running doing things unexpected
WS: synta error like u spelling sth wrong

This is similar amounts and types of discourse that occurred in Iteration 1. Note that the larger amounts of text used by JB and AM are a result of copy-pasting from their solution documents.

4.2.3.2 Iteration 2 technology designs and their use

Based on observations from Iteration 1 indicating low levels of student discourse in more teacher dominated learning episodes, redesigns in Iteration 2 attempted to engage more student-centred learning by redesigning interfaces for collaboration. As well, interfaces were redesigned to overcome weaknesses identified in transmissive approaches from Iteration 1. Student use of audio was trialled in this iteration, based upon Iteration 1 observation that it may be able to improve efficiency of collaborations. Several observations regarding how these redesigns impacted upon collaborations are summarized below, as well as associated design issues that arose from their implementation.

4.2.3.2.1 Designs for group-work

Having students complete activities in group-work rooms using text-chat allowed the teacher to simultaneously monitor all group interactions and hence provide accurately targeted remedial instruction and summary comments at the conclusion of an activity [I2T2OB1, I2T2KI6, I2T5KI1, I2T6KI3]. Creating a separate solution space for group-work problems allowed the content to be clearly delineated (filtered out) from ancillary coordinating discourse [I2T2OB2]. The capacity for the teacher to broadcast audio to one or many groups simultaneously afforded accurate direction of commentary [I2T3KI6, I2T9OB4]. Vignette 8 provides an example of this.

Vignette 8 [I2T2OB1]

For Topic 2 Tutorial Question 1, rather than the teacher asking for text-chat responses to identifying the classes, objects, instance fields, methods and local variables in a program (as in Iteration 1), students were divided into two rooms and asked to construct a group answer. The interface had been redesigned to provide the program in the middle column of the window, a communal solution space in the top right note-pod and a text-chat pod at the bottom right of the interface. A shared solution space was provided in order to allow activity to centre around students rather than the teacher. One such group-work room is shown in Figure 27 below.

The note-pod solution space in the top right corner shows the student constructed list of classes, objects, instance fields, methods, parameters and local variables. This is clearly separated from the formative collaboration that students conducted in the text-chat pod, allowing the declarative information in the solution to be clearly differentiated and organized. The approach enabled the various types of identifiers to be classified and distinguished, supporting abstraction of concepts.

During the activity the teacher was able to move between the rooms, review the group-work room text-chat transcripts and solution-pods to identify any remaining misconceptions, and then address them once students had returned to the main room. If the teacher wanted to interject during the episode, he could either use audio in one room or choose to use audio from the main room which would automatically be broadcast to all rooms.

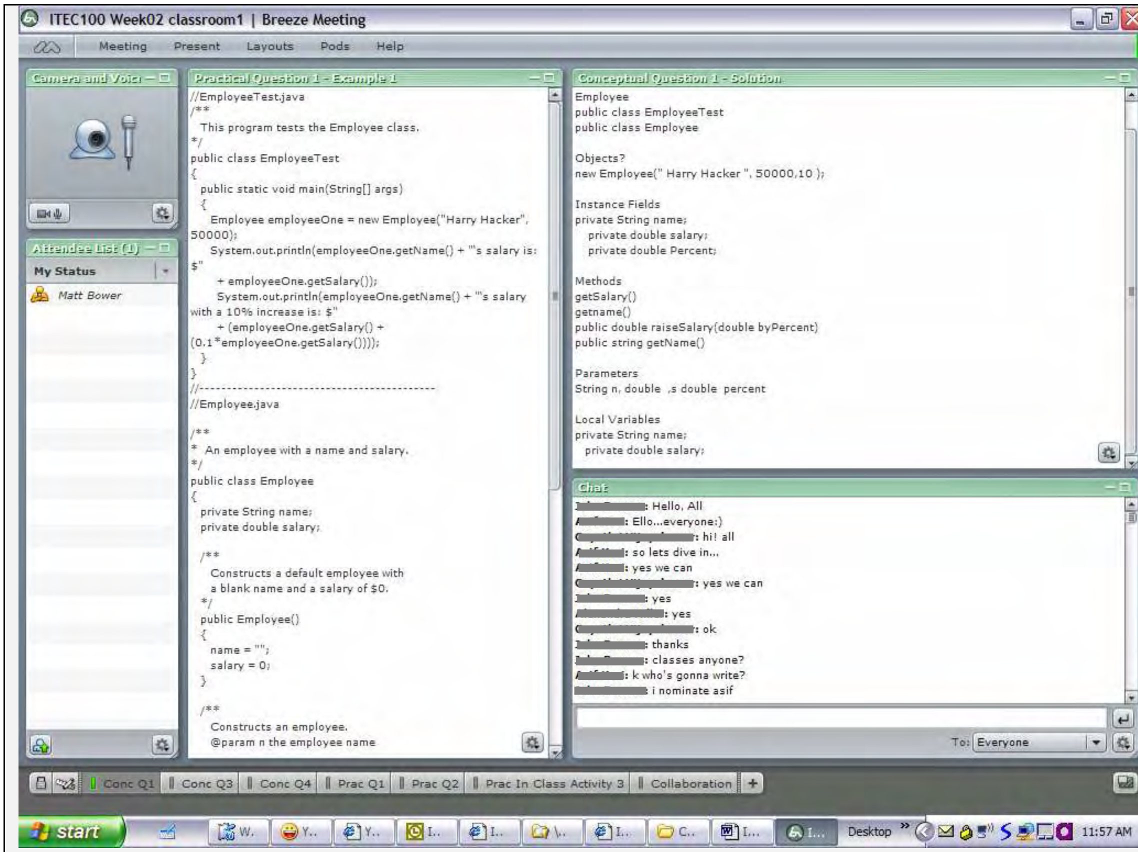

Figure 27 – Iteration 2 Topic 2 Group note-pod approach to declarative task

Students in both groups were able to complete this exercise in their groups, though the time required to do so was considerably longer than using the question-response approach of Iteration 1. A limitation of the note-pod solution space was that only one person could type at a time. To overcome this, students were encouraged to type lines of code in separate text areas and copy-paste into the note-pod.

The capacity to insert multiple note-pods into a layout afforded the potential for different code files to be incorporated into the one interface. This could be used to support a number of different tasks, for instance, integration of different program files to write new programs (refer to Vignette 9). By containing all the required program code within the one interface, split attention was avoided. As well, the approach provides students with equal access to the solution space.

Vignette 9 [I2T8OB3]

In Topic 8 students were required to combine a resize circle program and re-centre circle program into one applet so that a circle could be both re-centred and resized. For this interface the resize and re-centre programs were displayed in note-pods, and a third note-pod column was provided for students to write their combined program.

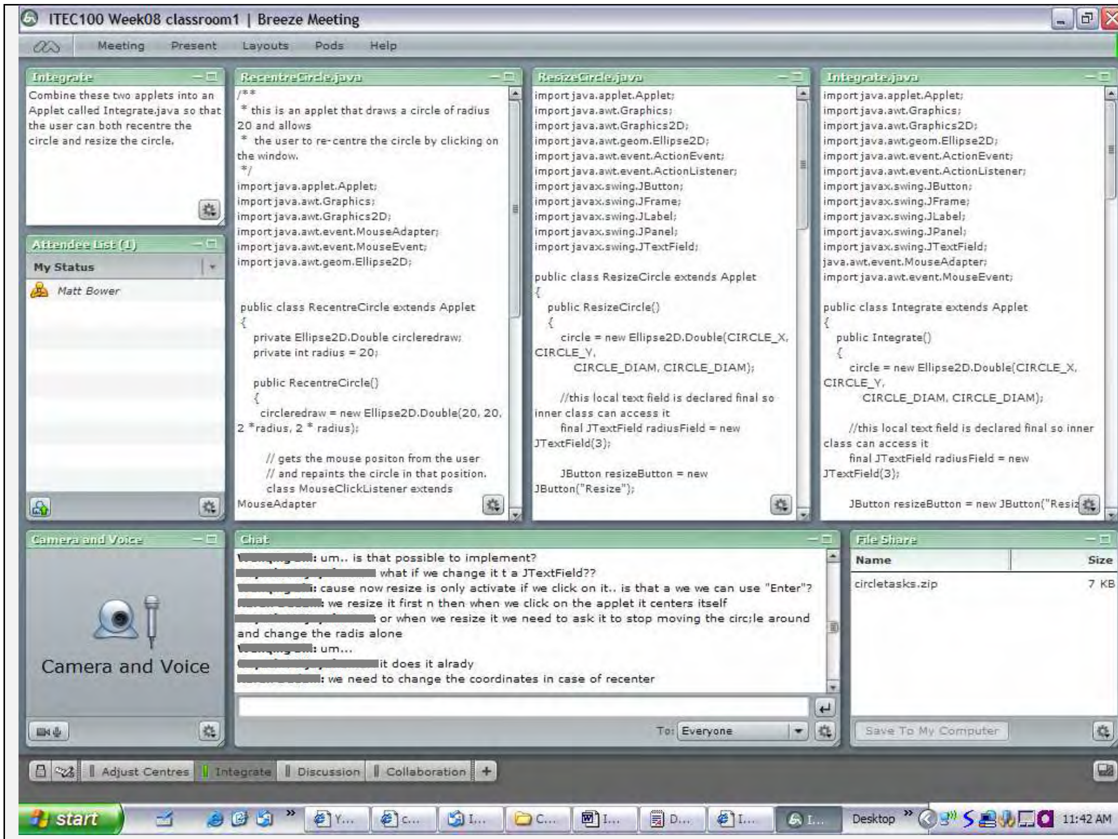

Figure 28 – Iteration 2 Topic 8 Interface Layout for Combine Applets Task

The layout allowed all the relevant information to be accessed from the one interface, resulting in less split attention than when the IDE is used. Once again the text-chat discourse allowed the teacher to easily review collaborations that had transpired in each room. The interface supported high levels of student contribution by providing spaces for people to collaboratively problem solve and discuss concepts. In this exercise Group 1 contributed 52 comments and Group 2 contributed 78 comments.

The solution space was equally accessible by all students, and was available for the teacher to review for diagnostic purposes. The teacher could see that Group 1 was unsure about how to solve this problem, making some progress but not being sure about where the code from RecentreCircle should be inserted into ResizeCircle. As well, Group 1 did not understand the need to turn the local variables into instance fields. Group 2 were more confident about how to solve the problem and completed the task relatively quickly (compared to group 1 who in the same time did not come close to completing the exercise).

During the learning episode the requirements of the interface changed. Once the relevant code from the re-centre and resize program had been incorporated into the solution space, the pods containing the code became redundant. This led to Group 2 also spontaneously deciding to maximize the pod containing the integrated program to cover the other obsolete note-pods.

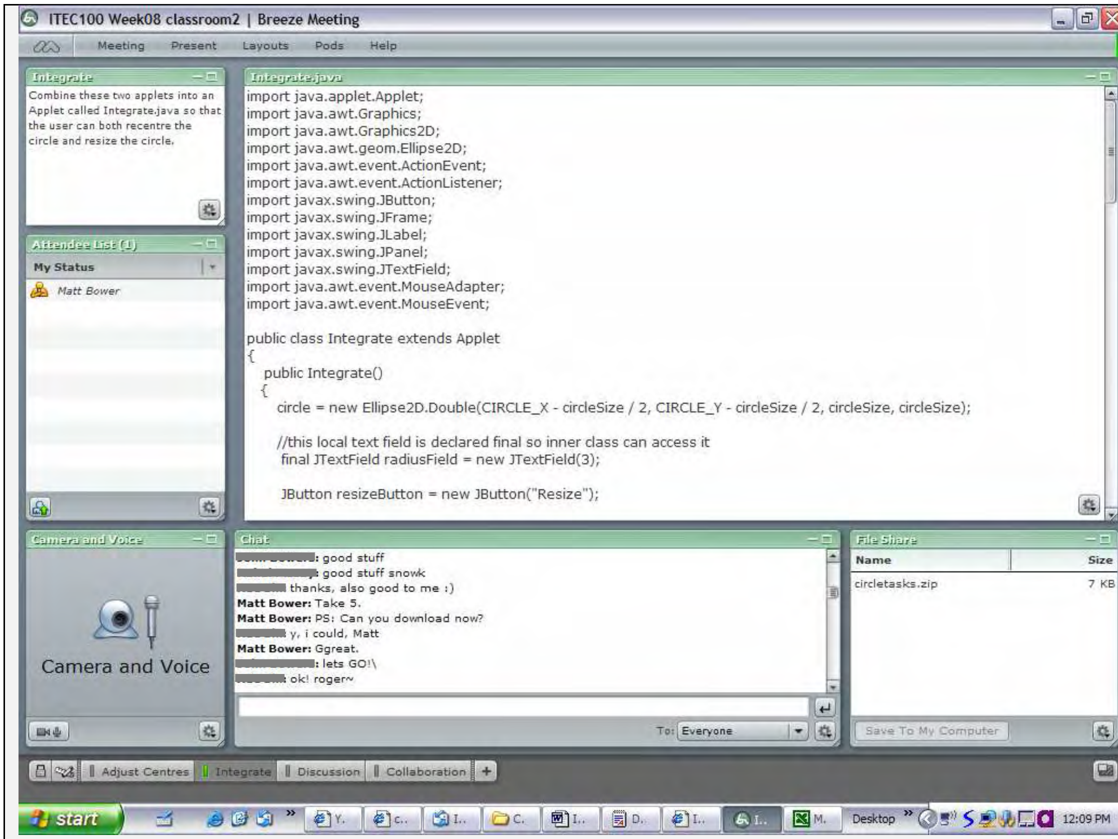

Figure 29 – Iteration 2 Topic 8 student adjustment of interface

This is an example of interface flexibility affording the capacity to dynamically adjust the interface to suit the changing collaborative and cognitive requirements of the activity (Hollan, Hutchins, & Kirsh, 2000).

By virtue of repeatedly using the web-conferencing tool throughout the semester the students developed astute interface design and tool selection skills. On occasions they would adjust the interface based on changing collaborative requirements. Vignette 9 exemplified this.

4.2.3.2.2 Visual Representations

Based on observations from Iteration 1, areas of student conceptual weakness were able to be anticipated. If areas of weak student understanding could be anticipated it allowed diagrams and ancillary resources to be constructed in advance, improving the quality and efficiency of instruction [I2T7OB4, I2T7KI3]. Using a whiteboard to visually represent conceptual relationships allowed more pieces of information to be simultaneously represented than could be held in working memory (as illustrated in Vignette 10).

Vignette 10 [I2T7OB4]

Based on the previous Iteration of Topic 7, weakly formed student schema had been anticipated regarding the concept of casting. As such a whiteboard diagram had been prepared prior to the class so as to provide visual support for audio explanations (leveraging the multimedia learning principle, Fletcher & Tobias, 2005). This facilitated more efficient instruction by avoiding the need to draw any diagrams during the lesson.

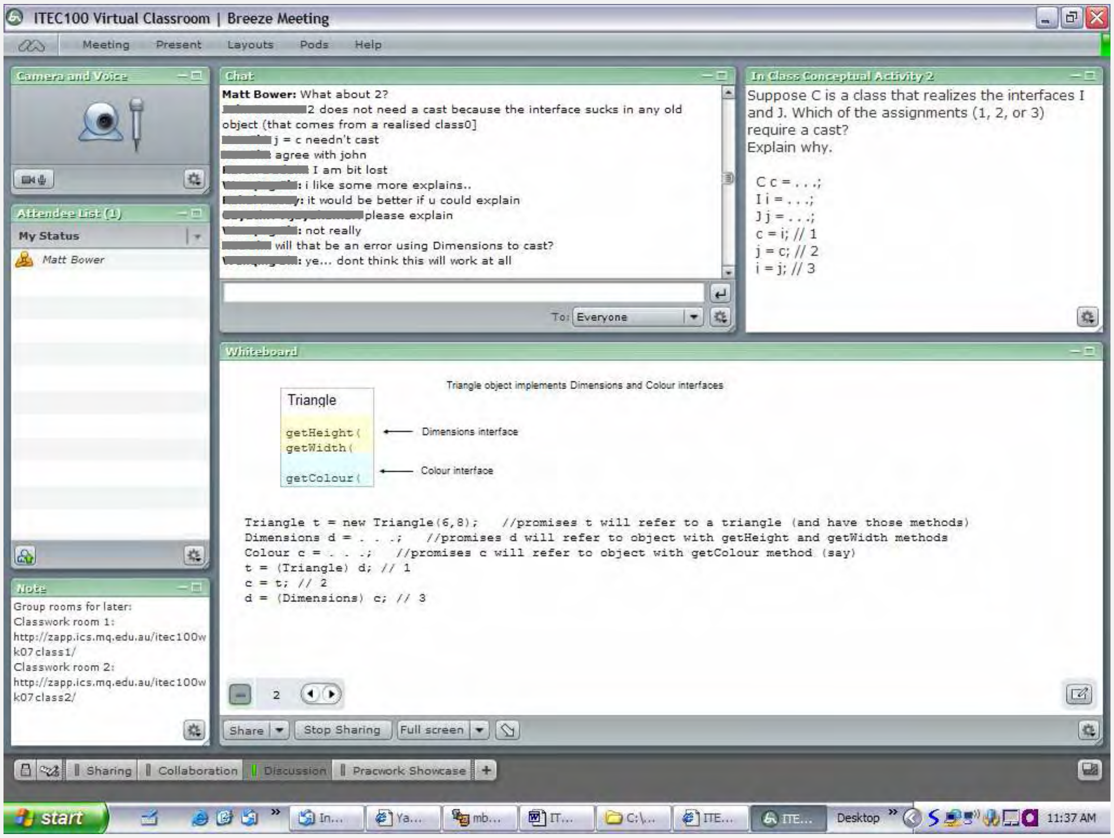

Figure 30 – Iteration 2 Topic 7 Pre-prepared diagram supporting explanation

The teacher presented the diagram to students and provided an audio explanation. Responses from students to formative assessment questions indicated improved understanding. Students also volunteered that the diagrammatic representation had supported their understanding. The whiteboard approach allowed dynamic adjustments to the diagram as part of the explanation process. This is an example of better anticipation of student level of knowledge allowing a more appropriate form of instruction to be provided.

To support the notion that appropriate use of visual representations facilitates mental model formation, there were instances where not using a diagram impeded conceptual understanding. For instance, the permutation generator and a Pascal's Triangle programs in Topic 11 required multiple pieces of information to be interrelated, and attempting to explain concepts without a diagram led to student confusion [I2T11OB3, I2T11OB4, I2T11KI2].

4.2.3.2.3 Student audio trials

In the previous iteration the use of audio by students was conjectured as a way to improve collaborations in the virtual classroom. In the trials of audio that occurred this semester it was noted that establishing audio communications can require some time at the beginning of a lesson or task, however once established allow more rapid and greater amounts of small group collaboration to occur than if using text-chat [I2T4OB1, I2T8KI1].

Audio communication did not guarantee more rapid communication between group members, as students may still choose to contribute infrequently or not at all [I2T4OB4]. However using the audio modality to facilitate group discussion allowed students to dedicate keyboard and mouse activity to textual or diagrammatic solution spaces (such as a note-pod or whiteboard) because they did not need to type their text-chat communications [I2T4KI1].

The fact that student audio was difficult to set-up and coordinate was the main impediment to it not being utilized in this iteration [I2T3KI3]. It is noted that in certain circumstances students may prefer to use text-chat. For instance, in cases where students have both audio and text-chat modalities available, students were observed to use text-chat to make less intrusive or more withdrawn contributions [I2T4KI3].

4.2.3.2.4 Interface Design Issue 1: use of note-pods versus screen-sharing for collaborative programming

There were two obvious alternatives for group programming activities; use a note-pod solution space or have one student in each group screen-share their IDE. There are trade-offs between using screen-sharing as opposed to a note-pod when conducting group-work activities, and student feedback supports this observation [I2T4OB5, I2T4KI2, I2T12OB5].

Using a note-pod to display multiple program files can reduce split-attention caused by viewing the files one at a time through the IDE, but may compromise the view if scrolling is required to navigate to different parts of the text. This is less crucial in read-only situations [I2T2OB4, I2T12OB4]. However if communal editing is required problems arise in determining a common focus of activity when scrolling needs to occur [I2T8KI3, I2T10KI3]. Being able to house the entire program or artefact in the visible section note-pod allows more efficient collaboration by alleviating this need [I2T5KI4].

Regardless of the program size, note-pods impose the constraint that only one person can contribute to a pod at a time since there is only a single cursor for each pod. A tactic to overcome this was suggesting students type their entries elsewhere (for instance in the chat-pod) then copy and paste text into the pod [I2T10KI3]. As well, version control problems can be caused when using a note-pod as a collaborative solution space if students amend copied code in their IDE and paste over note-pod amendments that other students have since contributed [I2T8KI2].

Students were still able to contribute lines of code to a program when using screen-sharing to perform group programming by typing into the text-chat and having the IDE operator paste them into place. However difficulties were experienced specifying the placement of the code and typing fast enough to keep pace with the facilitator [I2T3KI9].

Students selected the note-pod approach over screen-sharing to conduct group programming [I2T6OB5, I2T12OB5]. This approach allows all students to have equal access to the collaborative solution space, allows them to more easily view the text-chat contributions of their peers than when performing screen-sharing, and is easier to setup. This apparently outweighed the fact that it was not possible to compile programs directly in the note-pod and the difficulties coordinating a common focus when the entire program does not fit within the visible portion of the note-pod.

4.2.3.2.5 Interface design issue 2: Avoiding Split Attention

'Split-attention' (Ayres & Sweller, 2005) was observed to negatively impact on collaboration and learning in several instances in Iteration 2. Identification of these situations and reflection on their cause allowed solutions to be designed. Examples include:

- Having at most one textual or visual input channel requiring use at any one time avoided split-attention caused by having to monitor and contribute to two separate spaces. As well, having one audio and one visual channel allows students to utilize dual processing capabilities (Low & Sweller, 2005) [I2T5KI2, I2T6KI3, I2T9KI3, I2T10KI3].
- Requiring students to refer to task prescription and/or required learning artifacts on their tutorial sheets resulted in split attention by caused by having to refer to materials outside the web-conferencing environment. Including these within the interface was a way to overcome split attention [I2T3OB5, I2T3KI5, I2T5KI2].
- Difficulties were experienced when attempting to show relationships between several project files using a screen-share broadcast of the IDE due to split-attention caused by only being able to easily display one file at any time [I2T9KI4]. Slower navigation accompanied by explicit navigational support (for instance audio scaffolding) provides aid.
- Interfaces that did not support participants in identifying a common focus were observed to negatively impact upon collaboration [I2T8OB1, I2T8OB4]. Interfaces that allowed a common focus for consideration to be identified coincided with improved quality and quantity of discussion [I2T11OB1, I2T12OB1, I2T12KI2].

Whiteboards were also used to overcome split attention because they afforded the capacity to interrelate multiple items of textual and diagrammatic information in the one space. This is elaborated in the "Representing Content Using Technology" section.

4.2.3.2.6 Other interface issues

The ability of the teacher to anticipate collaborations and pre-prepare the interface could increase the efficiency of lessons [I2T3KI7]. For instance, only requiring students to download one zip file for the entire lesson rather than multiple separate files for each activity is more time efficient [I2T5KI3]. Several transitions between rooms and layouts throughout a lesson could be disconcerting for students and carries a time overhead [I2T2KI7, I2T3KI1]. Pre-prepared interfaces which provide clear task prescription, appropriately sized and placed collaborative solution spaces, and no unnecessary items allowed students to quickly orient themselves with, commence and complete tasks [I2T8OB2].

Observations regarding interface design from Iteration 2 validated observations made in Iteration 1. Inherent aspects of the various tools also affected the pace and quality of learning experiences. For instance, the sub-optimal usability of whiteboard compromised instructional delivery [I2T9OB3]. As well, the "green arrow" pointer tool was seldom used to highlight aspects of documents being broadcast because of the erratic behaviour observed in the previous semester. Incorrect matching of the size of the pods relative to the amount of information they will hold or their frequency of use can compromise the effectiveness of collaborations [I2T3KI2]. Students indicated that the size of a tool in the interface (relative to its use) was important [I2T8OB3].

Technological interferences also occurred in Iteration 2:

- Network crashes for up to half an hour [I2T2KI1, I2T4OB2]
- Use of lower bandwidth media in order to avoid network crashes [I2T4OB2].

Although technological interferences were identified in the previous semester, due to their external nature very little could be done to avoid them.

4.2.3.3 Iteration 2 (inter)activity designs and their implementation

The introduction of student-centred (group-work) approaches to learning affected collaborations. Much greater rates of student contribution and task engagement were observed during group-work activities than teacher dominated approaches [I2T2OB7, I2T3OB2]. In group-work approaches students were more likely to ask questions about concepts than during whole class teacher dominated activities [I2T3KI5]. In response to an in-class survey conducted in week 2 of Iteration 2, students indicated they appreciated the introduction of group-work approaches because it allowed them to be more active, more interactive, and provided them with exposure to a greater range of ideas [I2T2OB6, I2T2KI8].

Thoughtful implementation of group-work approaches was required to engage students in effective patterns of collaborations. During group problem solving tasks phases of coordinating roles and determining group approaches to solving the problem were observed [I2T10OB4]. One approach to accelerating students through these phases that was observed to be successful in Iteration 2 was teacher modelling of a collaborative pattern with the class preceding a group-work activity (for instance, question-response or group programming). This reduced the amount of explanation required for students to proceed with the activity [I2T3OB1, I2T3OB4]. Failing to model a collaborative pattern could result in greater levels of teacher explanation being required for student-centred tasks [I2T11OB4]. As well, care needed to be taken that more capable students did not overly dominate contributions especially on more difficult tasks. In such cases less able students appeared reluctant to expose their ill-formed conceptions [I2T7OB3].

The integration of group-work approaches required the overall approach to teaching the subject to be considered. Group-work activities required greater time than teacher-centred or teacher-led approaches [I2T2OB1]. Transmissive and other teacher dominated approaches were often adopted in Iteration 2 in order to make up for the extra time spent conducting group-work activities [I2T3OB3, I2T5OB7, I2T12K1]. As well, accurately targeted instructive approaches were observed to be more suitable than group-work for contexts where student understanding was low [I2T11OB5, I2T11KI3]. Thus the teacher needed to make decisions based on available time and perceived student ability levels as to whether it was appropriate to use group-work or more teacher dominated approaches.

However, increased teacher dominance during a task often corresponded with decreased student involvement, as was noted in Iteration 1 [I2T6OB6, I2T7OB2, I2T7OB6, I2T9OB5, I2T9OB6]. The teacher dominance in the learning episode could overshadow other more collaborative aspects of the learning design. An example of this is provided in Vignette 11.

Vignette 11 [I2T5OB6]

In Topic 5 a collaborative interface had been designed for the practical activity involving detecting whether or not a user specified point lay within a rectangle on an applet canvas. On the right hand side of the interface an anonymized student program was provided in a note-pod. The task was to consider how the program could have been more efficiently programmed. Students were also provided with a single zip file in a file-share pod (top-centre of interface) containing the practical files being presented so that they could download and run the programs for themselves.

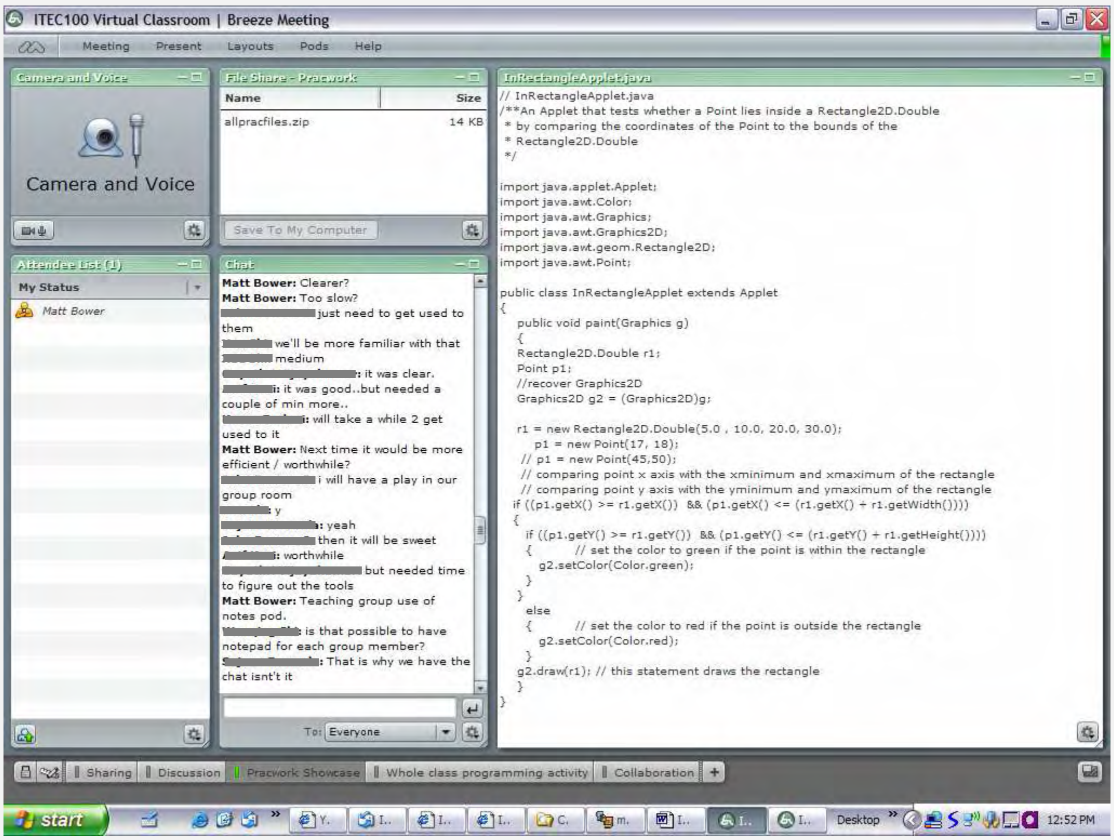

Figure 31 – Iteration 2 Topic 5 Collaborative interface overridden by transmissive approach

Having the program in the note-pod could have allowed students to make amendments. However a primarily instructive approach to covering this activity was adopted in order to save time, with the teacher performing all adjustments to the program and providing all explanations using audio. The teacher dominated approach resulted in a corresponding reduction in the amount of student collaborations, despite the collaborative potential of the interface. This reduced the capacity of students to share their mental models.

On the other hand, initial efforts to create a conversational classroom environment were also observed to lead to greater levels of student contribution [I2T7OB4]. Explicit encouragement by the teacher for students to contribute could lead to increases in student contribution [I2T7OB2, I2T7KI1]. In this iteration it was noted that posing specific questions rather than more general questions was more effective for stimulating student participation [I2T11OB1].

An obstacle to implementing more conversational approaches was the quality of explanation that the teacher could spontaneously apply in the web-conferencing environment. Problems were caused by the fact that the teacher did not always know in advance where areas of weak student understanding would lie and thus relied on the spontaneous ability to adjust the interface and explanation to best cater to student needs. Spontaneously applying instructive approaches when the teacher was unprepared often resulted in presentations that the teacher perceived as being of low quality [I2T9OB1, I2T9OB6, I2T9KI4, I2T11OB3, I2T11KI4]. This formed part of the teacher's developing competencies.

Successful patterns of collaboration from Iteration 1 were validated in Iteration 2. The "question-response" and "instructed teacher" approaches reliably eliciting student contribution for the tutorial and practical tasks [I2T1OB3, I2T10OB4, I2T10OB3]. As well, having students asking questions through the text-chat pod was observed to once allow their level of understanding to be quickly gauged and provide the opportunity for students to respond to other students' problems [I2T7OB1].

4.2.3.4 Iteration 2 task observations

In this iteration the pitch of tasks was again observed to affect the quality and extent of collaborations. Tasks which students found easy were observed to elicit less collaboration than tasks pitched at a level of enquiry more appropriately matched to students' ability level [I2T6OB4]. As well, lower levels of student contribution were noted in cases where students found the task difficult [I2T8OB3, I2T11OB3, I2T11OB4, I2T11KI3].

It was also noted that in this iteration the use of concrete and relevant examples facilitated student mental model development and abstraction of computing concepts more than if the abstractions were presented directly [I2T7OB5, I2T8OB1, I2T8OB4]. As well, tasks requiring students to relate abstract concepts to concrete examples were again observed to be effective in promoting discourse that revealed students' mental models [I2T12OB2, I2T12KI3]. Combining these observations, it appears that the process of moving from the concrete to the abstract is more important than focusing on one or the other. When the interface and activity were designed so this could occur in a collaborative space, student understanding was readily assessed. Vignette 12 illustrates this.

Vignette 12 [I2T12OB2]

The Topic 12 task regarding the identification of "inheritance", "dependency", and "association" relationships in the java source code file was transformed to require more student engagement by requiring them to summarize how these relationships could be detected in the separate note-pod solution space in the top-centre of the interface. The task challenges students' ability to relate theory to code. The task description and learning artefact (computer program) provided in note-pods. The text-chat area was enlarged to accommodate higher frequency of contribution. The teacher coordinates activity by prompting students for answers and students contribute 30 text-chat comments.

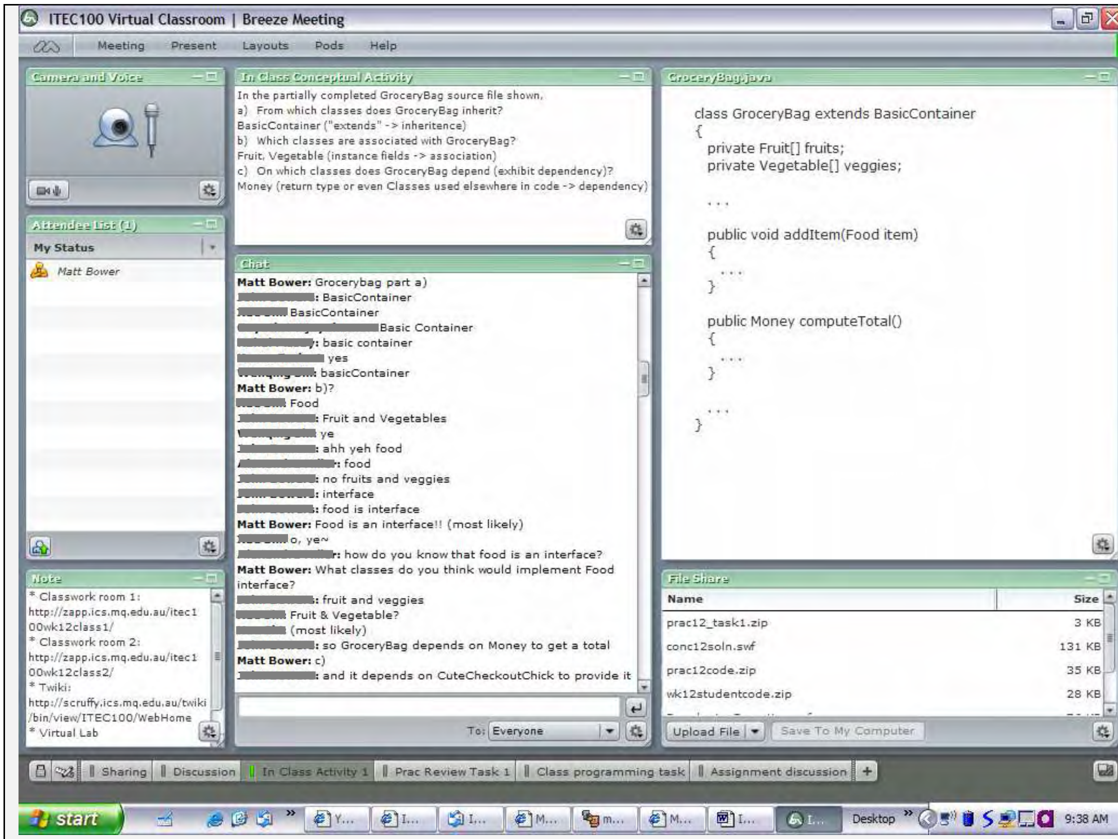

Figure 32 – Iteration 2 Topic 12 Task revealing abstraction process

For instance, in response to the teacher question "what's the difference between dependency and association from the code", students respond:

> JB: if the classes state hold a class object it is association
> AM: location in the programming?
> JB: if it just uses it but it is not an attribute of the class then it is dependency
> XS: association most likely to be instance field?
> JB: which is an IsA relationship
> JB: Instance Variables, HasA
> XS: a return type "object" is a dependency relationship
> JB: a local variable denotes dependence

Discourse arising from the process of forming the collaborative solution indicates the formedness and accuracy of student mental models as according to the SOLO Taxonomy (Biggs & Collis, 1982). AM conjectures that it could be the position of the variable in the class that determines its relationship, which shows a prestructural understanding of how the principles of association and dependency relate to code. XS confirms that object return types indicate dependency relationships, but is not certain about association relationships, indicating a unistructural understanding. JB describes how to identify the relationship based on the function of the variable in the program and is able to provide elaboration regarding other means of identifying the relationship, demonstrating a multistructural understanding (at least). The task requiring students to identify categories of relationships from the concrete representations provided facilitated performance of the action-process-object abstraction cycle (Aharoni, 2000). The activity (requiring students to form and articulate their abstractions in a shared space) was critical to revealing students' mental models.

As in Iteration 1 the relevance of the task was again observed to affect collaborations. High levels of student engagement and learning related discourse were observed for authentic problem solving tasks [I2T10OB4, I2T10OB5]. High levels of student interest were noted for tasks related to their assessment [I2T11OB6]. Review of other groups' work produced substantial amounts of discourse related to discussing and improving mental models, particularly in situations where mistakes had been made [I2T6OB1, I2T6KI1, I2T8KI4]. For review tasks students had attempted to solve the problems themselves and so appeared more interested in reflecting upon the understandings they and others had developed.

4.2.3.5 Iteration 2 representing content using technology [C-T]

There were cases in Iteration 2 where the whiteboard was used to overcome split-attention (Ayres & Sweller, 2005) problems in Iteration 1. The whiteboard offered the greatest flexibility in terms of placement and formatting of code (see Vignette 13), allowing for greater highlighting or 'signalling' (Mayer, 2005b).

Vignette 13 [I2T7OB1]

In Iteration 1 of Topic 7 the teacher's polymorphism explanation was difficult for students to follow because the teacher broadcast the four program files at separate times through his IDE. In Iteration 2 the four pieces of code were represented on the one whiteboard screen.

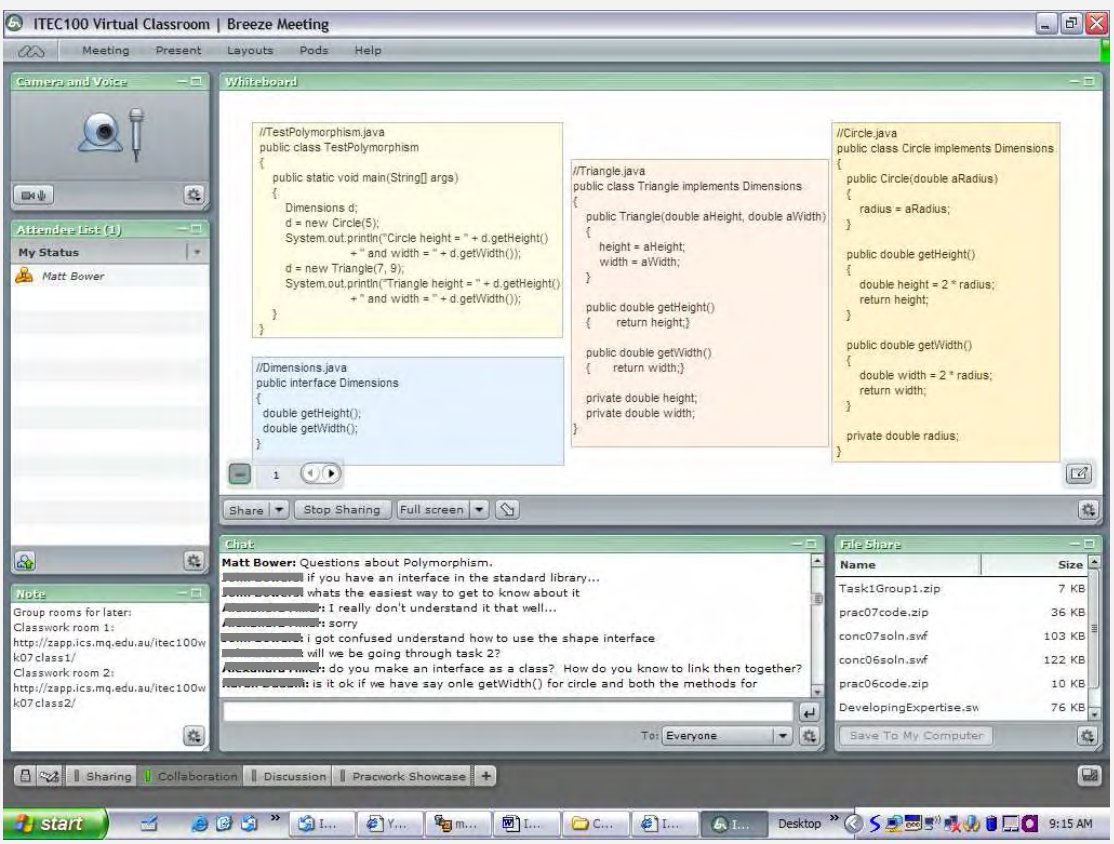

Figure 33 – Iteration 2 Topic 7 Whiteboard supporting interrelation of code

This allowed students to interrelate the interface file, two classes implementing the interface, and the file containing the main method without requiring them to store concepts in memory. This averted potential cognitive overload (van Merriënboer & Ayres, 2005).

It should be noted that while such an approach supports more effective communication of information, in itself it does not provide any indication of the amount of learning that had transpired. In terms of Laurillard's (2002) Conversational Framework, while students had the opportunity to apprehend the structure of the discourse, and interpret forms of representation, they had not been offered the chance to act on descriptions of the world and there had been no opportunity for the teacher to provide feedback. It was only when the teacher asked students whether they had any questions that aspects of their understanding was revealed to any extent. The student text-chat discourse that resulted included:

MB: Questions about Polymorphism.
JB: if you have an interface in the standard library...
JB: whats the easiest way to get to know about it
AM: I really don't understand it that well...
AM: sorry
JB: i got confused understand how to use the shape interface
JB: will we be going through task 2?
AM: do you make an interface as a class? How do you know to link then together?
KD: is it ok if we have say onle getWidth() for circle and both the methods for triangle?
JB: you would need to have an empty method in the realisation
GV: yes i think that would be ok
JB: you would need to define both methods in any class that realises an interface
XS: what does that mean? only implement getwidth() in circle?
JB: but one of the methods may not have any implementation
GV: ok
XS: could interface extends interface?
JB: why would you want to do that?
XS: o, got it

Various levels of understanding from the SOLO Taxonomy (Biggs & Collis, 1982) were evidenced, from prestructural (AM) to unistructural (KD) to at least multistructural (JB). Opening up discourse by asking for questions provides the opportunity for the teacher to remediate prestructural understandings, the potential for students to help each other develop their mental models (JB to KD) and the chance for the teacher to assist more capable students (XS). The effective teacher representation of content was useful to support formation of mental models, but comprised only one part of Laurillard's (2002) Conversational Framework.

Vignette 13 indicates how a whiteboard may be used to effectively interrelate pieces of information, but that the activity will determine the level of student engagement with that information and hence the effectiveness of the learning episode (both from the point of view of student learning and teacher interpretation of student understanding).

In Iteration 2 the spatial and formatting affordances of the whiteboard were also used to facilitate effective comparison and contrast, or "evaluation" tasks [I2T6OB2, I2T12OB3, I2T12KI4] in a more effective manner than in Iteration 1. This is illustrated in Vignette 14.

Vignette 14 [I2T12OB3]

In the "full-stop to exclamation mark" FileReader activity of Topic 12, students were asked to copy their solutions to the whiteboard. This facilitates interrelation of the different techniques they applied with the without causing split attention (Ayres & Sweller, 2005). Colour could also be used to distinguish and highlight different representations.

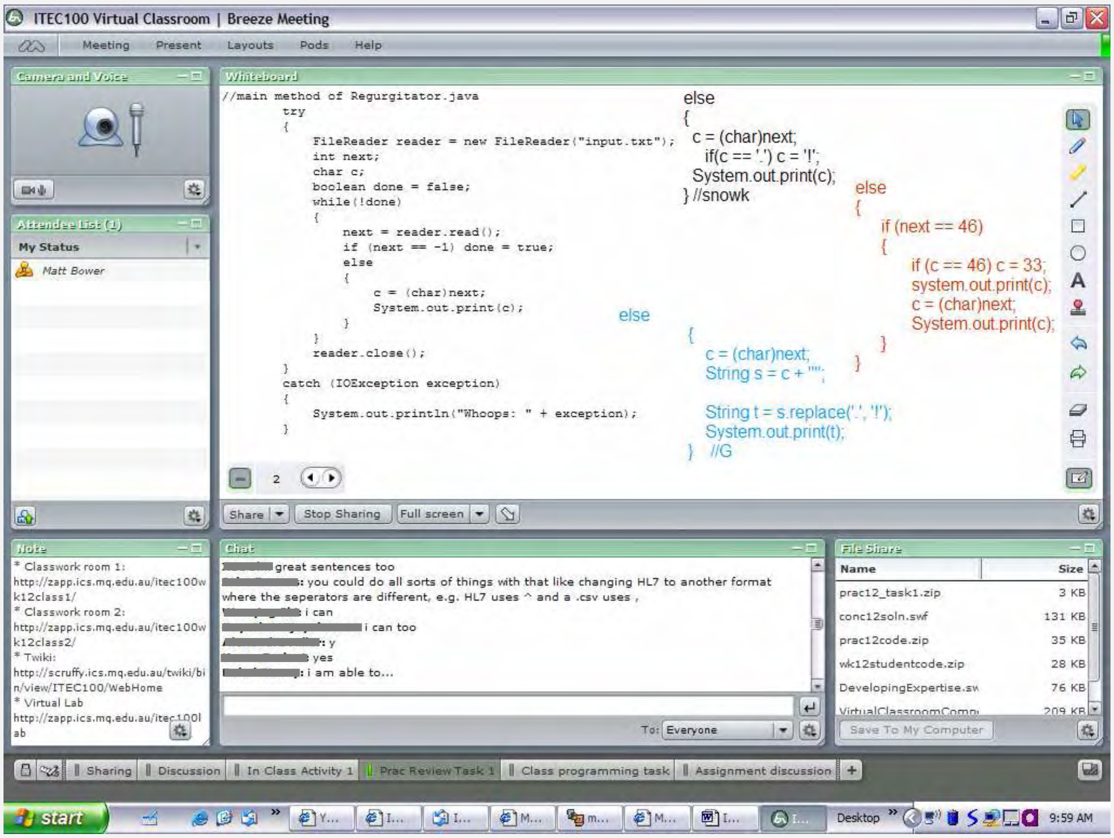

Figure 34 – Iteration 2 Topic 12 Whiteboard supporting interrelation of student models

The teacher and students are able to discuss and evaluate the different approaches all within the one interface. Students posted 33 comments, of which 28 were directly related to discussing the concepts at hand. Examples include:

> GV: i converted the char to string
>
> XS: i compute it by character, while GV did it by string
>
> XS: think replace mine clause with JB's number formula, it will be a good one
>
> JB: we should create two constants [like] private static final ASCII_FULLSTOP = 46;

The task encourages interrelation of different pieces of code, which in conjunction with their actual solutions allowed students to evidence a relational understanding of content. The interface facilitated the representation and interrelation of content.

The whiteboard compare and contrast approach described in Vignette 14 was easily implemented as only simple technological competencies were required to place coloured text on the whiteboard. This was not so for all collaborative approaches in the web-conferencing environment.

4.2.3.6 Iteration 2 Interactions using the Conferencing System [A-T]

When attempting more student-centred and interactive activities using the web-conferencing platform there was often an increase in the virtual classroom competencies required by the teacher. This also led to a new range of potential mistakes that the teacher could make and problems that could occur, such as:

- Linking the content of note-pods on two separate layouts and then replacing the contents with the wrong information [I2T2KI2]
- Not switching students to the correct layout in their group-work room (or not instructing students to do change layouts and how that may be achieved) [I2T2KI3]
- Inadvertently designing a collaborative interface for group programming in which students sharing their screen had no direct way to communicate with their peers (because they could not immediately access text-chat and did not have audio setup) [I2T3OB5].

Student-centred approaches to learning required more advanced student technological competencies in order to lead collaborations and control tool usage. Student virtual classroom competencies impacted upon the effectiveness and efficiency of collaborations. Examples include:

- not understanding how to broadcast the screen [I2T7OB7, I2T7KI2]
- not understanding the mechanics of performing a screen-share broadcast and hence making unnecessary screen transitions [I2T3KI8]
- needing to spend time becoming familiar earning how to use the whiteboard [I2T5OB5]
- asking (repeatedly) how they could increase the size of the screen-sharing display (even though they had been previously advised to use the scroll button) [I2T5KI5].

It became apparent that for successful collaborations the teacher needed to take responsibility for ensuring students had adequate prerequisite technological competencies.

Some virtual classroom competencies were quickly acquired, and this improved the efficiency with which lessons were conducted. For instance students quickly became familiar with and expert at transitioning between rooms and layouts [I2T3KI1]. Many virtual classroom competencies appeared to be related to practice. Students indicated that with practice they were able to markedly improve the efficiency and effectiveness with which they performed student-centred collaborations in the virtual classroom [I2T6OB3, I2T6KI2].

There were some virtual classroom competencies that related to compensating for deficiencies of the web-conferencing interface. For instance, students were asked to append their initials to any note-pod contribution in a communal solution space so that the contributor could be easily identified. Such an approach ultimately improved the efficiency of collaborations by obviating the need to discuss who had made a contribution [I2T5OB7].

This was an example of imposing a community rule in order to circumvent the constraints of the technology.

In Iteration 2 there were examples of how poor interface designs could negatively impact upon interactivity. For instance, collaborations could be adversely effected by including any tools in the interface that the students will not require or should not use [I2T2OB2, I2T2OB3, I2T2OB5, I2T2KI5]. As well, requiring students to download programs for compare and contrast tasks results in split attention (between the web-conferencing browser window and their IDE), whereas placing the artifacts to be compared within the web-conferencing environment would help to provide an integrated point of focus [I2T2OB5, I2T2KI5]. This is exemplified in Vignette 15.

Vignette 15 [I2T2OB5]

In Practical Task 2 of Topic 2 students were provided with two zip files of two programs in a file-share pod (bottom right) for them to download and compare. A pod allowing them to choose a whiteboard or screen-share was provided in the main area at the top of the layout. Students were not provided with directions on the ways that they should use the web-conferencing tools to collaborate during this exercise.

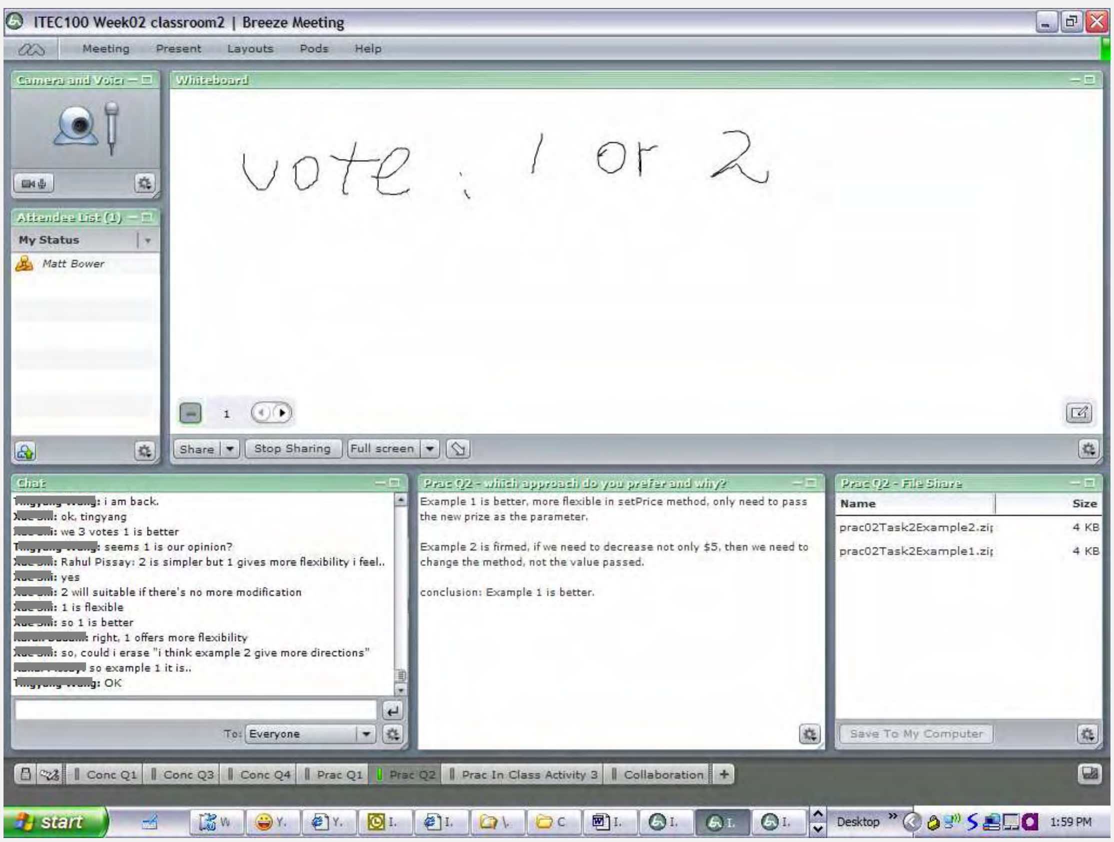

Figure 35 – Iteration 2 Topic 2 Ineffective collaboration through interface

Each room recorded some discussion in the text-chat pod, with the solution once again proposed by the most capable member of the group (which subsequently became the group solution). For instance, in Group-work room 2:

> Example 1 is better, more flexible in setPrice method, only need to pass the new prize as the parameter.
> Example 2 is firmed, if we need to decrease not only $5, then we need to change the method, not the value passed.
> conclusion: Example 1 is better.

The large sharing space for the whiteboard or screen-share was hardly used (and used ineffectively) by the two groups. For instance, one student in group 2 attempted to conduct a vote using the whiteboard, which was a less time effective approach than using the text-chat. The fact that students downloaded the two separate files on their own machine meant there was no common artefact to which they could refer. This process also caused an unnecessary time overhead compared to if the code had been placed in note-pods. The multimodal cluster that was provided to students in this instance resulted in ineffective collaboration and isolated learning.

4.2.3.7 Iteration 2 coordinating collaborative problem solving [A-C]

Based on findings from Iteration 1 revealing the negative impact of poor task specification upon student activity, Iteration 2 focused on attempting to improve problem description. In Iteration 2 broad task prescriptions requiring students to conduct a general review often coincided with shallow and infrequent student contribution [I2T9OB1, I2T10OB1]. As well, task prescriptions omitting instructions on how to perform the problem solving process (for instances, ways of starting) could lead to impeded task progress [I2T9KI2]. When process guidance was provided in a subsequent episode progress was expedited [I2T10OB4].

In Iteration 2 coordinating activity between group members (discussing how to collaborate, agreeing upon steps to solve the problem, deciding when to progress to the next part of the problem) could impose a collaborative overhead that added to the discourse required by students to solve a problem [I2T6OB4, I2T10OB4]. Guidance and suggestions by the teacher on how people should collaborate (e.g., assigning roles for different parts of the problem) could provide a means to reduce the need for students to hold this discourse.

When presented with a group problem solving situation, students were observed to hold differing learning objectives (for instance, obtain the correct answer as opposed to develop an understanding). This may lead to students constructing group answers using a "majority rules" voting approach rather than striving for a negotiated meaning [I2T2OB2]. Less mental model forming discourse was observed when students emphasized producing the solution rather than understanding underlying concepts [I2T6OB4]. Vignette 16 demonstrates this.

Vignette 16 [I2T6OB4]

In Topic 6 students were allocated to one of two groups and then asked to complete two in-class activities relating to 'loops'.

> Task 1
> How often do the following loops execute? Assume that i is an integer variable that is not changed in the loop body.

```
a) for (i = 1; i <= 10; i++) . . .
b) for (i = 0; i < 10; i++) . . .
c) for (i = 10; i > 0; i--) . . .
d) for (i = -10; i <= 10; i++) . . .
e) for (i = 10; i >= 0; i++) . . .
f) for (i = -10; i <= 10; i = i + 2) . . .
g) for (i = -10; i <= 10; i = i + 3) . . .
```

Task 2

What does the following code print?

```
for (int i = 1; i <= 10; i++)
{
    for (int j = 1; j <= 10; j++)
        System.out.print(i*j % 10 + " ");
    System.out.println();
}
```

The interface had been designed to facilitate collaboration regarding the task. The question document had been placed in the major pod along the top-right of the room. A separate answer space was provided for each of the two questions in which students could collaboratively negotiate solutions. A medium sized chat-pod was provided at the bottom-left of the room for students to hold conversations.

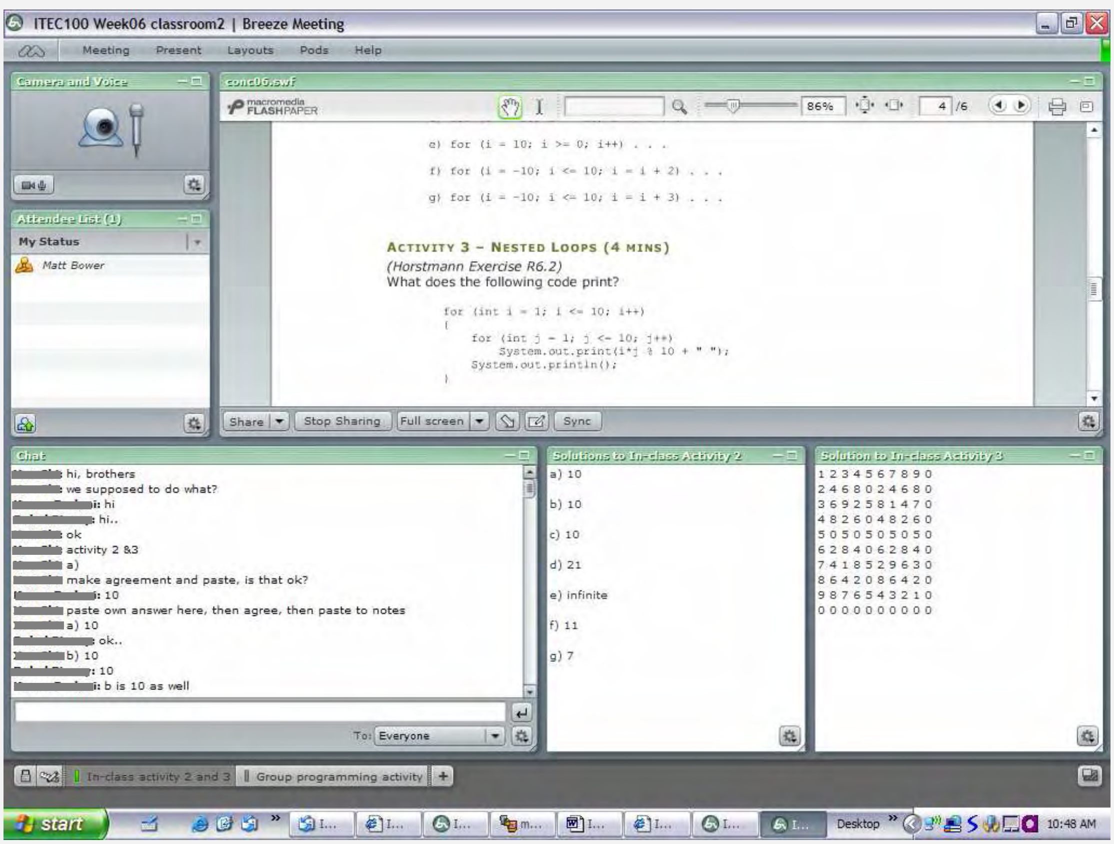

Figure 36 – Iteration 2 Topic 6 Interface

Group 1 appeared to complete task 1 with ease, requiring little collaboration to complete it. For task 2 Group 1 did not conduct any collaboration, apparently because one student ran the program on their computer and copied the output directly into the solution pod. As a result there was less evidence of mental model formation in Group 1; their discourse related directly to proposing and agreeing upon solutions rather than explaining the underlying logic of the loops.

In Group 2 students conducted much greater amounts of discourse (70 text-chat contributions as opposed to 25 in group 1). This was partly due to more discussion regarding how the loops function, but also due to more ancillary conversation. In Group 1 only one comment out of 25 was not directly discussing the subject matter at hand, whereas in Group 2 there were 30 out of 70 text-chat contributions that were discussing matters other than content such as how to collaborate, whether to move onto the next question, and social discourse. Note that for the second task Group 2 students still used the strategy of running the program in order to determine the output.

For tasks where students placed emphasis on obtaining the correct answer, the most capable student would often provide the solution [I2T2OB2, I2T2OB4, I2T2OB5, I2T2KI4]. More evenly distributed collaborations are possible in tasks emphasizing a group process. Providing clear direction about the objective of the learning activity was posited to improve the focus and approach that students adopted for a task.

4.2.3.8 distributed cognitive tool [A-C-T]

There were instances in Iteration 2 where group-work attempted resulted in a shift towards using the web-conferencing platform not only as a communicative tool but also as a distributed cognitive tool. On these occasions students were able to not only share their ideas through the virtual classroom but use the technology to support the collaborative formation of conceptions. The content, technology and activity design determined whether or not this occurred. Vignette 17 provides an example of using the web-conferencing system as a distributed cognitive tool.

Vignette 17 [I2T5OB4]

In order to clarify student understanding of "if-then-else" sequences of Topic 5 tutorial question 3, students were allocated into groups and asked to plot the output of a series of conditional statements on number lines (see Figure 37).

An example representation was provided for the first question (in accordance with Or-Bach & Lavy, 2004) to illustrate how the technology could be applied to represent the output ranges. Students could then apprehend, interpret and apply the semiotic system in relation to the sequence of if-then-else statements. They were then encouraged to use the whiteboard tools to adjust their representations on the basis of the evolving understanding negotiated by the group.

This interface was designed to facilitate exposure and sharing of students' mental models regarding how the four if-then-else sequences operated. Using the collaborative space allowed students to review each other's representations and provide critique and suggestions. This enabled a negotiated meaning to be derived. The task, interface and activity design led to the web-conferencing environment being used as a distributed cognitive tool.

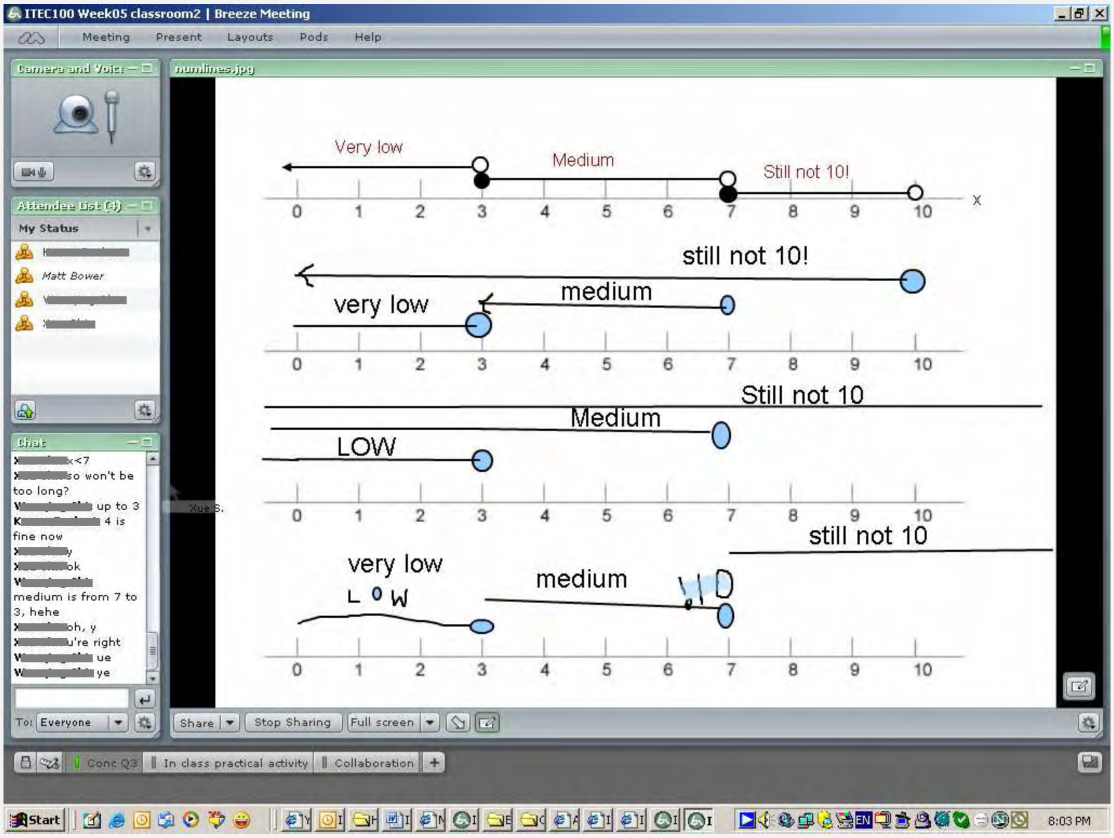

Figure 37 – Iteration 2 Topic 5 Enabling collaborative solution construction and revelation of underlying conceptions

However there were two ways in which the interface could have been improved. Firstly, the questions could have been placed adjacent to the number lines to reduce the split attention caused by referring to separate worksheets. Secondly, the text-chat modality could have been replaced by audio, again avoiding split visual attention and allowing people's dual processing capabilities to be leveraged.

When asked by the teacher "what did you think of doing question 3 on the number line" students responses indicated that it "makes it more clear", was "really interesting and helpful", and "fun". Students indicated that they "needed time to figure out the tools" and that it would be quicker once they were able to "get used to them". The teacher saw this activity as a way for students to become familiar with the whiteboard tools, so that their competencies would be improved for future collaborative activities involving the whiteboard.

For a the web-conferencing environment to be used as a distributed cognitive tool students required a task that allowed them to demonstrate their evolving understanding, an activity design that required them to negotiate shared meaning, and an interface that supported collaborative representation. To use the web-conferencing environment as a distributed cognitive tool it appears critical that students have an integrated understanding of:

i) how the technology can and does operate,

ii) how to coordinate work between members,
iii) the content-based output required for the task.

As such it is conjectured that appropriate instruction covering each of these aspects should be provided. This reduces unnecessary student discourse relating to questioning and discussing best ways to collaborate. The use of the web-conferencing environment as a distributed cognitive tool was to be further investigated in Iteration 3.

4.2.4 Discussion – Iteration 2

Developing collaborative interfaces for lesson redesigns in Iteration 2 initially took considerable time and thought (up to 3.5 hours per lesson) [I2T2RN1]. However, as the teacher became more familiar with building the virtual classroom interfaces and developed a greater appreciation of how to apply appropriate design principles the process became more streamlined (usually requiring approximately 2 hours) [I2T3RN6]. Conducting group-work also increased the amount of in-class technology management and aptitude required by the teacher [I2T2RN5]. However, the process of managing the tasks and reflecting upon the strengths and weaknesses of previous design attempts allowed the quality of the designs to be incrementally improved between weeks [I2T2RN2, I2T2RN6, I2T3RN3].

A notable aspect of Iteration 2 was the tradeoffs between transmissive and group-work approaches. Transmissive approaches appeared more appropriate than group-work approaches in cases where student understanding was weakly formed [I2T11RN2]. Group-work appeared suitable for consolidating understanding, developing process knowledge and relating abstract concepts to concrete examples. However group-work approaches required considerably more time to complete than equivalent instructive approaches. This emphasizes the need for teachers to carefully select the most appropriate tasks in which to apply group-work approaches [I2T2RN3]. The increased time required to conduct group-work activities in-class either meant that less time could be allocated to other tasks in the lesson or some tasks were necessarily omitted. However, this did not imply that learning was decreased, especially if the group-work tasks were holistic in nature so as to cover a broad spectrum of concepts in a topic.

The task type appeared to influence the type of thinking in which students engage. Declarative tasks requiring students to explain "what is" are important – they underpin higher level concept formation. Automaticity with this knowledge allows students to progress confidently through the curriculum. However, tasks encouraging students to explain "why" required them to form a complete understanding of the learning domain. Such tasks were observed to be more likely to elicit students' mental models and facilitate their development [I2T7RN2]. As well, active and authentic learning tasks where students are required to engage in the process of programming once again appeared to encourage the develop of more complete mental models than listening tasks or tasks relating solely to abstractions [I2T8RN1, I2T8RN2].

Several observations from Iteration 1 were validated in Iteration 2. In terms of technology design, application of multimedia learning principles (such as using visual and audio modalities in synthesis rather than one modality alone) appeared to improve the quality of instruction [I2T9RN3]. Text-chat was valuable for facilitating sharing of and response to several people's thoughts simultaneously [I2T3RN4]. The usability of the technology (for instance the whiteboard) impacted upon the quality of collaborations [I2T9RN2].

In terms of the activity that transpired in the web-conferencing environment, teacher domination of the collaborative space was once again observed to coincide with lower rates of student contribution. The question-response and instructed teacher approaches were validated as consistently promoting student engagement. The clarity and specificity of task prescription (learning objective, roles, technology use) were once again observed to impact upon task performance [I2T6RN3, I2T10RN1], as were students' virtual classroom competencies [I2T3RN5]. As well, the importance of regular student input to compensate for the lack of environmental cues was once again noted [I2T3RN1].

On the basis of enacting and analyzing designs in Iteration 2, strategic redesign possibilities were identified. Students appeared to be more engaged when the teacher completed a process with them as opposed to when a process was presented to them [I2T8RN4]. This was in effect dependent on the teacher's capacity to construct a conversational classroom. Conversational approaches engaged students, exposed their conceptual weaknesses and allowed their mental models to be rapidly developed. This was implemented in some instances in Iteration 2, and Iteration 3 provided the opportunity to deliberately explore how conversational approaches could be more effectively implemented.

The fact that student audio was often time consuming to set up and could be difficult to coordinate in class led to the teacher seldom requiring its use. On the other hand it was apparent from Iteration 2 that using audio could markedly improve collaborations in some circumstances [I2T2RN3, I2T2RN4, I2T4RN2, I2T12RN1]. Iteration 3 offered the potential to use audio more extensively and test its utility.

Iteration 3 also provided the opportunity to search for other learning design possibilities. Were there new approaches to using multimedia learning principles to provide more effective interfaces? Were there designs that could more effectively support the sharing of mental models, particularly through the use of the web-conferencing system as a distributed cognitive tool?

Finally, Iteration 3 afforded the potential to seek out improved approaches to implementation. Ways in which prescription and management of learning episodes could be improved to provide better coordination of activity, representation of concepts and engagement with tasks could be investigated. Possibilities for using the flexibility afforded by the interface to support collaborative learning could be examined.

As well, some observations from Iteration 2 were earmarked for validation in Iteration 3:

- whether or not specific learning designs were in fact optimal (for instance, note-pod versus screen-sharing approach to group programming)
- whether tasks requiring reformulation or representation of student knowledge in new ways resulted in deeper processing than reproductive tasks [I2T4RN1]
- whether development of the teacher's virtual classroom competencies could improve collaboration and learning.
- whether similarity in learning designs again caused a similarity in the type of collaborations that transpired between iterations.

These investigations and validations were enacted as part of the third and final phase of the design-based research process.

4.2.5 Iteration 3 results

4.2.5.1 Comparison with Iteration 1 and 2

A similar approach as the previous two iterations was once again adopted for the introductory lesson, except that audio was setup for all students and a collaborative pattern was introduced (appending initials to provide identity of the note-pod contributor) [I3T1OB1]. Similar patterns of discourse to the previous two iterations were observed. Vignette 18 demonstrates the approximately equivalent discourse when using a similar learning design for Topic 1 Question 3.

Vignette 18 [I3T1OB2]

As in the previous two iterations, a question-response approach was used for Topic 1 Question 3, with a similar interface design (apart from students using audio). In response to the teacher's questions requiring short declarative answers, students gave similar sorts of responses (type and length) as if text-chat was being used.

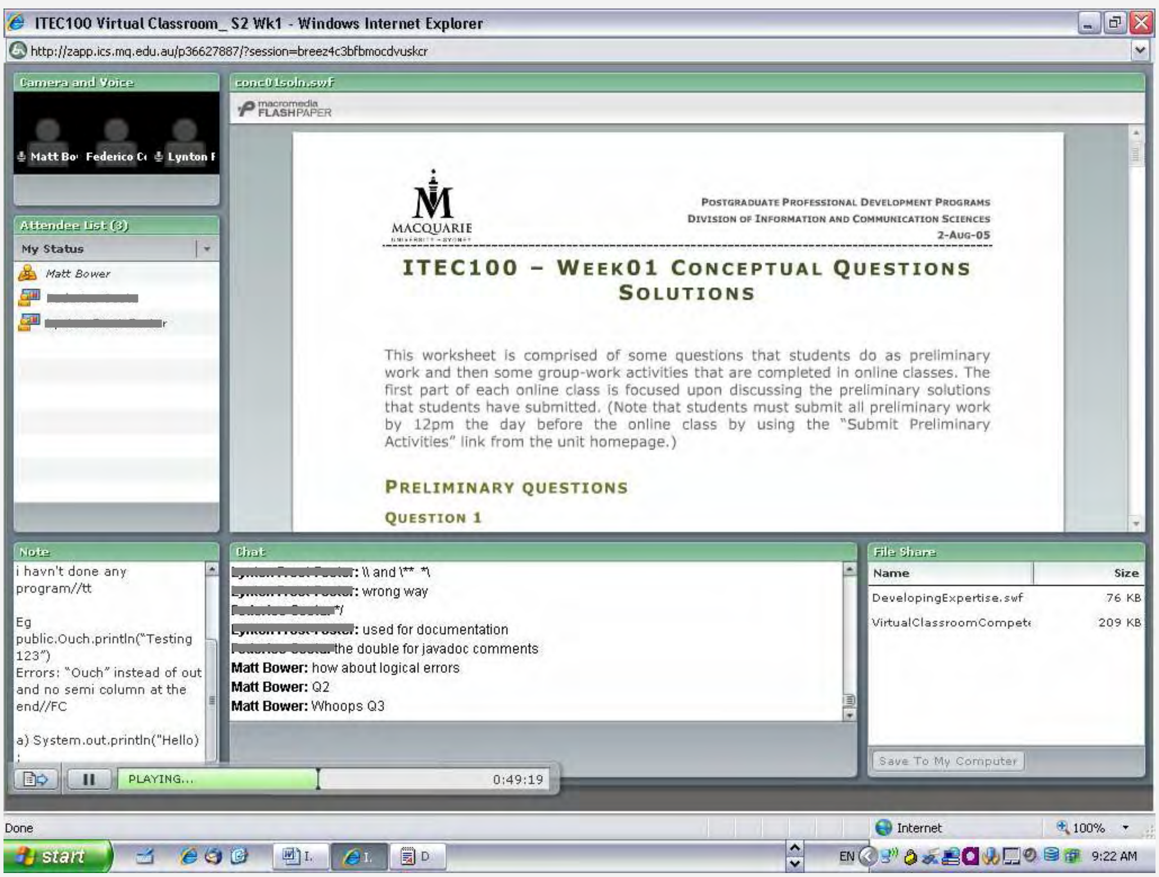

Figure 38 – Iteration 3 Topic 1 Similar learning design to previous iterations

The audio contributions provided by students in response to teacher prompts for solutions to Tutorial Question 3 are provided below. Note that the examples provided by students were in textual form into the note-pod.

LF: I got this one wrong I think
FC: Syntax means it wont compile.
FC: E.g. public.Ouch.println("Testing 123")
Errors: "Ouch" instead of out and no semi column at the end//FC
LF: a) System.out.println("Hello);
FC: Are logic errors and runtime errors the same thing?
LF: Yeah, I think that's right.
FC: So the compiler doesn't eliminate all errors.
FC: I see. Thanks.

The lower number of overall student contributions should be considered in light of the fact that there were only two students present in this first lesson of Iteration 3 (as opposed to eleven in Iteration 2 and eight in Iteration 1).

Student use of audio did not appear to have a major influence on the types of collaborations under repetition of teacher dominated approaches. However, audio did provide benefits when the collaborative space was handed over to students, as explicated below.

4.2.5.2 Iteration 3 interface design and use

4.2.5.2.1 Utility of Audio

Students pervasively used audio in Iteration 3 as a result of the pilot uses in Iteration 2 and the potentials for more effective collaboration that were identified. Audio was observed to allow a single student with centre stage to contribute more discourse for the same amount of time than text-chat, and make those contributions with greater ease [I3T1OB12, I3T1KI1]. However, as observed in the previous iteration, the use of audio carries a collaborative overhead in terms of troubleshooting technical problems (as compared to text-chat which incurs none) [I3T2KI1].

Even when audio was set-up and available to all class members, there were times where text-chat was preferred:

- when students wished to answer a question without interrupting the teacher's commentary [I3T2KI2, I3T3OB2, I3T3KI3, I3T4OB2]
- when the teacher wanted students to simultaneously contribute a short response [I3T2OB2].

During teacher-led programming sessions, pervasive student audio did not necessarily result in a greater rate of student contribution than when students used text-chat [I3T1OB4, I3T1KI2]. Audio also has the disadvantage that the teacher can only monitor audio based group-work collaborations in one (or perhaps two) rooms at a time, as opposed to several rooms if text-chat is being used [I3T8KI5].

However, students favoured audio above text-chat for the vast majority of discursive contributions [I3T3KI1]. Using audio in small group situations allowed more rapid and extensive contribution and interchange than possible with text-chat [I3T6OB2, I3T8OB3]. Utilizing audio for student-centred tasks reduces split attention caused by monitoring and contributing to two visual channels at once (note-pod and text-chat or whiteboard and text-chat), thus allowing people's dual processing capabilities to be utilized [I3T3OB4, I3T5OB3, I3T6OB2]. This is exemplified in Vignette 19.

Vignette 19 [I3T5OB3]

The 'if-then-else' exercise of Topic 5 provides an example of the utility of audio. Students were once again asked to represent the output of the if-then-else statements of Question 3 on the whiteboard. However students used audio rather than text-chat to collaborate.

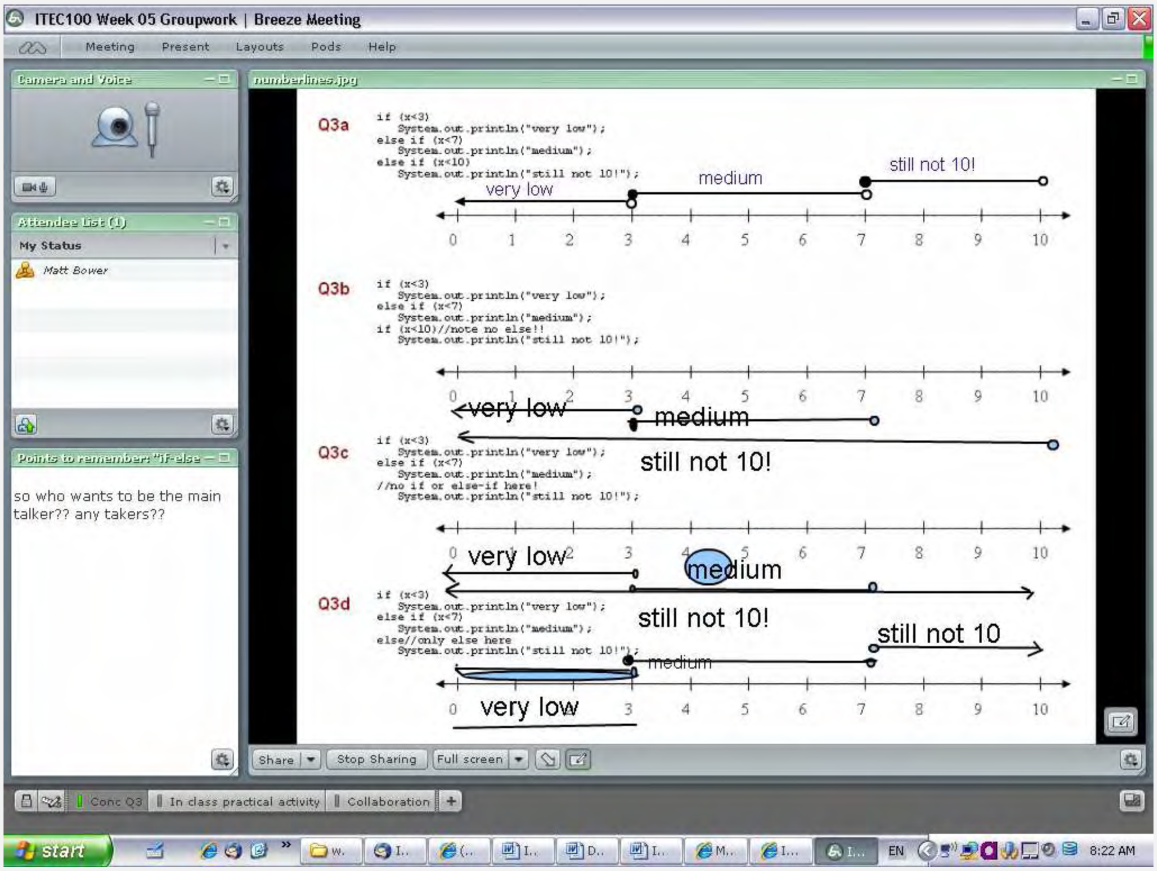

Figure 39 – Iteration 3 Topic 5 Refinement of the If-Then-Else learning episode

Using audio enabled discourse to be contributed and interpreted at the same time as people drew their representations on the whiteboard (leveraging dual processing capabilities, Low & Sweller, 2005). The text-chat approach to discussion used in Iteration 2 represented another visual channel, which resulted in split attention (Ayres & Sweller, 2005). Note also that the interface in this iteration has been adjusted to display the question next to the solution space. This also alleviates split attention caused by having to refer to separate question documents.

As well, students completed the pre-class preliminary conceptual questions considerably faster in this iteration than in the previous iteration where audio was not used [I3T5OB1]. This is another example of the utility of audio for small group-work situations.

4.2.5.2.2 Validating note-pod approach to group programming

In Iteration 2 there was evidence to support the use of note-pods for collaborative programming tasks, however the evidence was equivocal and Iteration 3 provided an opportunity to gather further evidence. For group programming activities in Iteration 3 students indicated a preference for the note-pod over the screen-sharing approach because it allowed them to more easily contribute to the solution space and was clearer to see (without movement or screen resolution issues) [I3T12OB6]. It was noted that when using note-pods for group programming ensuring the size of the pod was large enough to accommodate the entire program code in its visible portion improved the ability of users to monitor changes, as opposed to situations where scrolling was required [I3T3OB4, I3T10OB3, I3T10KI3]. Providing multiple files in note-pods allowed students to work on different files at the same time as their peers as well as relate code between files [I3T5OB6, I3T5KI2]. Vignette 20 illustrates this.

Vignette 20 [I3T5OB6]

For instance the Topic 5 group programming activity requiring students to use the Month and LeapYear classes that they had previously written so that the main program could return exactly how many days were in a particular month (for instance, February 2008). This task was conducted in a purpose built interface with note-pods containing the relevant code as a starting point.

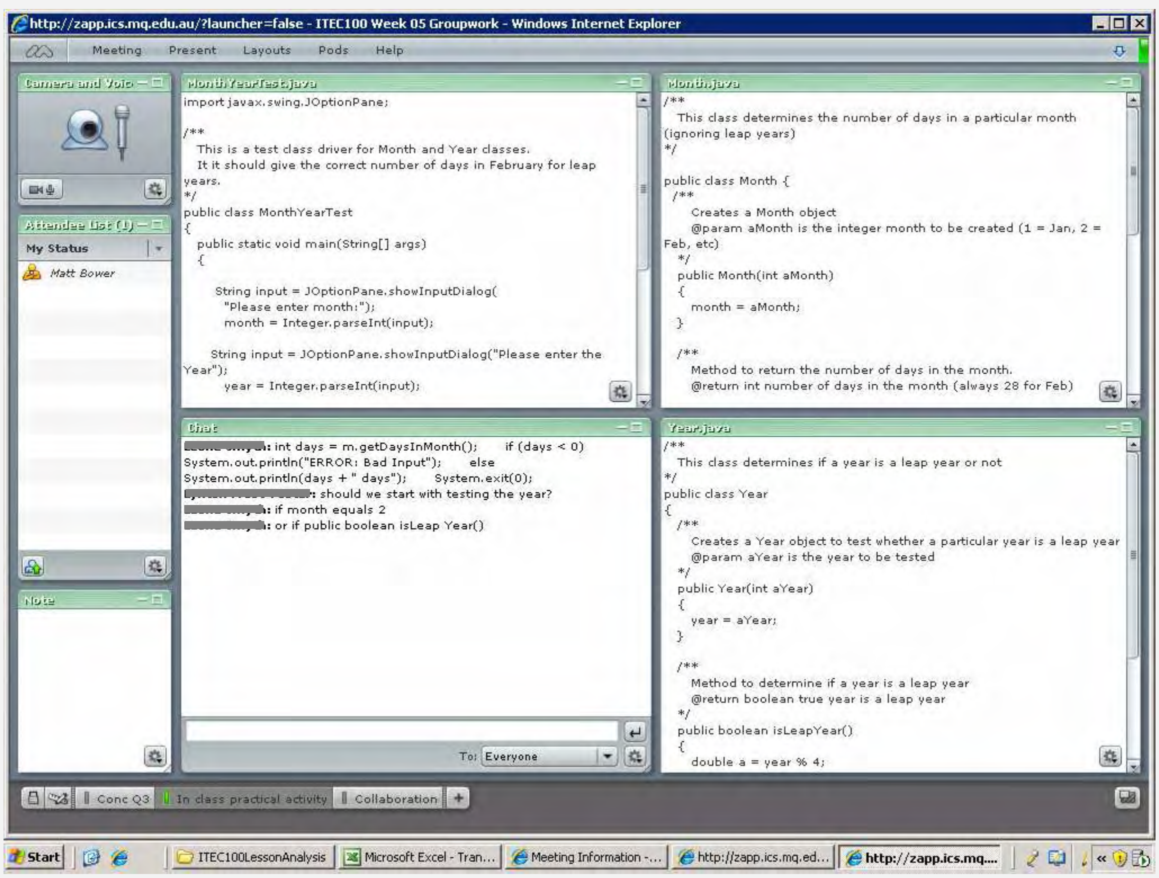

Figure 40 – Iteration 3 Topic 5 group programming learning design

The interface allowed all code required to be viewed in one window and provided equal access to all students. This is in contrast to having a screen-sharing approach where the code is segmented between several files and one person has control of the editing process. Students could work on different classes at the same time.

Vignette 20 also illustrates how audio improved note-pod based interfaces for conducting group programming activities; it allowed students to simultaneously contribute to the programs and discuss strategies with one another. Audio could be used to indicate focus and explain actions. Audio discussion could overlay task based actions which allowed for more efficient processing than if text-chat were used. As another visual form text-chat required independent processing to amendments made in the note-pods.

4.2.5.2.3 Ongoing technology issues

Once again the technology imposed a collaborative layer throughout the iteration, the reliability of which compromised communications. For instance:

- In one lesson the teacher lost audio while three conceptual questions were being covered, requiring him to instead use text-chat while the issue was resolved [I3T3KI2]
- In another lesson students report that the teacher's audio drops out for several seconds and request that explanations be repeated [I3T10KI4]
- While delivering a presentation a student's audio drops in and out which causes their discussion to be poorly understood [I3T8OB1, I3T8KI1].

No progress was made in resolving issues relating to bandwidth, other than being able to more effectively monitor and troubleshoot such problems.

4.2.5.3 Iteration 3 (inter)activity designs and their implementation

In Iteration 2 it was noted that conversational approaches (Laurillard, 2002; Waite, Jackson, & Diwan, 2003) engaged students, exposed their conceptual weaknesses and allowed their mental models to be rapidly developed. For this reason a greater emphasis on conversational approaches was adopted in Iteration 3 and approaches to effective implementation explored.

The application of conversational classroom approaches was observed to lead to a less uniform treatment of pre-planned questions, as curriculum coverage tended to result from enquiry based discussion evolving from considering one or two questions [for instance, I3T2OB2, I3T4OB3]. The interactions that evolved from conversational classroom approaches indicated that collaborative environment appeared to be effective in eliciting student questions and contributions [I3T1OB1, I3T3OB1, I3T6OB5]. More in-depth and concept forming discussion was also noted during conversational episodes [I3T12OB6].

A key factor underpinning engaging more conversational approaches in Iteration 3 was the dynamic redesign of interfaces to support the changing collaborative needs of the evolving conversation. For instance, in the Topic 4 practical task requiring students to create a drawing object that could be placed anywhere on an applet canvas, the teacher adjusted the interface mid-episode based on the level of understanding students indicated during the discourse [I3T4OB3]. This is explicated in Vignette 21.

Vignette 21 [I3T4OB3]

Initially a purpose built interface was being used to facilitate a programming exercise requiring students to allow the coordinates of the top-left corner of the drawing object to be specified in the constructor. The entire program code (main method and drawing object) was provided in the two note-pods along the right hand side of the interface in an attempt to create more negotiated and collaborative approaches to meaning making than had arisen from the independently performed applet drawing task in Iteration 1 and Iteration 2.

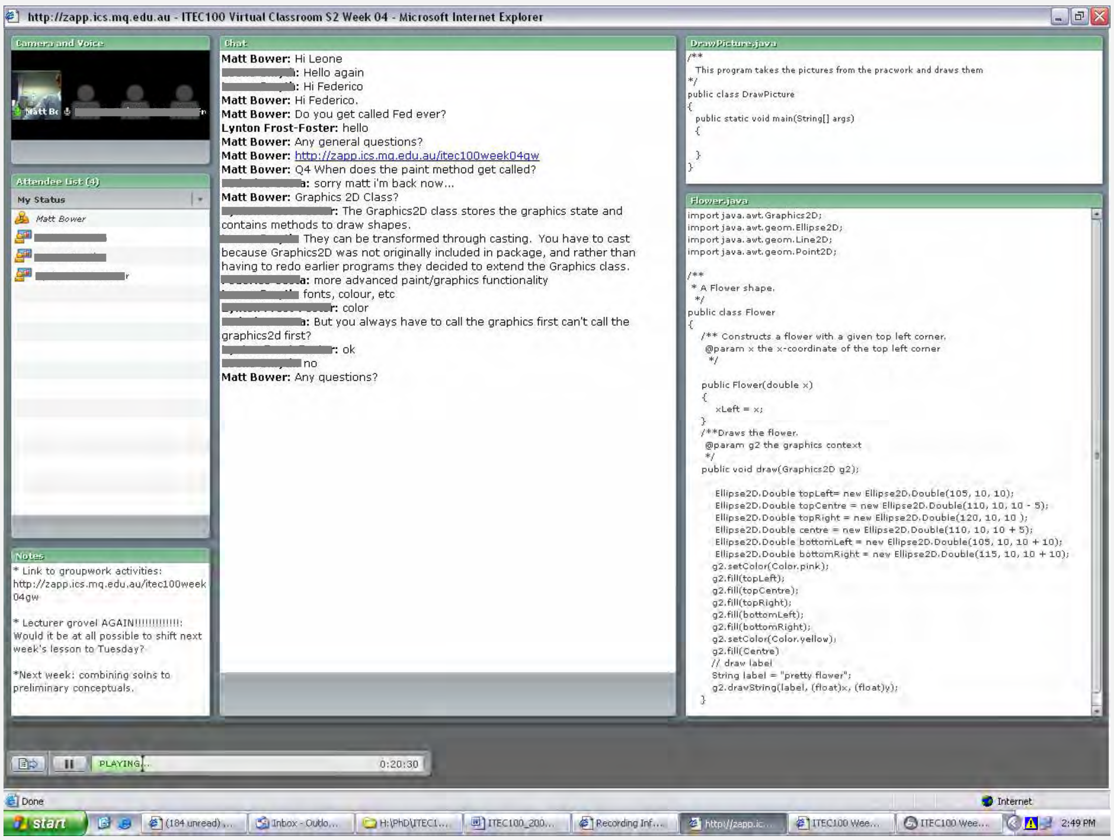

Figure 41 – Iteration 3 Topic 4 Initial design of the applet drawing episode

The conversational approach allowed the teacher to ascertain that students had difficulty understanding how the coordinate system of the drawings related to the coordinate system of the canvas. In order to clarify the way in which these coordinate systems interrelated, the teacher spontaneously adjusted the interface to incorporate a whiteboard (see Figure 42). This is in accordance with Salomon's (1994) Symbol System Theory which advocates representing information in the most cognitively efficient form, and with the multimedia learning principle (Fletcher & Tobias, 2005) which recommends the use of pictures to support word based explanations.

As well as supporting the teacher's explanation, the whiteboard allowed students to represent their amended conceptions so that the teacher could gauge whether they had developed accurate mental models. The picture is adjacent to the program code, which enabled students to relate the conceptual knowledge represented in the diagram to the concrete process occurring in the note-pod. This supported the development of students' abstractions by relating phases of the action-process-object cycle (Aharoni, 2000). Students then collaboratively adjusted the flower program to incorporate the provision of x and y coordinates in the constructor. This represented the apprehension and application components of Laurillard's (2002) Conversational Framework.

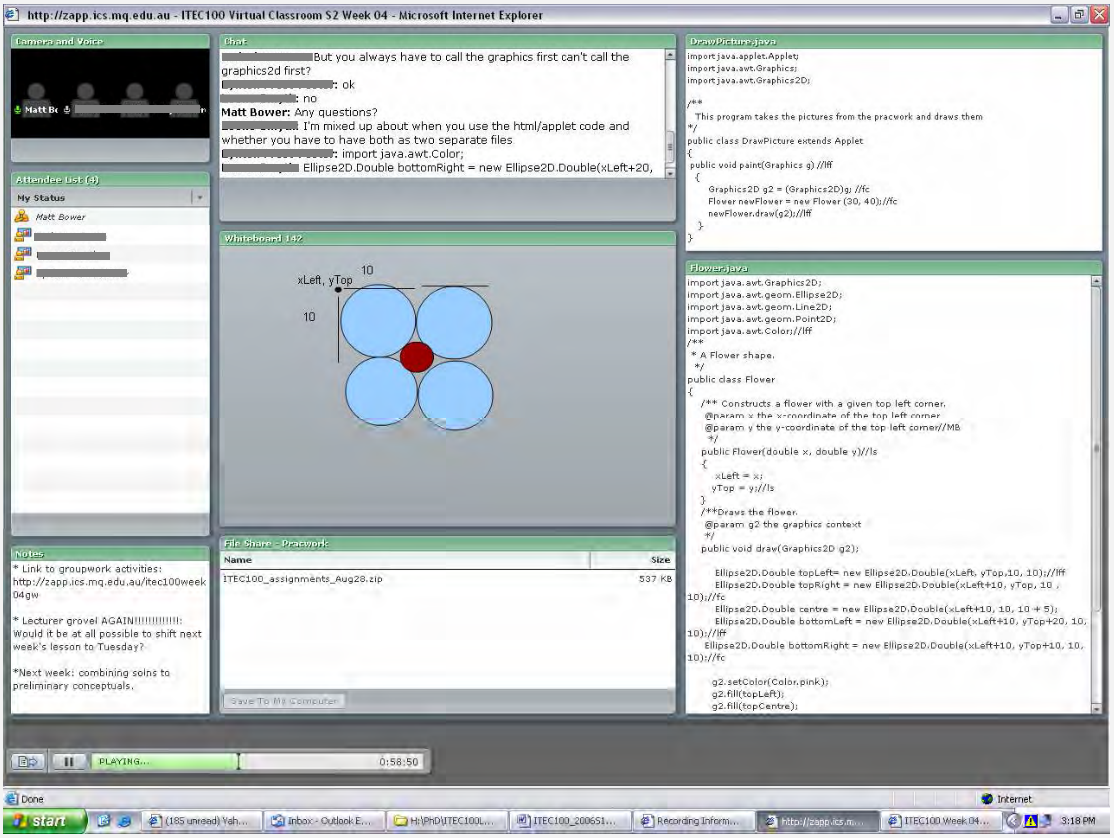

Figure 42 – Iteration 3 Topic 4 Dynamic adjustment to interface enabling effective conversational approach

Other questions regarding aspects of programming such as the relationship between applets and complex drawing objects are asked and discussed, broadening out the curriculum matter addressed beyond the original scope of the task. Sixty minutes was spent on this task by the time the initial objective has been completed. Based on the teacher's observations and student comments, the questions asked and the discussions held were all relevant and effectively supported student learning, even though it was sometimes not directly related to the task. Teacher adaptation of the goals of the learning episode based on student feedback allowed the direction of the learning episode to be adjusted to better meet student needs. This is a utility afforded by the feedback cycle of Laurillard's (2002) Conversational Framework. The adjustment of the interface in order to meet the changing cognitive and collaborative requirements of the learning episode was a critical part of effectively implementing the Conversational Framework in the web-conferencing environment.

There were several similarities between activity observations of Iteration 3 teaching and the previous two iterations, providing validation of effects:

- the "instructed teacher" design pattern was consistently efficient in eliciting student participation, and its success in promoting contribution was noted to depend on the extent to which the teacher chooses not to dominate the conversation [I3T4OB6, I3T7OB4, I3T8OB5]
- pre-prepared diagrams allowed cognitive development to be supported in a time effective manner [I3T6OB1, I3T7OB3, I3T9OB4, I3T10OB1]
- spontaneous attempts to perform a demonstration or explanation could carry a considerable time overhead to setup [I3T6OB5]
- time restrictions cause instructive compromises to occur [I3T2OB4, I3T3OB4].

In Iteration 3 the teacher again adopted instructive approaches on some tasks to compensate for time lost in group-work activities and in-depth discussion resulting from the conversational classroom environment [I3T2OB2, I3T3OB6, I3T4OB4, I3T4OB5, I3T6OB5, I3T8OB4, I3T11OB4, I3T12OB4, I3T12KI2]. However the impact of adopting more instructive approaches upon student engagement and learning were once again noted; for instance describing programs did not stimulate learning conversation to the same extent as setting tasks that require students to interpret or reformulate a program [I3T10OB2, I3T11OB1].

4.2.5.4 Iteration 3 influence of task

Fostering a more conversational classroom in Iteration 3 provided the opportunity for students to steer the direction of the lesson to meet their interests. This was observed to increase levels of student engagement and allowed the teacher to more accurately target commentary to students' needs [I3T1OB3].

Several task observations from the previous two iterations were validated in Iteration 3. Questions that appeared appropriately pitched to students' ability levels were observed to stimulate learning conversations and high levels of engagement [I3T3KI5, I3T3KI6]. For instance, tasks that focus on remedying weakly formed student conceptions result in high levels of student interest [I3T11OB2]. Student engagement and participation was observed to increase for tasks involving rectification of an ill-conceived student program (which was relevant due to their attempts to independently solve the problem) [I3T3OB5, I3T9OB7, I3T9KI3]. On the other hand, tasks that were overly difficult were observed to negatively impact upon students' comfort level with the material and their subsequent participation [I3T1KI3].

Tasks requiring students to solve authentic problems and complete processes coincided with more specific and detailed questions from students [I3T11KI2]. Conceptual tasks not requiring negotiation of understanding often resulted in limited discussion [I3T4OB1]. Holistic, meaningful tasks requiring more elaborate reasoning stimulated more collaboration [I3T12KI4]. However it was noted that tasks high in appropriate content may still not stimulate student contribution if the activity with which they are asked to engage lacks purpose or is weakly specified [I3T10KI2].

In terms of mental model formation, tasks involving specific questions and concrete examples stimulated more detailed discussion and mental model formation than more broad tasks or those focusing on abstract representations [I3T4KI2, I3T5OB5, I3T9OB1, I3T9OB7, I3T9KI1, I3T9KI4, I3T11OB1, I3T11KI1, I3T12OB2]. Tasks requiring students to relate concrete examples to conceptual knowledge supported students to develop abstractions [I3T12OB3, I3T12KI1]. Task prescriptions that emphasized process as opposed to answers resulted in greater revelation of student mental models and discussion of content leading to conceptual development [I3T6OB3]. Having students engage in more authentic, problem solving tasks was once again observed to facilitate full exposure of students' mental models [I3T5KI5, I3T10OB3].

4.2.5.5 Iteration 3 representations of knowledge [C-T]

Based on the findings from the previous two iterations, further efforts were made in Iteration 3 to support the clear representation of knowledge in the web-conferencing environment. For instance, spontaneous use of whiteboards to augment audio instruction was used more frequently to support easier concept acquisition (by applying the multimedia learning principle and reducing cognitive load) [I3T4OB3, I3T4KI3, I3T8OB2, I3T8KI2, I3T9OB5, I3T9KI3, I3T11OB2, I3T11OB3, I3T11KI4]. In this iteration whiteboard were used to allow students to effectively and concretely represent their mental models (and the teacher to intercept and remedy areas of conceptual weakness) [I3T5OB3, I3T9OB4, I3T11OB2]. The shared use of the whiteboard between the teacher and students to represent concepts as part of conversational approaches to learning has already been discussed in Vignette 21.

Refinements in approaches to implementation in Iteration 3 led to more efficient representation of concepts. Providing students with an exemplar representation allowed students to complete abstract representation tasks without needing to consider or discuss how forms should be depicted [I3T5OB3, I3T9OB4, I3T9KI2]. By offering guidance on approaches to representing concepts the teacher supported more efficient and effective sharing of mental model representations [I3T9OB4, I3T11OB2]. For instance, Iteration 3 of the previously teacher-centred "shallow versus deep" copy whiteboard explanation was adjusted to a student-centred activity requiring them to apprehend and practise a representational form. Providing an example of how objects could be represented accelerated the rate at which students were able to share their conceptions (see Vignette 22).

Vignette 22 [I3T9OB4]

Based on students' weak understanding of the difference between shallow copies and deep copies from previous semesters, the teacher prepared a whiteboard activity in advance. A diagram of a shallow copy was shown on one half of the whiteboard, and students were asked to draw a representation of a deep copy on the other half. The drawing of the deep copy only took students approximately two minutes to complete, which was much faster than the time taken for the teacher to spontaneously draw the entire diagram to supplement his explanations in previous iterations (see Figure 43).

The approach allowed students to be active and productive, and reveal their mental models. From the diagram they provided the teacher could immediately see whether they understood the concept and could interrelate its components. The fact that a representational form had already been provided for a shallow copy meant that students did not need to spend time discussing how to depict objects and references (as conjectured by Or-Bach & Lavy, 2004). Student feedback validated that the approach had clarified their understanding of the difference between a shallow and deep copy.

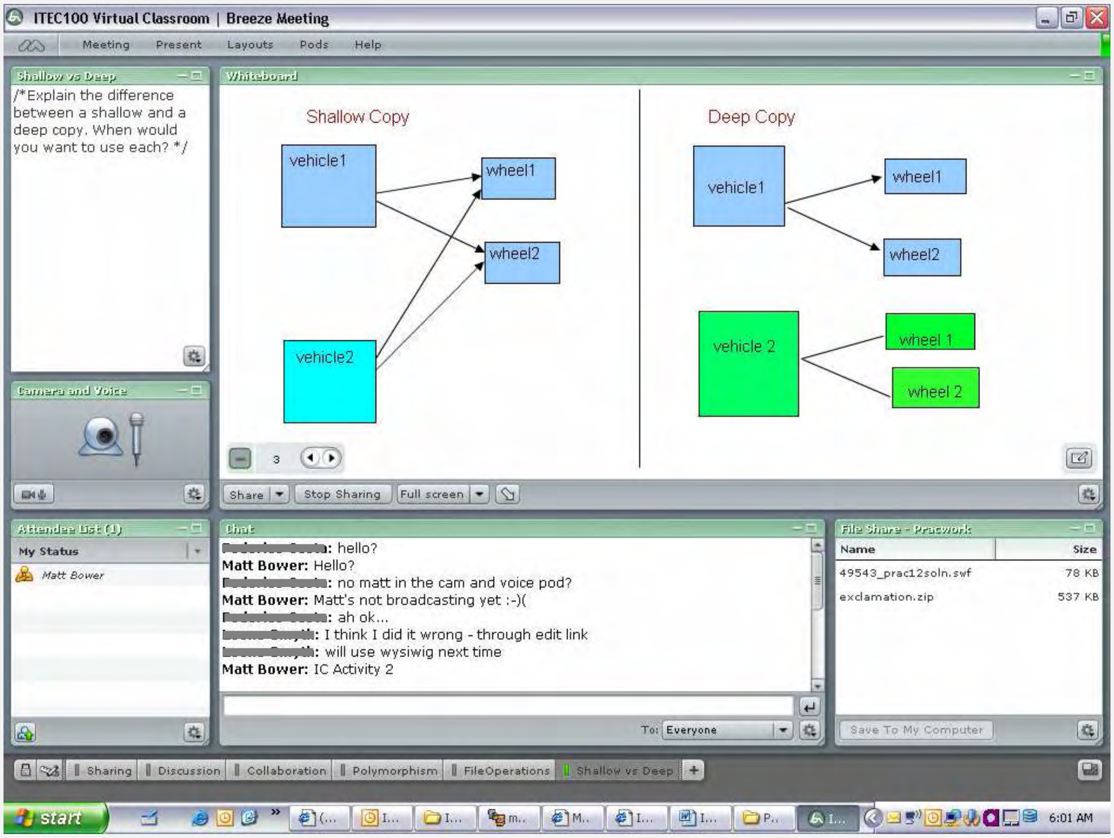

Figure 43 – Iteration 3 Topic 9 Student-centred whiteboard use revealing mental models

As in Iteration 2, the debugger was often broadcast to demonstrate how a program was executed line by line [I3T6OB1, I3T6OB3, I3T6KI1]. This again supported students in developing their notional machine (du Boulay, O'Shea, & Monk, 1989) by providing a dynamic model of how program code creates variables and operates upon them.

4.2.5.6 Iteration 3 interactions using the conferencing system [A-T]

The teacher's virtual classroom competencies improved between semesters [I3T6KI2]. As the teacher's familiarity with the web-conferencing platform improved, so could the quality of advice regarding how students could best use the tools [I3T2KI4]. At the same time, even in this third iteration there were still several occasions where the teacher misused the web-conferencing system [I3T6KI2, I3T12OB5, I3T12KI3]. There were also several indications that the teacher was still learning about optimal ways to use the web-conferencing tool [I3T3KI7, I3T4KI4, I3T7OB2, I3T7KI2]. Student virtual classroom competencies evolved in the same manner as previous semesters. For instance there were still repeated enquiries regarding how to enlarge the size of the screen broadcast throughout the semester [I3T2KI4].

The general improvement in the teacher's virtual classroom competencies led to an increased ability to spontaneously adjusting the interface to meet arising collaborative needs of the episode [I3T6OB5, I3T8OB2, I3T8OB3]. Thus teacher virtual classroom competencies supported the teachers ability to engage a conversational classroom (Laurillard, 2002; Waite, Jackson, & Diwan, 2003). When offered the opportunity, students were also able to make spontaneous improvements to the virtual classroom interface from the user's perspective. In some cases they applied design reasoning that had not been considered by the teacher [I3T8OB3, I3T8KI4].

It should be noted that as the semester progressed more advanced approaches to using the collaborative technology were attempted, which reduced the rate at which technological mistakes abated [I3T12KI3].

4.2.5.7 Coordinating collaborative problem solving [A-C]

In Iteration 2, potential for improving implementation and management of learning episodes was identified. Consequently an increased emphasis was placed on this in Iteration 3, and this positively impacted upon collaborations and learning. For instance, explaining the collaborative expectations for tasks to students was observed to improve levels of student participation [I3T8KI3, I3T10OB3, I3T10OB4, I3T11OB2]. Simply pausing and asking for student questions allowed the typically one way flow of information under transmissive approaches to become bidirectional [I3T7OB1, I3T7KI1]. This allowed more conversational approaches to be implemented and areas of student conceptual weakness to be identified and bolstered in the process. Partial teacher withdrawal from the problem solving process also coincided with higher levels of student contribution [I3T6OB2]. On the other hand more instructive teacher approaches once again led to decreased levels of student contribution [I3T1OB5, I3T6OB4, I3T7OB5, I3T9OB6, I3T10OB1, I3T10OB2].

As well as adopting approaches to encouraging a more conversational classroom, strategies were applied to improve collaboration during student-centred episodes. A facilitative role was consciously adopted during Iteration 3 student-centred episodes, whereby the teacher provided guidance on activity and technology matters [for instance, I3T11OB2]. This allowed student discussions to focus on the curriculum matter rather than negotiating how to collaborate [I3T4OB1]. For example, simply initially allocating students to a different part of the question in the 'if-then-else' numberline task of Topic 5 allowed students to immediately commence problem solving [I3T5OB3]. The 'division-of-labour' (Engeström, 1987) by the teacher effectively circumvented the need for students to hold activity coordination discussions relating to how complete the task, allowing them to focus on content. Intentionally withdrawing from the discourse as part of implementing a student-centred activity design once again allowed students to play a more active role in the problem solving process [I3T5OB6], validating observations from Iteration 2. This approach not only enabled students to negotiate meaning amongst themselves but also allowed the level of students' understanding to be more accurately gauged.

In Iteration 3, a more concerted effort was exerted to prescribe collaborative patterns. For instance, throughout the initial parts of the semester the teacher repeatedly encouraged students to append their initials after note-pod contributions to identify the contributor. Once such collaborative patterns became embedded as 'community rules' (Engeström, 1987), they reduced the need for coordinating discussion regarding who had contributed to a note-pod [I3T4OB1].

The interaction between task specification and collaboration was also observed during Iteration 3. A well specified task could reduce collaborations required for students to orient themselves to the task, allowing them to spend more time addressing the curriculum matter [I3T2OB1]. Providing students with a template upon which their program can be based supports rapid commencement of problem solving tasks [I3T3OB3]. Incorporating the task specification into the interface once again supported rapid task commencement [I3T8OB2, I3T9KI2].

4.2.5.8 Distributed cognitive tool [A-C-T]

Enacting the design-based research process in Iteration 3 resulted in an evolution towards more frequent use of the web-conferencing environment as a distributed cognitive tool. Previous pre-planned approaches were reiterated, for instance, using numberlines to share and develop conceptions about the output produced by sequences of "if-else" statements [I3T5OB3]. However in Iteration 3, points of student misunderstanding gave rise to spontaneous use of the environment as a distributed cognitive tool. Examples include:

- Collaborative drawing on a whiteboard to forming a shared understanding of how program code translated into an Applet drawing (as discussed in Vignette 21)
- Group tracing of a nested loop to decipher how a program produced its output [I3T11OB2]
- Representing transactions between two arrays in order to interpret how a program produced a permutation of the first ten non-negative integers [I3T11OB3].

This last example is described in Vignette 23. It depicts how the web-conferencing system could be used in a shared way to collaboratively develop mental models.

Vignette 23 [I3T11OB3]

The permutation generator practical task of week 11 commenced by the class reviewing a student's erroneous program. The teacher ran the program on his IDE and broadcast his screen to demonstrate how it was (incorrectly) repeating certain numbers. The teacher then adjusted the code to function correctly and explained how the correct program functioned. However students still indicated uncertainty about the underlying logic of the program. Based on this feedback the screen-share was stopped and a whiteboard was used to allow dynamic representation of the program execution (see Figure 44).

The diagram afforded the dynamic and evolving representation of how elements were extracted from a random position in an array (originally containing numbers zero to nine in ascending order) and placed in a second array (while the last element in anArray is shifted to the gap created by the extraction). The teacher provided initial guidance regarding the representational forms to use and the mechanisms by which the algorithm functioned. After this, students could practise executing lines of code, allowing the accuracy of their mental models to be gauged and remediation offered where necessary.

The numerous pieces of information could be represented and interrelated in a way that would have most likely caused cognitive overload if students were required to follow a purely auditory explanation (van Merriënboer & Ayres, 2005). The public solution space allowed cognitive load to be offloaded to the environment (Hollan, Hutchins, & Kirsh, 2000). The visual representation and audio discussion leveraged the advantages inherent in the multimedia principle (Fletcher & Tobias, 2005) and the modality principle (Low &

Sweller, 2005). Central to the approach is the discourse facilitating apprehension of structure, interpretation and application of semiotic forms, feedback and reflection (Laurillard, 2002).

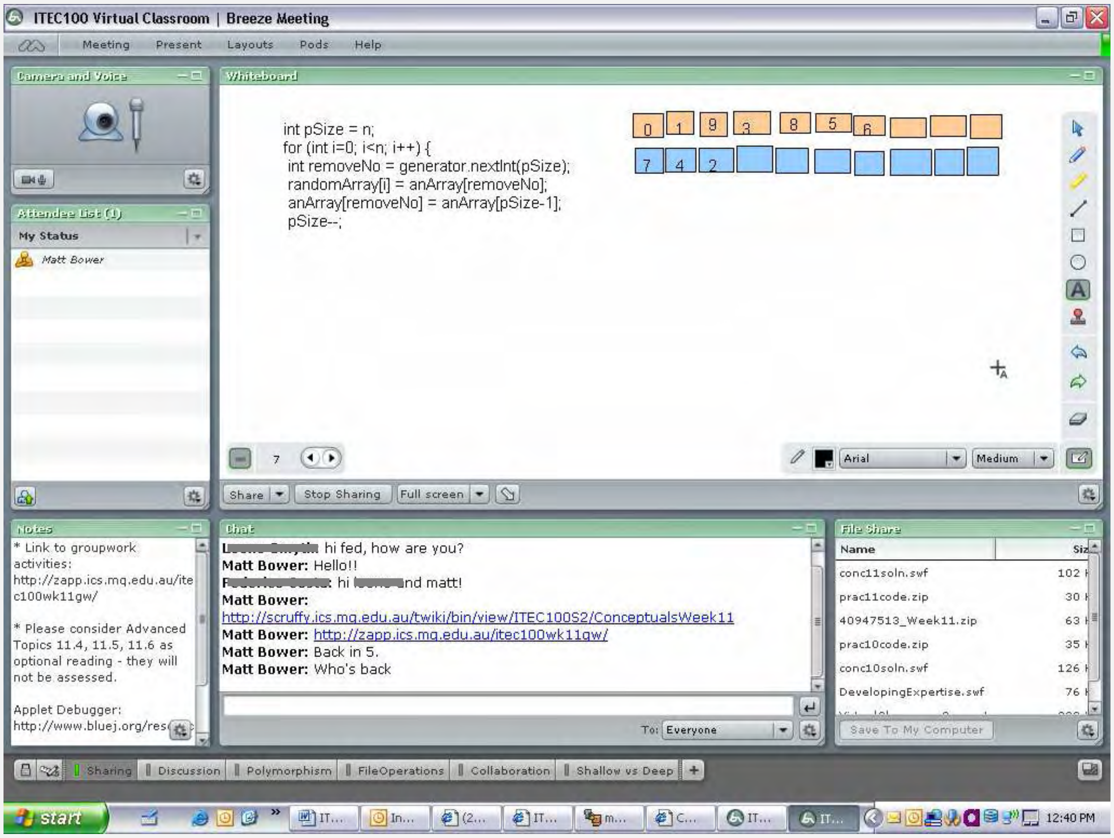

Figure 44 – Iteration 3 Topic 11 Teacher guides scaffolds students through an emulation of the virtual machine on the whiteboard

Although the approach described in Vignette 23 took an extended period of time (almost 28 minutes), it allowed the process of using arrays to perform selections to be comprehended by students whereas in previous iterations explanations had been poorly understood. Dynamically adjusting the interface so that the web-conferencing environment could be used as a shared cognitive tool enabled mental models to be interactively represented and developed.

4.2.6 Discussion – Iteration 3

In Iteration 3 the pervasive use of student audio appeared to offer advantages over text-chat in some situations but not others. In more collaborative small group activities audio allowed rapid contribution and could be used more effectively with visual modalities than text-chat correspondence. However because only one person can make audio-based comments at a time the rate of contributions per person may decrease as the number of group members increases. Thus audio did not appear to offer an advantage in whole class situations unless one person wished to make a substantial contribution [I3T1RN1].

The quality of learning discourse was observed to depend upon on the teacher's ability to engage students in a conversation and facilitate students engaging with one another [I3T12RN1]. The move towards a more conversational classroom often meant that learning episodes were of longer duration, but this did not imply inefficiency of learning. A task that is conducted directly and superficially in one lesson may be extracted yet enriching in another class. The breadth and depth of conversational approaches often reached beyond the anticipated learning objectives of tasks [I3T4RN1].

Authentic and meaningful problem solving tasks were once again the most successful in engaging students and revealing their mental models. A conversational environment was more easily created when a practical problem solving task was being preformed due to the questions and issues that arose by virtue of attempting the task [I3T4RN2].

Implementation of conversational approaches was improved by setting collaborative expectations and ensuring students were provided with the appropriate collaborative space [I3T9RN3]. Student-centred designs benefited from teacher guidance regarding the division of labour, methods of collaborating and ways of representing semiotic forms. Effective implementation then supported more efficient representation of student mental models, which in turn enabled the teacher to more effectively assess student understanding and provide appropriate feedback.

Conversational approaches allowed conceptual weaknesses to be more accurately targeted as the direction of the lesson could be adjusted to cater to student needs. The spontaneous redesign of interfaces to meet the collaborative requirements of a learning episode enabled conversational approaches to be more effectively engaged. Using the web-conferencing environment as a distributed cognitive tool enabled the negotiated representation and development of student mental models.

Approaches from Iteration 2 were validated in Iteration 3, such as the note-pod approach to group programming, pre-prepared diagrams in anticipated areas of student weakness, and the "instructed teacher" approach to teacher-led programming. Iteration 3 also validated that task content, interface design, and activity design all influence the quality and quantity of collaboration and learning. If any of these factors was deficient then the quality of the learning episode was usually compromised. That is to say, the task, interface and activity design need to be appropriately aligned and implemented in order to engage effective collaborative learning episodes [I3T6RN1].

4.3 Summary of Design-Based Research Study

The design-based research study revealed ways in which different modalities (audio, text-chat, visual representations on screen broadcasts and whiteboards) interacted to affect different patterns of collaboration. The process allowed successive refinements to existing designs and the evolution of new designs based on the movement towards more interactive and student-centred approaches.

Throughout the study the utility of the technology designs depended on the capacity to effectively leverage the multimedia principle and modality principle while avoiding extraneous load upon cognition. This was achieved through representation of information in cognitively inefficient forms and avoiding split attention. Authentic and meaningful problem based tasks were consistently observed to increase levels of student engagement. Tasks that facilitated the abstraction process by progressing from concrete examples to conceptual understanding supported the formation of student mental models.

The process of enactment was fundamental to the design-based research process, as well as being a significant part of the results. Teacher and student virtual classroom competencies played a substantial role in the success of learning episodes. Teacher management of activity and technology was observed to allow students to focus more effectively on the content of the learning episode, and tactics could be applied to help overcome distributed process loss. Providing guidance on how semiotic representations could be made allowed students to practise applying those representations in the learning domain rather than spending time re-inventing representational forms.

Designing for more student-centred learning led to new learning designs that incorporated the use of whiteboards and note-pods to facilitate distributed cognition and negotiated meaning making. The efficiency with which audio allowed students to contribute tightly coupled collaborations in group-work situations. Conversational approaches allowed student misconceptions to be more readily identified and the direction of the lesson to be more accurately targeted to student needs. Dynamically redesigning the interface enabled more effective implementation of the Conversational Framework (Laurillard, 2002). The epistemological shift towards using the web-conferencing environment as a distributed cognitive tool afforded the potential for students to collaboratively develop their mental models.

Chapter 5 - Multimodal Discourse Analysis Results

This chapter presents the results of conducting the multimodal discourse analysis upon the sample of 24 learning episodes. The analysis of each learning episode is based upon quantitative data derived from performing the coding process, as well as qualitative observations distilled from the detailed review of the learning episode recordings and associated artifacts. Quantitative data are used throughout to support qualitative claims that are made.

5.1 Introduction

The results described in this chapter are based upon the 24 learning episodes summarized in Appendix B. As discussed in the methodology chapter, the multimodal discourse analysis aimed to characterize teaching and learning in web-conferencing environments and illuminate how different learning designs affected changes in discourse. The coding distinguished discourse by its emphasis on the curriculum matter (object), participants (subjects) or the web-conferencing environment itself (mediating tool). These related to the ideational, interpersonal and textual emphasis of the discourse. As well, the coding scheme also addressed the nature of interaction between participants and how modalities are used for different learning designs.

Conducting the analysis produced results on several levels:

- Within learning episode results – findings relating to collaborations within a learning episode based on the learning design that was implemented.
- Within topic results (between learning episodes) – observations relating to how the successive design changes between iterations of the same learning task impacted upon collaborations.
- Global results – summaries of the entire dataset that serve to characterize teaching and learning collaborations across all 24 learning episodes.
- Learning design results – results stemming from considering how the dimensions of variation (interface, task type and activity design) effected collaborations.

A summary of the data and results for the three iterations of the Topic 10 "RadioButton to ComboBox" exercise is first presented in order to exemplify the within learning episode and within topic (between learning episode) analysis process. This demonstrates how the multimodal discourse analysis was used to examine each learning episode and scrutinize the effects of design changes between iterations for a particular learning task. Appendix B – "Summary of Multimodal Discourse Analysis Data" contains the complete within and between learning episode analysis for the entire dataset of 24 learning episodes.

The within topic (between episode) analysis is interwoven throughout the learning episodes in Appendix B in order to maintain the connection between the data and the analysis. This allows the effect of different learning designs for the same task type to be immediately related to the data recorded for the learning episodes. The results of the within episodes and within topic analysis are integrated into the "Consolidated Findings" section at the end of this chapter.

Global results relating to the subject of discourse, the nature of interactions, and the modalities used are reported after the Topic 10 exemplar, providing a characterization of the entire sample. The global results describe relationships and differences between teacher and student discourse and activity.

Following this, results regarding how learning designs affected discourse are drawn. Careful attention is applied to aspects of validity (particularly in relation to the existence of intervening variables) and in each case the grounds for using a particular form of analysis is either justified or refuted.

The final "Consolidated Findings" section integrates observations from all levels of analysis to form a set of consolidated results. Note that a summary of all actions and across the entire dataset is provided at the end of this chapter.

As well as containing a summary of the data and analysis for all 24 learning episodes, Appendix B contains a discussion of the limitations of the dataset, and an example transcript and the details of all statistical tests applied in this study. Review of this appendix is required in order to understand the results contained in this chapter.

5.2 Within Episode and Topic Results – An Example

5.2.1 Using Topic 10 to exemplify within Episode and topic analyses

Topic 10 provides an example of the within episode and within topic (between episodes) analysis that was conducted. Summarizing the analysis and results for one topic explains how the global results and consolidated observations were derived. Topic 10 has been selected because although none of the topics sampled in the multimodal discourse analysis perfectly exemplify the approach to redesign across iterations applied in this study, the episodes in Topic 10 are the most representative.

5.2.2 The Topic 10 task

The task analyzed for the three episodes in Topic 10 was a procedural exercise requiring students to meet the following design specification.

> "Adjust the program your wrote in the pre-class activities that changed the background colour of a panel using radio-buttons so that it now changes the colour using a dropdown menu."

In Iteration 1 the teacher broadcasted his desktop containing the IDE and prompted students for suggestions about how to change the program so that it uses a dropdown menu instead of radio-buttons (teacher-led design). In Iteration 2 students complete the task in purpose built group-work rooms, with the teacher moving between the two rooms to observe their work (student-centred design). In Iteration 3 the three students complete the task using the same group-work room design as Iteration 2, except that audio is used to facilitate collaboration.

5.2.3 Topic 10 analysis and results

5.2.3.1 Iteration 1

Activity Design: Teacher-Led Programming
Interface Design: Presentational
Number of students: 8
Duration: 21.5 minutes

Brief Summary of Episode:
In this episode a standard desktop sharing interface was used, although once again the text-chat pod had been enlarged across the bottom of the screen to allow more written discourse to be read at once (see Figure 45). This allowed the teacher to broadcast his IDE using the screen-sharing facility and prompt students with questions about how to solve the programming problem. Students could make contributions of ideas (including lines of programming code) through the text-chat pod.

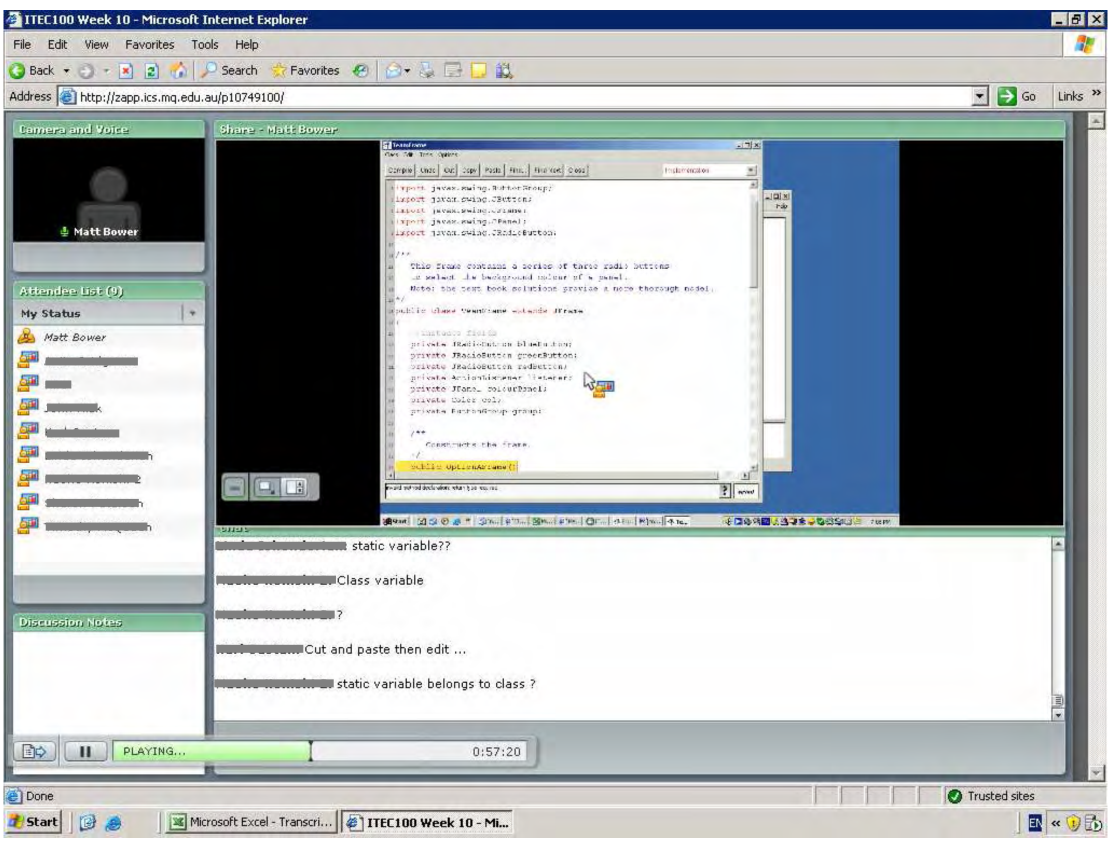

Figure 45 – Interface for Topic 10 Iteration 1 "RadioButton to ComboBox" episode

The teacher performed most of the activity in this episode, contributing 60 separate recorded instances of teacher modelling programming actions and four instances of the teacher highlighting text to provide emphasis (ref. Table 32 at the end of this chapter). All 126 of the teacher textual discourse contributions were made using audio (ref. Table 32). The majority of the teachers' comments related directly to Content (77 out of 126 textual discourse contributions, ref. Table 8) indicating that the teacher played a significant knowledge bearing role in this episode.

T10_2005S2	Independent Question	Independent Statement	Question response to Question	Question Response to Statement	Statement Response to Question	Statement Response to Statement	Question Response to Action	Statement Response to Action	Totals
Content	16	36	1	2	7	13	0	2	77
Activity	1	8	0	0	3	0	0	0	12
Technology	0	0	0	0	0	0	0	0	0
Activity-Content	2	9	0	1	0	6	0	0	18
Activity-Technology	0	0	0	0	0	0	0	0	0
Activity-Content-Tech.	0	0	0	0	0	0	0	0	0
Content-Technology	0	0	0	0	0	0	0	0	0
Task sentiments/attitudes	3	7	0	0	0	4	0	1	15
Unrelated/Unclassifiable	1	2	0	0	0	0	0	1	4
Totals	23	62	1	3	10	23	0	4	126

Table 8 – Topic 10 Iteration 1 Subject-Interaction Counts for TEACHER textual discourse during learning episode

T10_2005S2	Independent Question	Independent Statement	Question Response to Question	Question Response to Statement	Statement Response to Question	Statement Response to Statement	Question Response to Action	Statement Response to Action	Totals
Content	3	8	3	1	19	2	0	0	36
Activity	3	2	0	0	1	1	0	1	8
Technology	0	0	0	0	0	0	0	0	0
Activity-Content	0	6	0	0	2	2	0	0	10
Activity-Technology	0	0	0	0	0	0	0	0	0
Activity-Content-Tech.	0	0	0	0	0	0	0	0	0
Content-Technology	0	0	0	0	0	0	0	0	0
Task sentiments/attitudes	0	5	0	0	4	1	0	0	10
Unrelated/Unclassifiable	0	0	0	0	0	0	0	0	0
Totals	6	21	3	1	26	6	0	1	64

Table 9 – Topic 10 Iteration 1 Subject-Interaction Counts for STUDENT textual discourse during learning episode

Thirty of the 126 teacher textual discourse contributions related in some way to coordinating activity (ref. Table 8). Many of the 12 Activity statements that the teacher contributed occurred at the beginning of the task. These were to set the expectation for activity during the learning episode and to describe how students should be engaging in this task, for instance "I'm just a robot and you've got to tell me what things we need to change". The teacher also made 18 Activity-Content statements throughout the task. Once again a large proportion of these occurred at the beginning of the learning activity. These contributions establish how the class should interact with the content (for example, "And what we're going to do is turn the code that we have into a dropdown menu").

Students only communicated using text-chat, contributing a total of 64 textual discourse contributions using this means (ref. Table 33 at the end of this chapter). The teacher-led activity design whereby the teacher prompted students for suggestions about what to do next resulted in students being less directive in discussing the curriculum matter; most of the Content comments made by students were Statement Responses to Questions (19 out of 36, ref. Table 9). Students also make 10 Activity-Content statements (ref. Table 9). These resulted from providing explicit directions to the teacher about the steps that should be performed to solve the problem, such as "add the panel".

However, the design that was implemented did not render students entirely passive, providing them with some space to direct learning. Students contributed three Independent Student Questions and eight Independent Statements all relating specifically to Content (ref. Table 9). In many cases this caused the teacher to adopt a more responsive role; 37 of the 126 textual discourse contributions made by the teacher were responses to student questions or statements (ref. Table 8).

No difficulties with the communication approaches were experienced during this learning episode, and as such no Technology or Technology related discourse contributions were recorded by either the teacher or students (ref. Table 8, Table 9). Both the teacher and students were adequately familiar with the mode of interaction associated with teacher-led programming. However it should be noted that the interface design did not allow effective student contribution to the solutions space. On two occasions the teacher pasted code suggested by the students in the text-chat pod to the IDE, but this involved the inefficient transition back the web-conferencing environment in order to make the copy (ref. Table 32).

The teacher-led activity design allowed the teacher to demonstrate how to adjust programs and articulate logic relating to the task. The process of debugging code could also be demonstrated, with the class able to offer debugging suggestions at each obstacle. The screen-sharing approach utilized a modality that most efficiently represents the programming process information being communicated in a context that most resembles that in which students would be expected to apply that information (Symbol System Theory, Salomon, 1994)

Under this activity and interface design it was only possible to assess that students have a "multistructural" (Biggs & Collis, 1982) level of understanding. In this episode students did not evidence that they could complete all aspects of the problem solving process – with the teacher often "filling in the gaps".

5.2.3.2 Iteration 2

Activity Design: Group Programming
Interface Design: Collaborative
Number of students: 7
Duration: 32.75 minutes

Brief Summary of Episode:
In this implementation of the exercise students completed the programming task in groups using virtual classrooms that had been specifically designed for the activity (see Figure 46). The task was specified in the top left note-pod. The text-chat pod was larger to allow more student textual discourse to be reviewed at one time. There was a file-share pod for students to share programming files, though this was not used. All students had equal access to the large note-pod solution space on the right hand side of the window.

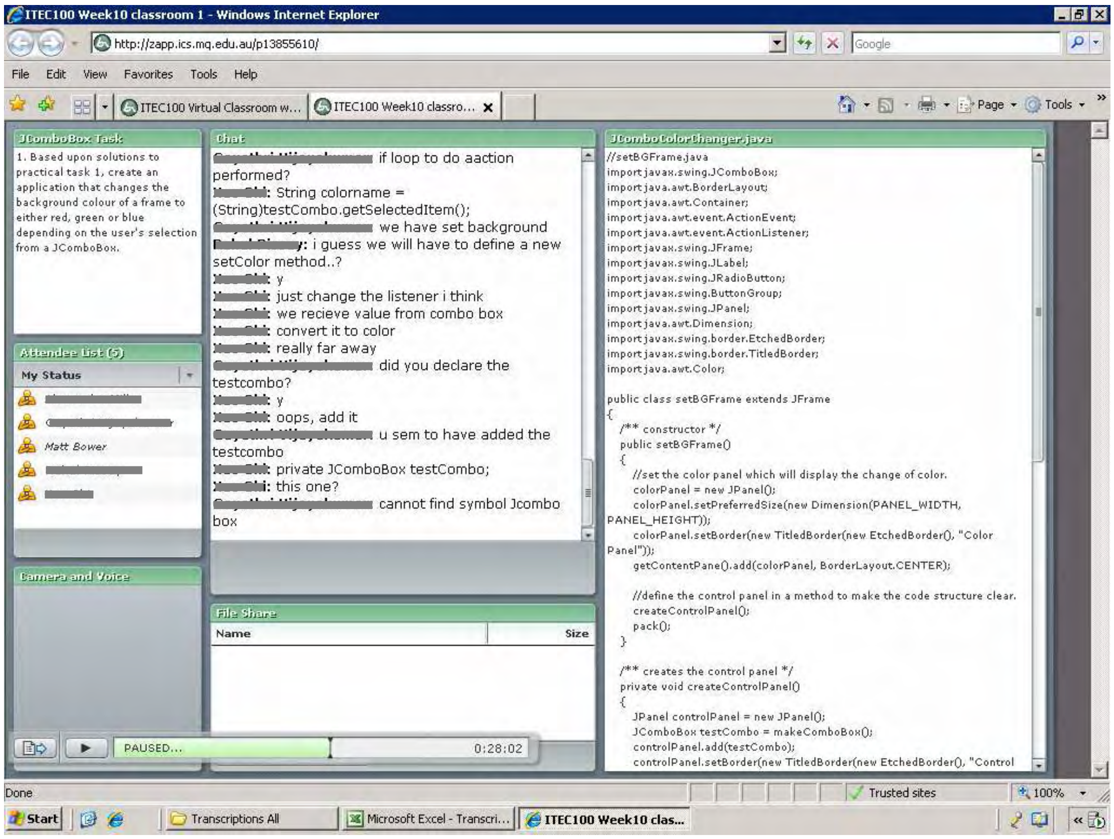

Figure 46 – Interface for Topic 10 Iteration 2 "RadioButton to ComboBox" episode

The teacher adopted a more facilitative role under this student-centred learning design than the teacher-led design of Iteration 1. The teacher concentrated on monitoring student progress rather than leading it, switching between the two student group-work rooms 12 times throughout the learning episode (ref. Table 32). The teacher used audio broadcast to encourage student contribution and occasionally make suggestions. The role of knowledge bearer was relinquished, with only 4% of teacher textual discourse being Content responses to students (6 out of 140 comments, ref. Table 10) as opposed to 18% in Iteration 1 (23 out of 126 comments, ref. Table 8). On the other hand 71% of teacher comments related to coordinating activity in this episode (100 out of 140 comments, ref. Table 10) as opposed to 24% in Iteration 1 (30 out of 126 comments, ref. Table 8).

The student-centred activity design enabled far greater student involvement. Students posted 147 textual discourse contributions using the chat pod, as compared to 64 in the teacher-led programming learning design of Iteration 1 (ref. Table 33). As well, the students in their two groups made 73 note-pod actions relating to creating the program (ref. Table 33), instead of the teacher making all the programming actions in Iteration 1 (60 in total, ref. Table 32).

T10_2006S1	Independent Question	Independent Statement	Question response to Question	Question Response to Statement	Statement Response to Question	Statement Response to Statement	Question Response to Action	Statement Response to Action	**Totals**
Content	0	13	0	0	3	3	0	1	**20**
Activity	13	42	0	1	0	3	0	4	**63**
Technology	0	0	0	0	0	0	0	0	**0**
Activity-Content	4	5	0	0	2	3	0	0	**14**
Activity-Technology	3	16	0	1	0	0	0	3	**23**
Activity-Content-Tech.	0	0	0	0	0	0	0	0	**0**
Content-Technology	0	0	0	0	0	0	0	0	**0**
Task sentiments/attitudes	0	6	0	0	0	6	0	0	**12**
Unrelated/Unclassifiable	0	8	0	0	0	0	0	0	**8**
Totals	**20**	**90**	**0**	**2**	**5**	**15**	**0**	**8**	**140**

Table 10 – Topic 10 Iteration 2 Subject-Interaction Counts for TEACHER textual discourse during learning episode

T10_2006S1	Independent Question	Independent Statement	Question Response to Question	Question Response to Statement	Statement Response to Question	Statement Response to Statement	Question Response to Action	Statement Response to Action	**Totals**
Content	9	11	0	7	14	2	0	0	**43**
Activity	6	10	0	3	16	11	1	2	**49**
Technology	0	0	0	0	0	0	0	0	**0**
Activity-Content	10	11	0	4	8	5	1	3	**42**
Activity-Technology	0	6	0	0	0	1	0	0	**7**
Activity-Content-Tech.	0	0	0	0	0	0	0	0	**0**
Content-Technology	0	0	0	0	0	0	0	0	**0**
Task sentiments/attitudes	0	0	0	0	1	2	0	0	**3**
Unrelated/Unclassifiable	0	1	0	0	1	1	0	0	**3**
Totals	**25**	**39**	**0**	**14**	**40**	**22**	**2**	**5**	**147**

Table 11 – Topic 10 Iteration 2 Subject-Interaction Counts for STUDENT textual discourse during learning episode

More coordination of activity was required by students under this learning design. Of the 147 student textual discourse contributions 66.7% were Activity related (49 Activity, 42 Activity-Content, 7 Activity-Technology, ref. Table 11). The larger than usual proportion of Activity-Content contributions were due to students negotiating with one another about how to collaboratively perform the problem solving process, with statements like “lets define the getSelected [method] now”. Only 29% of student textual discourse contribution were solely related to Content (43 out of 147, ref. Table 11), as opposed to 56% in Iteration 1 (36 out of 64, ref. Table 9). This is a highly significant difference ($\chi^2 = 13.9$, p = 0.0002, d.f. = 1, ref. Statistical Test 16). The teacher coordination role in the teacher-led programming design of Iteration 1 appeared to allowed students to focus more directly on Content than in the student-centred programming design where students were responsible for coordinating activity.

Students also adopted more control over the direction of learning under this student-centred activity design than in the teacher-led programming design of Iteration 1. Twenty-five out of 147 student textual discourse contributions were independently initiated questions (17%) as opposed to six from 64 or 9% in Iteration 1 (ref. Table 9, Table 11). As well, the majority of student responses to questions and statements were to their peers rather than to the teacher.

The duration of this student-centred episode was longer than for the teacher-led programming approach of Iteration 1 (32.75 minutes as opposed to 21.5 minutes). This can be explained in part by the collaborative overheads incurred in setting up the activity (organizing students into groups, move people to rooms, suggesting how students should commence with the task). As well, when the teacher was coordinating the activity in Iteration 1 he could choose to accelerate the pace of the learning episode as required, by "filling in the gaps". Thus it stands to reason that the student-led group-work approach should take longer.

The shared note-pod solutions space provided all students with equal access to the solution space, promoting heightened involvement. Because all students were responsible for constructing the solution, a truly negotiated meaning could be formed. The best aspects of students' understandings could be combined, leveraging the advantages of the distributed cognition approach. As well, the note-pod solution space filtered out activity related discourse which may have been mixed with programming code when students only used the text-chat modality to collaborate. This reduced extraneous cognitive load when attempting to focus on the solution. Finally the note-pod solution space allowed students to copy and paste several lines of program code at once, which was not possible using the text-chat pod during the teacher-led screen-sharing session of Iteration 1.

However there were trade-offs against the advantages of the note-pod approach to group programming. Students run into version control problems if they copy the code from the note-pod into their IDE and make adjustments – they have to merge these changes back into the note-pod. As well, scrolling on the note-pod is not synchronized between participants, meaning it is difficult to coordinate a common point. Further, the note-pod does not indicate the identity of the contributor or provide a way to focus attention on particular line of code. These last three factors all contribute to distributed process loss when using a note-pod solution space as opposed to a screen-share of the IDE. They also make the activity harder for the teacher to monitor.

Because students were engaged in an authentic and meaningful task that required them to complete all aspects of the problem solving process, the teacher was able to determine whether or not each group had achieved a relational understanding of the subject matter. Because the teacher was present during the process of students forming their understanding there is greater opportunity to provide cognitive support at the time it is most required (rather than merely reviewing solutions in retrospect). As a qualitative observation, the focus of student discussion in this exercise is at times both specific and conceptually deep.

5.2.3.3 Iteration 3

Activity Design: Group programming
Interface Design: Collaborative
Number of students: 3
Duration: 36 minutes

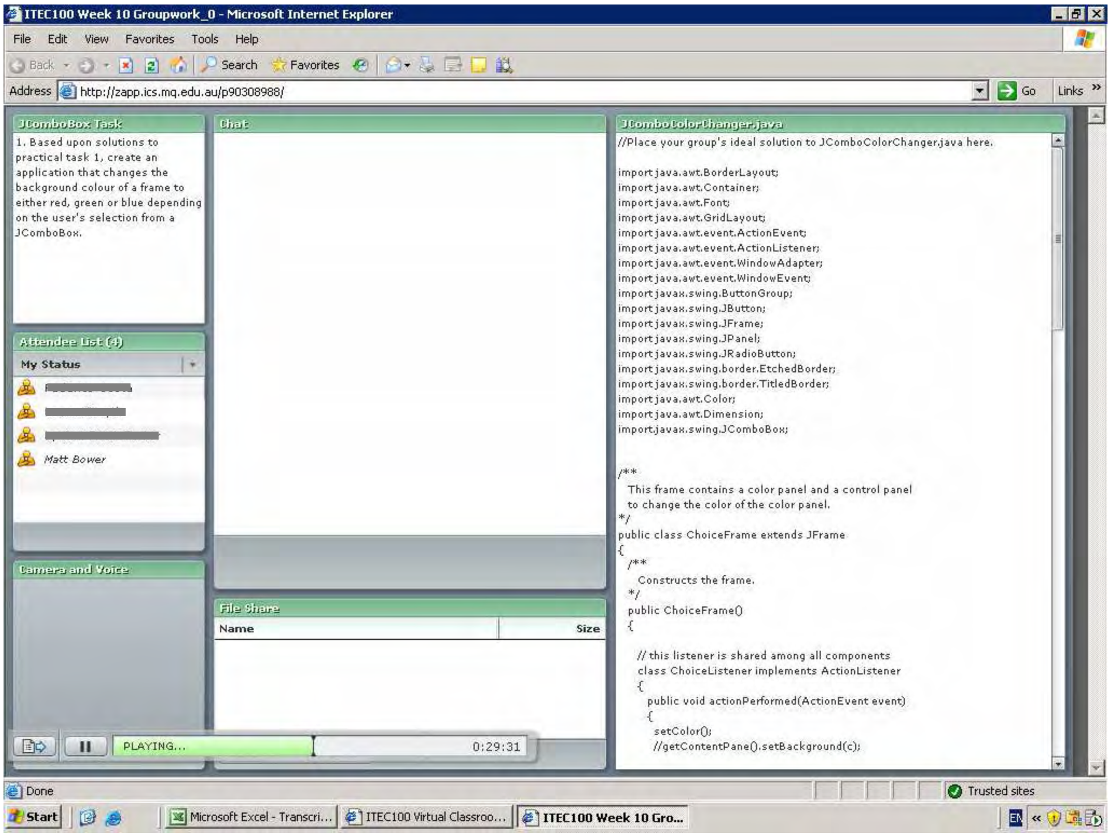

Figure 47 – Interface for Topic 10 Iteration 3 "RadioButton to ComboBox" episode

Brief Summary of Episode:
In this learning episode the same group-work room interface was used as in Iteration 2, except that all students used audio to collaborate (see Figure 47). The 263 student textual discourse contributions made through audio in Iteration 3 was a substantially greater number than the 147 in Iteration 2 and the 64 in Iteration 1 (ref. Table 33). It is worth noting that even though the duration of the Iteration 3 learning episode is 3.25 minutes or 10% longer than Iteration 2, there were only three students as opposed to seven. This provides evidence that audio may facilitate increased rates of collaboration in small group activities.

There was substantially less teacher textual discourse in this iteration than the previous two iterations of this task, even though Iteration 3 was the longest. In Iteration 3 the teacher made 60 comments over 36 minutes as opposed to 140 comments over 32.75 minutes in Iteration 2 and 126 comments over 21.5 minutes in Iteration 1 (ref. Table 32). This was in part due to the teacher's conscious effort to devolve as much control of the episode to students as possible.

As in Iteration 2, the facilitative role of the teacher is evidenced by high proportion (66%) of activity related textual discourse contributions (22 Activity, 6 Activity-Content, and 12 Activity-Technology, ref. Table 12). The Activity comments occurred more frequently at the commencement of the lesson, with statements such as "I'm going to say as little as possible and have you guys collaborate as much as possible". The Activity-Technology statements related to explaining how students should be both using audio and typing in the note-pod, and at one point asking whether they would prefer to be using screen-share (an offer that they declined). The teacher only made seven Content contributions throughout the entire 36 minute learning episode.

T10_2006S2	Independent Question	Independent Statement	Question response to Question	Question Response to Statement	Statement Response to Question	Statement Response to Statement	Question Response to Action	Statement Response to Action	Totals
Content	1	1	0	0	0	3	0	2	7
Activity	1	16	0	2	1	2	0	0	22
Technology	0	0	0	0	0	0	0	0	0
Activity-Content	1	3	0	1	1	0	0	0	6
Activity-Technology	3	8	0	0	0	1	0	0	12
Activity-Content-Tech.	0	0	0	0	0	0	0	0	0
Content-Technology	0	0	0	0	0	0	0	0	0
Task sentiments/attitudes	1	7	0	0	1	0	0	0	9
Unrelated/Unclassifiable	0	4	0	0	0	0	0	0	4
Totals	7	39	0	3	3	6	0	2	60

Table 12 – Topic 10 Iteration 3 Subject-Interaction Counts for TEACHER textual discourse during learning episode

T10_2006S2	Independent Question	Independent Statement	Question Response to Question	Question Response to Statement	Statement Response to Question	Statement Response to Statement	Question Response to Action	Statement Response to Action	Totals
Content	19	21	1	7	29	29	0	4	110
Activity	9	9	2	7	16	5	0	5	53
Technology	0	0	0	2	0	0	0	0	2
Activity-Content	20	29	0	5	14	14	0	3	85
Activity-Technology	0	0	0	0	3	0	0	0	3
Activity-Content-Tech.	0	0	0	0	1	0	0	0	1
Content-Technology	0	0	0	0	0	0	0	0	0
Task sentiments/attitudes	0	4	0	0	0	1	0	1	6
Unrelated/Unclassifiable	0	3	0	0	0	0	0	0	3
Totals	48	66	3	21	63	49	0	13	263

Table 13 – Topic 10 Iteration 3 Subject-Interaction Counts for STUDENT textual discourse during learning episode

On the other hand students were both taking ownership of their learning and performing substantial interaction with one another. Of the 263 student textual discourse contributions, 66 were Independent Statements and 48 were Independent Questions (ref. Table 13) demonstrating the control that students were exercising over the discussion. There was also a strong representation of Question Responses to Statements, Statement Responses to Questions and Statement Responses to Statements (21, 63, and 49, ref. Table 13) indicating the extent of interaction that was occurring between students. The discussion was able to focus on curriculum matter, with 195 of the 263 student textual discourse contributions being content related (110 Content contributions, 85 Activity-Content contributions, ref. Table 13).

Students again owned the solution space, making 29 note-pod non-textual discourse contributions as they collaboratively wrote the solution to the computer programming task (ref. Table 33). Note that in this iteration they were encouraged to use the convention of putting their initials preceded by a double forward slash at the end of a line of code in order to be able to identify the contributor to the note-pod each time. Not only is the file-share pod unused in Iteration 3, but neither is the text-chat pod since students make all of their 263 textual discourse contributions using audio (ref. Table 33). Potentially both of these pods could have been removed for the iteration using audio which would have allowed the solution space to be larger.

Audio was a synergistic modality to use in combination with the textual note-pod contributions. Audio could be used while students were contributing to the solution space without splitting students' attention, as was the case when the note-pod and text-chat were used together in Iteration 2 (Modality principle, Low & Sweller, 2005). The 13 Statement Response to Actions (ref. Table 13) mainly related to student responding to other students contributions to the note-pod as part of writing the solution computer program, such as "we need it [the instance field] down the bottom".

As in Iteration 2 the learning design led to a more complete revelation of students' mental models than in Iteration 1 and thus allowed the teacher to more accurately gauge students' level of understanding. The process based nature of the task meant that the teacher could observe students forming their mental models and interject with remedial instruction if necessary. It should also be noted that all the advantages and disadvantages of using a note-pod as compared to a screen-share for group programming that were identified in Iteration 2 apply to Iteration 3 as well.

5.2.4 Summary of Topic 10

From the above analysis and results it can be seen how:

- The shift from a teacher-led activity design in Iteration 1 to a student-centred design in Iteration 2 and Iteration 3 corresponded with heightened levels of student activity and discourse.
- Students took a more directive role in the student-centred learning design as compared to the teacher-led design, but incurred a collaborative overhead in order to coordinate their activity.
- Students' mental models were more completely revealed in the student-centred designs of Iteration 2 and 3, allowing the teacher to assess when student groups had achieved a relational understanding of the content.

- The use of the audio modality in Iteration 3 coincided with substantially greater rates of student contribution, as well avoiding the split attention caused in Iteration 2 by using the text-chat and note-pod in combination.
- The varying advantages and disadvantages of the note-pod solution space versus the screen-sharing of the IDE were able to be gauged, with the note-pod providing an equally accessible and format preserving shared space while the screen-share was able to more aptly portray programming process information and circumvent distributed process loss.
- Patterns of collaboration existed whereby teacher Activity statements introducing the exercise were more likely to appear at the outset of the episode, followed by Activity-Technology statements explaining how technology should be used to complete the task and Activity-Content statements relating to coordinating problem solving between people.

The multimodal discourse analysis was able to reveal the way in which the authentic, problem based task, an interface providing a shared working space and an activity requiring students to negotiate a solution influenced collaborations and learning. The successive refinements to the learning design between Iterations led to increased levels of collaboration and engagement with the task.

A complete account of the multimodal discourse data and analysis for all 24 learning episodes sampled is provided in Appendix B. Combining this data and analysis allows global results, learning design results and consolidated observations to be derived.

5.3 Global Results

5.3.1 Textual discourse

A total of 2241 teacher textual discourse contributions and 1584 student textual discourse contributions were coded in the transcripts. This equates to the teacher contributing 58.6% of comments students contributing 41.4% of comments during the learning episodes. Note that the range of teacher versus student textual discourse within the dataset varies greatly around these amounts.

5.3.1.1 Subject of textual discourse

The proportion of teacher textual discourse contributions and student textual discourse contributions classified by Subject category across all 24 learning episodes are represented in Figure 48 and Figure 49 respectively.

A Chi-square test for homogeneity of Teacher and Student proportions of Subject textual discourse types revealed a significant difference between Teacher and Student contributions ($\chi^2 = 60.3$, $p < 0.0001$, d.f. = 8, ref. Appendix B Statistical Test 17).

Individual Subject categories were analyzed to determine significant differences between Teacher and Student discourse using a Bonforroni adjusted significance level of $\alpha = 0.05 \div 9 = 0.00556$ to account for the 9 categories of Subject textual discourse types being examined. The results of this analysis are represented in Table 14.

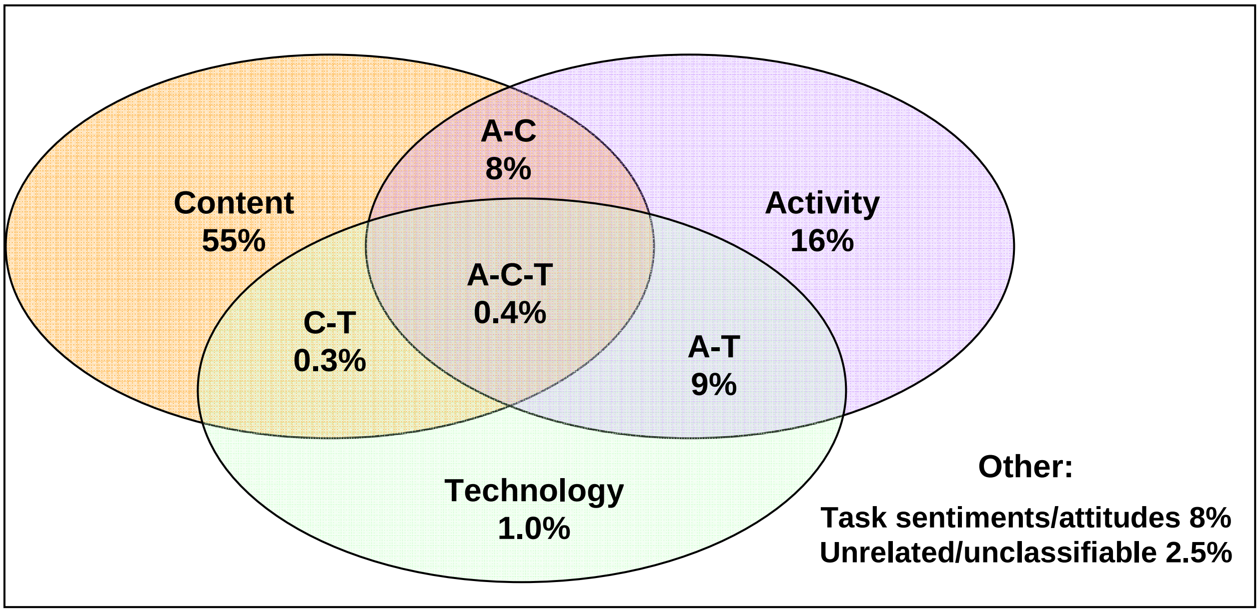

Figure 48 – Proportion of Teacher textual discourse by Subject type based on 2241 contributions (all episodes)

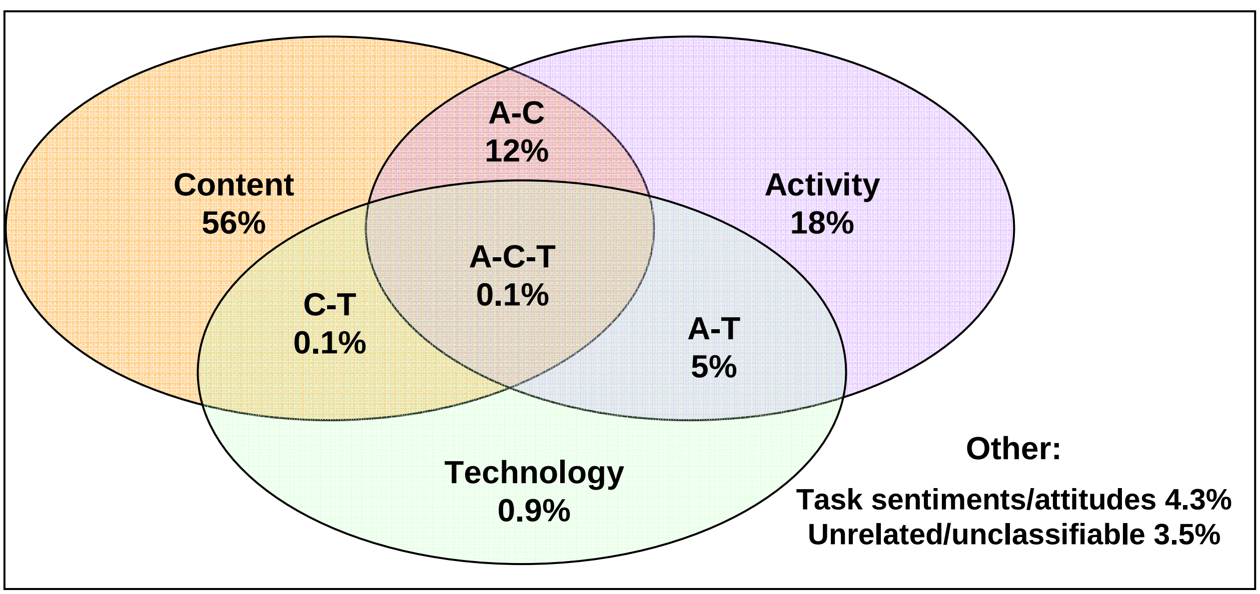

Figure 49 – Proportion of Student textual discourse by Subject type based on 1584 contributions (all episodes)

Subject	Ch-sqr	P-val
Content	0.17376	0.67679
Activity	3.39927	0.06523
Technology	0.01169	0.91391
Activity-Content	14.98032	0.00011*
Activity-Technology	16.70434	0.00004*
Activity-Content-Tech.	4.74980	0.02930
Content-Technology	2.12683	0.14474
Task sentiments/attitudes	20.12192	0.00001*
Unrelated/Unclassifiable	2.81611	0.09332

*Indicates a significant result at α = 0.00556 (all Chi-square tests executed with 1 d.f.)

Table 14 – Tests for homogeneity of Teacher and Student textual discourse by Subject category

The larger proportion of Activity-Content contributions by students as compared to the teacher (12% as opposed to 8%) can be explained by the group-work activities they undertake – when collaboratively problem solving students not only need to discuss what is to be done but also by whom.

The greater proportion of Activity-Technology contributions by the teacher as compared to students (9% as opposed to 5%) can be explained by the need for task instructions to establish how the technology is to be used, as well as the need to guide and troubleshoot during activities.

The greater proportion of task related sentiments and attitude contributions by the teacher as compared to students (8% as opposed to 4.3%) can be explained by the proactive teacher attempt to establish an encouraging learning environment and endow students with a positive attitude towards computing studies.

5.3.1.2 Nature of Interaction of textual discourse

The percentage of the 2241 teacher textual discourse contributions and 1584 student textual discourse contributions classified by Nature of Interaction category across all 24 learning episodes are represented in the following two tables:

GRAND TOTALS	Independent Question	Independent Statement	Question response to Question	Question Response to Statement	Statement Response to Question	Statement Response to Statement	Question Response to Action	Statement Response to Action	Totals
Teacher	**13.5%**	**55.2%**	**0.5%**	**1.8%**	**6.1%**	**18.0%**	**0.1%**	**4.7%**	**100.0%**
Students	**10.9%**	**25.4%**	**2.5%**	**4.3%**	**35.7%**	**17.8%**	**0.4%**	**3.0%**	**100.0%**

Table 15 – Teacher and Student proportions of textual discourse by Interaction type

A Chi-square test for homogeneity of Teacher and Student proportions of textual discourse classified by Interaction types revealed a significant difference (χ^2 = 699, p < 0.0001, d.f. = 7, ref. Appendix B Statistical Test 18).

Individual Interaction categories were once again analyzed to determine significant differences between Teacher and Student discourse. A Bonforroni adjusted significance level of $\alpha = 0.05 \div 8 = 0.00625$ was used to account for the 8 categories of Interaction textual discourse types being examined. The results of this analysis are represented in Table 16.

Nature of Interaction	Ch-sqr	P-val
Independent Question	5.75	0.01646
Independent Statement	337.94	0.00000*
Question response to Question	26.19	0.00000*
Question Response to Statement	21.28	0.00000*
Statement Response to Question	542.73	0.00000*
Statement Response to Statement	0.03	0.85843
Question Response to Action	4.92	0.02659
Statement Response to Action	7.18	0.00737

*****Indicates a significant result at $\alpha = 0.00625$ (all tests executed with 1 d.f.)

Table 16 – Tests for homogeneity of Teacher and Student textual discourse by Interaction category

The larger proportion of Independent Statement contributions by the teacher as compared to students (55.2% as opposed to 25.4%) can be explained by the instructive and directive role often assumed by the teacher.

The larger proportion of Question response to Question contributions by the students as compared to the teacher (2.5% as opposed to 0.5%) can be explained by the need for students to clarify understanding relating to questions posed in class, both of concepts being discussed and of the meaning of a particular question.

The larger proportion of Question response to Statement contributions by the students as compared to the teacher (4.3% as opposed to 1.8%) can be explained by the need for students to clarify the meaning of both content related discussions as well as those relating to task instructions.

The larger proportion of Statement response to Question contributions by the students as compared to the teacher (35.7% as opposed to 6.1%) can be explained by the large number of responses students provide during teacher-led question-response sequences.

Differentiating between Statements and Questions in the Interactive nature layer of coding allowed the effectiveness of teacher questioning as a strategy for promoting collaboration to be examined. Linear regression analyses were performed to determine whether the per-minute rate of Teacher Independent Questions in learning episodes influenced the per-student rates of contribution.

Initially a linear regression analysis of the rate of teacher Independent Questions to the per-student textual discourse contributions across the 24 learning episodes was performed. The results of these tests indicated no statistically significant correlation between the rate of teacher Independent Questions and the rate of per-student textual discourse (ref. Appendix B Statistical Test 19, $\hat{\beta} = -0.154$, $r^2 = 0.0243$, $p = 0.4671$). The low correlation between the two variables can be observed by inspecting the scatter-plot in Figure 50.

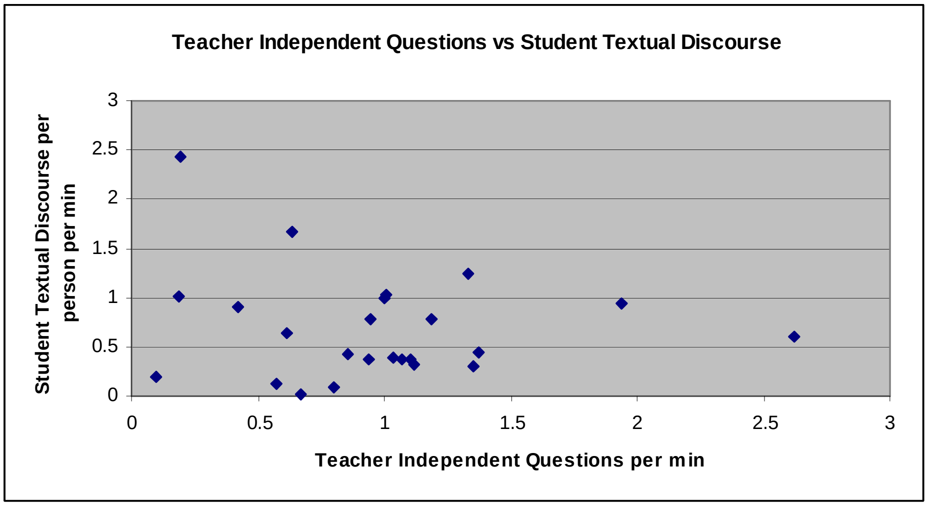

Figure 50 – Teacher Independent Questions versus per-student textual discourse across all episodes

However, a linear regression analysis of the rate of teacher Independent Questions per-minute against the per-student Student Responses to Questions per minute (both Statement and Question responses) resulted in a statistically significant positive correlation ($\hat{\beta}$ = 0.184, r^2 = 0.252, p = 0.0125, ref. Appendix B Statistical Test 20). Figure 51 illustrates this relationship between the rate of teacher Independent Questions per minute and the rate of per-student Responses to Questions per minute.

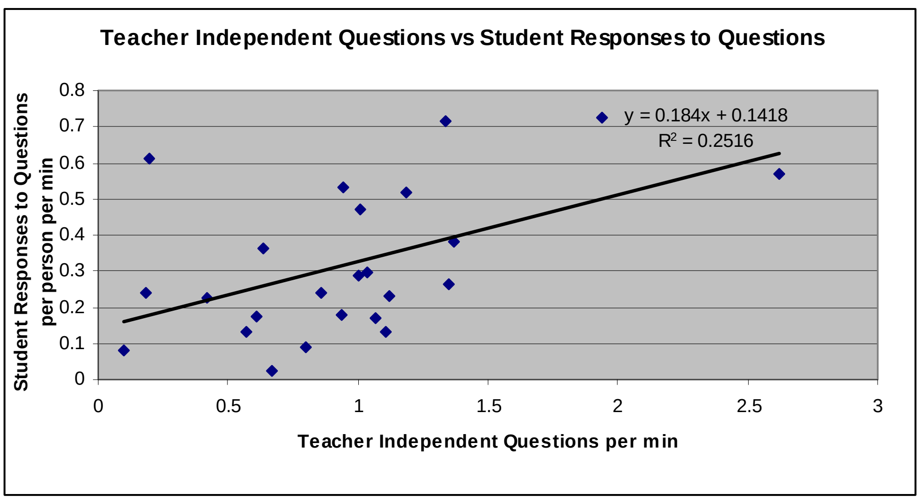

Figure 51 – Teacher Independent Questions versus per-student Responses to Questions

These results indicate that increasing the rate of teacher questioning may be an easily implemented strategy for increasing the rate of Student Responses to Questions, but when incorporated into a dataset containing group-work episodes, does not in itself lead to an increase in overall textual discourse.

The following factors should be taken into account when considering the results in this subsection:

- student Responses to Questions also include responses to questions of their peers
- teacher Independent Questions do not include task instructions (for instance, the teacher sentence "What are local variables in this program?" would be an Independent Question whereas "Tell me the local variables in this program" would be an Independent Statement). That is to say, while teacher Independent Questions by their nature always invited response, teacher Statements could in some cases be intended to encourage collaborations. Including these as part of the independent variable may lead to different results regarding the effectiveness of teacher prompting and levels of student collaborations.

5.3.1.3 Subject–Interaction profile of textual discourse

The Subject-Interaction profile of textual discourse contributions across all learning episodes is represented in Table 17 and Table 18 below. Cells containing a frequency of 5% or greater are represented in a heavier shade so they can be more easily discerned.

TEACHER	Independent Question	Independent Statement	Question response to Question	Question Response to Statement	Statement Response to Question	Statement Response to Statement	Question Response to Action	Statement Response to Action	Totals
Content	7.6%	28.8%	0.3%	1.0%	3.9%	11.8%	0.0%	1.7%	55.1%
Activity	1.6%	10.8%	0.1%	0.2%	0.6%	1.5%	0.0%	1.0%	15.8%
Technology	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	1.0%
Activity-Content	2.8%	3.3%	0.1%	0.2%	0.7%	1.1%	0.0%	0.3%	8.4%
Activity-Technology	0.9%	5.6%	0.1%	0.3%	0.2%	0.5%	0.0%	1.0%	8.6%
Activity-Content-Tech.	0.1%	0.3%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.4%
Content-Technology	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
Task sentiments/attitudes	0.4%	3.6%	0.0%	0.0%	0.4%	2.9%	0.0%	0.6%	7.9%
Unrelated/Unclassifiable	0.1%	2.0%	0.0%	0.0%	0.1%	0.3%	0.0%	0.1%	2.5%
Totals	13.5%	55.2%	0.5%	1.8%	6.1%	18.0%	0.1%	4.7%	100.0%

Table 17 – Subject-Interaction profile of Teacher discourse (all episodes)

STUDENT	Independent Question	Independent Statement	Question response to Question	Question Response to Statement	Statement Response to Question	Statement Response to Statement	Question Response to Action	Statement Response to Action	Totals
Content	4.5%	11.9%	1.8%	1.8%	24.7%	9.8%	0.2%	1.0%	55.7%
Activity	2.5%	4.8%	0.4%	1.2%	4.5%	3.8%	0.2%	0.6%	18.1%
Technology	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.3%	0.9%
Activity-Content	3.0%	3.9%	0.1%	0.7%	2.4%	1.6%	0.1%	0.5%	12.2%
Activity-Technology	0.4%	1.3%	0.1%	0.3%	2.5%	0.3%	0.0%	0.2%	5.1%
Activity-Content-Tech.	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%
Content-Technology	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Task sentiments/attitudes	0.0%	1.6%	0.0%	0.0%	0.9%	1.4%	0.0%	0.3%	4.3%
Unrelated/Unclassifiable	0.3%	1.6%	0.0%	0.2%	0.5%	0.8%	0.0%	0.0%	3.5%
Totals	10.9%	25.4%	2.5%	4.3%	35.7%	17.8%	0.4%	3.0%	100.0%

Table 18 – Subject-Interaction profile of Student discourse (all episodes)

Table 17 indicates the relative discursive emphasis of the teacher across the dataset. The main category of Subject-Interaction discourse contributed by the teacher was Independent Content Statements (28.8%), indicating the degree of emphasis on independently initiated explanation of curriculum matter. The teacher also attempted to engage students in Content related discourse (as indicated by the 7.6% Independent Content Questions) and would engage in Content discussions with students (11.8% Content Statement Responses to Statements). A relatively large proportion of teacher discourse is also dedicated to explaining to students how activity should be coordinated (10.8% Independent Activity Statements) and how to use the technology to coordinate activity (5.6% Independent Activity-Technology Statements).

On the other hand Table 18 indicates that nearly half of all student discourse related to Content Statements, either Independent (11.9%), responding to questions of others (24.7%) or responding to statements of others (9.8%). Compared to the teacher, students also contribute a higher proportion of Activity Statement Responses (4.5% Activity Statement Responses to Questions, 3.8% Activity Statement Responses to Statements), indicating the extent to which they negotiate activity as opposed to the teacher who more often directs activity.

5.3.1.4 Metacognitive contributions in textual discourse

A summary of the types of teacher and student metacognitive textual discourse contributions made throughout the learning episodes is provided in Table 34 (at the end of this Chapter). A correlation between teacher comments on the understanding and thinking of others and student comments relating to their own understanding and thinking can be observed in this table. The low frequency of data-points inhibited the use of statistical tests to validate this claim. However, review of the transcripts confirmed that student metacognitive self reflection was often pre-empted by teacher questions or statements regard their thinking and understanding.

5.3.1.5 Size of textual discourse contributions

It is worth noting that the size of the textual discourse contributions varied by contributor and media. The average number of words per audio sentence and text-chat contribution are represented in Table 19 and Table 20 respectively.

The average size of teacher audio sentences was 53% larger than that of students. This can be explained by the way in which the teacher used audio to provide elaborate task explanations and conceptual descriptions. The average size of student text-chat sentences was 38% larger than that of the teacher. This can be explained by the fact that in most cases text-chat is the primary mode of contribution for students, and so they at times need to provide more extensive descriptions or requests than the teacher. The teacher usually used text-chat to briefly reiterate a contribution that had already been made using audio.

Audio contributions are were average over double the length of text-chat contributions (9.9 words per sentence as opposed to 4.2 words, ref. Table 19 and Table 20). A potential reason that audio contributions were longer than text-chat contributions is the ease and pace with which contributions could be made (once audio was operational). This supports the argument for having students use audio (as in Iteration 3). As well, these results indicate that audio is suitable whenever more extensive contributions are required, whereas text-chat is suffice where only smaller contributions are needed.

	Number of Contributions ("sentences")	Amount of Contribution (words)	Average Size of Contribution (words)
Teacher	2195	23460	**10.7**
Students	549	3833	**7.0**
Total	**2744**	**27293**	**9.9**

Table 19 – Size of Textual Discourse for Audio Contributions

	Number of Contributions ("sentences")	Amount of Contribution (words)	Average Size of Contribution (words)
Teacher	38	118	**3.1**
Students	875	3758	**4.3**
Total	**913**	**3876**	**4.2**

Table 20 – Size of Textual Discourse for Text-chat Contributions

Combining results in Table 19 and Table 20 revealed that the average teacher contribution through the two media was approximately double the number of words of the average student contribution (10.6 words per sentence versus 5.3 words per sentence for students). This larger teacher contribution provides another measure of presence the teacher exerted within the learning episodes analyzed. Also, in most episodes the teacher used audio whereas students used text-chat, meaning the teacher could make larger contributions more easily.

5.3.2 Actions

The non-textual discourse contributions (Actions) made by the teacher and students in the learning episodes analyzed is represented in Table 21 below:

Action	Teacher	Student
Adjusting VC interface to better facilitate communication	35	16
Broadcasting document with Qs or As or content	17	0
Highlighting text with cursor to emphasize	76	2
Moving information between resources and pods	21	12
Moving of people between layouts and rooms	28	34
Note-pods non-textual discourse contributions	10	113
Recording lesson	6	0
Screen-share modelling programming	332	74
Unrelated to task	15	0
Whiteboard adding to and editing	58	33
Total	**598**	**284**

Table 21 – Summary of Teacher and Student Actions (all episodes)

The table illustrates the managerial role that the teacher has assumed over the technology (adjusting the virtual classroom interface to better facilitate communication and recording lessons). As well, the often instructive role of the teacher is evidenced (screen-share modelling programming, broadcasting document with questions or answers or content, highlighting text with cursor to emphasize). The use of collaborative learning designs in some episodes led to a large number of student non-textual discourse contributions through the note-pods (to write programs). This is the only action in the virtual classroom where student contribution outnumbered teacher contribution (except for moving between layouts and rooms, which is to be expected because there are more students). Students made contributions to the whiteboards and moved information between resources and pods, however these were outnumbered by equivalent teacher actions in the ratio of almost two to one.

5.3.3 Techno-pedagogic tactics

A summary of the techno-pedagogic tactics used across all learning episodes is provided in Table 22 below. This includes both textual discourse and action based contributions.

Audio repeating student text-chat to emphasize	47
Repeating own audio using text-chat to emphasize	12
Audio describing student actions to emphasize	7
Audio repeating student audio to emphasize	1
Highlighting text with cursor to emphasize	76

Table 22 – Teacher techno-pedagogic tactics observed (all episodes)

All techno-pedagogic tactics relate to emphasizing artifacts or discourse within the virtual classroom. Note that the first four categories of techno-pedagogic tactics relate to textual discourse contributions, while the last category "highlighting text with cursor to emphasize" is a pre-existing action category. No evidence was found to suggest that the use of techno-pedagogic tactics increased either during semester or across semesters. Nor was there any hard evidence indicating that techno-pedagogic tactics improved the efficiency or effectiveness of learning, although based on subjective review of the lesson recordings the use of techno-pedagogic tactics provided focus and reinforcement. In order to determine the existence of these effects a more controlled experimental design would need to be employed.

5.4 Learning Design Results

5.4.1 The Dimensions of Variation

Initially it was intended that statistical tests could be performed to determine differences in collaborative profiles along the following dimensions of variation:

1. Task Type (declarative, procedural, conceptual)
2. Interface (presentational, collaborative)
3. Activity Design (teacher-centred, teacher-led, student-centred)

However, after performing detailed analyses of the learning episodes it was immediately apparent that performing quantitative analysis along the Task Type and Interface dimensions contained inherent flaws relating to internal validity.

5.4.2 Rationale for not performing quantitative analysis along the Task Type dimension

It would be possible to run statistical comparisons of the amount and type of Subject-Interaction collaborations for different task types, however from reviewing these learning episodes in detail it was apparent that the effect of the task type (declarative, procedural, conceptual) was overshadowed by the activity design. For instance, to assume that the Subject-Interaction profile of the three "Nested-Loop Array Output" episodes was homogenous and should be grouped together would belie the fact that the teacher-led approach adopted in Iteration 3 resulted in substantially different discourse to the teacher-centred approaches of Iteration 1 and Iteration 2.

Any relationships that were detected between task type and the Subject-Interaction discourse would be both affected by and a result of the activity design that was implemented, and would thus be misleading. It is the responsibility of the researcher to detect the presence of intervening variables in order to uphold internal validity. Hence, although statistically significant results may have been achieved by analyzing how different task types affected discourse, it was the activity design that was associated with the task that would have been influencing the level and types of collaborations.

It should also be noted that categorizing task type into declarative, procedural and conceptual levels is a coarse generalization. There are many vastly different task types incorporated within each level. For instance a debugging task and a program writing task both focus on procedural knowledge, yet require vastly different levels of skill and understanding. To group them under one category of task type and claim that the category caused different types of discourse and activity would be misleading. As well, grouping such a small number of tasks as used in this study and proposing that they represent the entirety of a particular Level of Knowledge on Anderson and Krathwohls' (2001) Taxonomy of Assessment poses external reliability issues.

5.4.3 Rationale for not performing quantitative analysis along the Interface dimension

It would also be possible to run statistical comparisons of the amount and type of Subject-Interaction discourse for different interface designs for each episode, however it was once again immediately evident that the impact of the interface was secondary to the activity design implemented in the learning episodes. For instance, the collaborative interface for the shallow versus deep copy task in Iteration 1 Topic 9 provided a whiteboard that the students could have used to represent their understanding. However the teacher adopted a transmissive (teacher-centred) approach to instruction which entirely overshadowed any effect upon collaborations that may have been achieved by the interface design. This effect is observed in several other episodes, as outlined in Appendix B – Multimodal Discourse Analysis Summary of Data. Once again the activity design represents an intervening variable when analyzing the effect of the interface on the Subject-Interaction profile of textual discourse contributions, and as such statistical analysis with the interface type (either presentational or collaborative) as the independent variable was not performed in order to uphold the internal validity of the analysis.

The fact that the effect of the interface was overshadowed by the interactive approach engaged by the teacher does not imply that interface design cannot have an effect on collaborations, ceteris paribus. The interface can make a critical difference to how people collaborate, depending on adherence to multimedia learning principles and sensible combinations of modalities. However, the actual approach to interaction that the teacher engaged in each learning episode was observed to override the effect of the interface, which discounts the credibility of statistical analysis performed based on the interface design.

It should also be noted that to perform statistical comparisons based on classification of interfaces as collaborative versus presentational would be a gross simplification that fails to acknowledge subtle effects of interface design at the level described in Appendix B. More useful than solely using quantitative data to analyze the efficacy of different interface designs are qualitative interpretations drawn from performing a quantitative analysis, which has been provided in the next section titled "Consolidated Observations".

5.4.4 Analysis along the Activity Design dimension

From the review and analysis of the 24 learning episodes it appeared that the activity designs were a direct causal influence on collaborations, thus allowing statistical analysis to proceed without concern for internal validity. The activity design for each of the 24 learning episodes is summarized in Table 23.

Learning Episode	Task Description	Activity Design	# Students	Time Taken
Topic 01 Iteration 1	Debug Cube Program	teacher-led	9	7
Topic 01 Iteration 2	Debug Cube Program	teacher-led	11	6.25
Topic 01 Iteration 3	Debug Cube Program	teacher-led	2	10.5
Topic 02 Iteration 1	Distinguish Program Features	teacher-led	8	7.25
Topic 02 Iteration 2	Distinguish Program Features	student-centred	8	27.25
Topic 02 Iteration 3	Distinguish Program Features	student-centred	3	27.5
Topic 03 Iteration 1	Write SoftDrinkCan Program	teacher-led	8	18.5
Topic 03 Iteration 2	Write SoftDrinkCan Program	student-centred	9	19
Topic 03 Iteration 3	Write SoftDrinkCan Program	teacher-led	3	17
Topic 04 Iteration 1	Applet Comprehension Questions	teacher-led	9	8.75
Topic 04 Iteration 2	Applet Comprehension Questions	student-centred	8	17.25
Topic 04 Iteration 3	Applet Comprehension Questions	student-centred	3	7
Topic 09 Iteration 1	Shallow vs Deep Copies	teacher-centred	9	11.75
Topic 09 Iteration 2	Shallow vs Deep Copies	teacher-centred	7	8.5
Topic 09 Iteration 3	Shallow vs Deep Copies	student-centred	4	6.75
Topic 10 Iteration 1	RadioButton to ComboBox	teacher-led	8	21.5
Topic 10 Iteration 2	RadioButton to ComboBox	student-centred	7	32.75
Topic 10 Iteration 3	RadioButton to ComboBox	student-centred	3	36
Topic 11 Iteration 1	Nested Loop Array Output	teacher-centred	9	4.5
Topic 11 Iteration 2	Nested Loop Array Output	teacher-centred	6	10.5
Topic 11 Iteration 3	Nested Loop Array Output	teacher-led	2	27.75
Topic 12 Iteration 1	Adjust FileReader	teacher-centred	9	5
Topic 12 Iteration 2	Adjust FileReader	teacher-led	7	11.5
Topic 12 Iteration 3	Adjust FileReader	teacher-led	3	6.75

Table 23 - Table of activity design classifications for all learning episodes

In order to compare and contrast learning episodes it was necessary for standardizations to be performed on the following levels:

1. Duration of learning episodes
2. Number of students in each learning episode.

If learning episodes were not standardized based on their duration, longer episodes could not be compared to shorter episodes in terms of their Subject-Interaction profile. To account for this the teacher and student Subject-Interaction matrices were divided by the duration in minutes to determine a rate of contribution per minute for each of the cells.

As well, student Subject-Interaction matrices were divided by the number of students to derive per-student contributions per minute for each of the matrix cells. Measuring per-student contributions per person per minute as opposed to total student contributions per minute accounts for biases to contribution rates caused by having more students in one learning episode than another, thus allowing for more accurate comparison and contrast of episodes. As well, measuring per person activity allows individual involvement in each learning episode to be gauged.

The results of performing these standardizations and then averaging across all 24 learning episodes for teachers and students is represented in Table 24 and Table 25.

TEACHER	Independent Question	Independent Statement	Question response to Question	Question Response to Statement	Statement Response to Question	Statement Response to Statement	Question Response to Action	Statement Response to Action	**Totals**
Content	0.547	2.207	0.020	0.092	0.234	0.882	0.002	0.129	**4.112**
Activity	0.082	0.655	0.005	0.009	0.024	0.084	0.002	0.058	**0.918**
Technology	0.004	0.059	0.000	0.004	0.002	0.004	0.000	0.004	**0.075**
Activity-Content	0.237	0.207	0.005	0.015	0.031	0.059	0.000	0.013	**0.569**
Activity-Technology	0.052	0.296	0.004	0.018	0.013	0.040	0.000	0.057	**0.479**
Activity-Content-Tech.	0.006	0.019	0.000	0.000	0.003	0.000	0.000	0.000	**0.028**
Content-Technology	0.002	0.013	0.000	0.000	0.002	0.000	0.000	0.000	**0.016**
Task sentiments/attitudes	0.028	0.233	0.000	0.000	0.024	0.200	0.000	0.061	**0.546**
Unrelated/Unclassifiable	0.004	0.141	0.000	0.000	0.003	0.018	0.000	0.003	**0.170**
Totals	**0.961**	**3.830**	**0.034**	**0.138**	**0.336**	**1.286**	**0.003**	**0.326**	**6.913**

Table 24 – Rates of teacher textual discourse contributions per minute, averaged across all 24 learning episodes

PER-STUDENT	Independent Question	Independent Statement	Question response to Question	Question Response to Statement	Statement Response to Question	Statement Response to Statement	Question Response to Action	Statement Response to Action	**Totals**
Content	0.027	0.065	0.019	0.012	0.217	0.087	0.002	0.006	**0.435**
Activity	0.011	0.025	0.002	0.007	0.024	0.017	0.001	0.003	**0.091**
Technology	0.002	0.002	0.002	0.001	0.001	0.000	0.000	0.001	**0.009**
Activity-Content	0.015	0.020	0.000	0.003	0.013	0.008	0.000	0.002	**0.061**
Activity-Technology	0.003	0.007	0.002	0.001	0.018	0.001	0.000	0.001	**0.034**
Activity-Content-Tech.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**
Content-Technology	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	**0.001**
Task sentiments/attitudes	0.000	0.010	0.000	0.000	0.016	0.009	0.000	0.002	**0.037**
Unrelated/Unclassifiable	0.002	0.008	0.000	0.001	0.003	0.005	0.000	0.000	**0.019**
Totals	**0.059**	**0.137**	**0.027**	**0.025**	**0.292**	**0.127**	**0.003**	**0.016**	**0.687**

Table 25 – Rates of per-student textual discourse contributions per minute, averaged across all 24 learning episodes

From these tables it can be seen that when the average teacher contribution per minute across all 24 learning episodes was averaged, the measure was ten times the average per student contribution rate per episode (average of the teacher contribution rates per episode = 6.913 contributions per minute, average of the per student contribution rates per episode = 0.687 contributions per minute). Note that rates of contribution in these tables are unweighted by topic duration, meaning longer topics do not count for more in these calculated averages than shorter topics.

Calculating average teacher and per-student textual discourse contributions per minute classified by activity designs revealed differences as represented in Table 26.

	Teacher-centred	Teacher-led	Student-centred
Teacher	6.0936	8.6068	5.0969
Per-student	0.1607	0.5858	1.1538

Table 26 – Rates of teacher and per-student textual discourse by activity design

These rates are represented graphically in Figure 52.

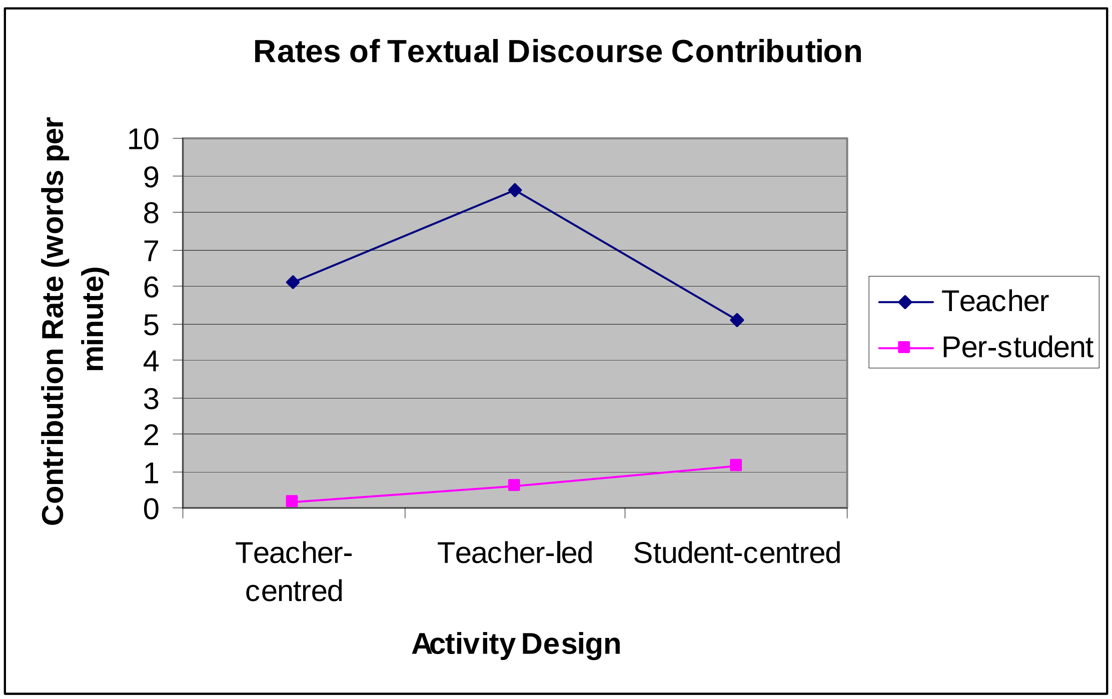

Figure 52 – Rates of teacher and per-student textual discourse by activity design

One-way analysis of variance was conducted to determine whether there were statistically significant differences in the total contribution rates between the three activity designs (teacher-centred, teacher-led, and student-centred). The results of these tests indicated that there was a highly significant difference between the rates of teacher textual discourse between the activity designs ($F = 11.52$, $p = 0.0004$, ref. Appendix B Statistical Test 21). As well, there was a highly significant difference between the per-student rates of textual discourse between activity designs ($F = 9.20$, $p = 0.0013$, ref. Appendix B Statistical Test 22).

In order to determine where these differences between activity designs lay, two-tailed Student T-tests were conducted on the three permutations of activity design pairs. Based on a Bonferroni adjusted significance level of 0.05/3 = 1.67%, the following teacher results were observed:

- a significant difference between the average rate of teacher contribution for the teacher-centred and teacher-led activity designs (T = -3.779, p = 0.0020, ref. Appendix B Statistical Test 21), with the teacher-led rate being larger.
- a significant difference between the average rate of teacher contribution for the teacher-led and student-centred activity designs (T = 4.267, p = 0.0005, ref. Appendix B Statistical Test 21), with the teacher-led rate once again being larger.

The fact that there was no significant difference between the average of the rates of teacher textual discourse contributions for the teacher-centred and student-centred (T = 0.951, p = 0.3619, ref. Appendix B Statistical Test 21) was surprising. However as later analysis reveals, under student-centred activity designs the Subject-Interaction profile of the teacher's discourse is less content based and more related to managing activity and technology than in the teacher-centred design.

As well, the average of the rates of teacher textual discourse contribution for the teacher-led activity design was higher than the rates for the teacher-centred rate, which defied expectations (as one would expect there to be more teacher sentences per minute if the teacher was adopting a predominantly transmissive approach). Two possible explanations for this are that the teacher was pausing and talking more slowly in teacher-centred designs, or that longer sentences were used in teacher-centred designs.

Table 27 provides the average sentence length for the different learning designs, and it can be seen that the average teacher sentence length for teacher-centred activity designs is over 29% longer than for teacher-led activity designs.

	Teacher	Students
Teacher-centred	12.81	5.03
Teacher-led	9.92	4.74
Student-centred	10.75	6.20

Table 27 – Average textual discourse sentence length for different activity designs

This implies that the amount of teacher textual discourse in words per minute for teacher-centred activity designs is actually 78.1 words per minute as opposed to 85.3 words per minute for the teacher-led designs (reducing the relative difference in teacher textual discourse contribution between the two designs). Still, discounting longer words being used it appears that the teacher must have been speaking more slowly and/or making greater pauses in the teacher-centred activity designs. A manual review of the transcripts and learning episodes validated this conjecture; the teacher-led designs appeared to have a more kinetic energy as a result of being more conversational.

Equivalent analysis of the per-student textual discourse rates at the same 1.67% significance level yielded the following results:

- a significant difference between the average rate of per-student contribution for the teacher-centred and teacher-led activity designs (T = -2.762, p = 0.0153, ref. Appendix B Statistical Test 22), with a 265% larger rate of per-student contributions for the teacher-led design.
- a significant difference between the average rate of per-student contribution for the teacher-centred and student-centred activity designs (T = -3.565, p = 0.0044, ref. Appendix B Statistical Test 22), with a 618% larger rate of per-student contributions for the student-centred design.
- no significant difference between the average rate of per-student contribution for the teacher-led and student-centred activity designs (T = -2.646, p = 0.0170, ref. Appendix B Statistical Test 22), with the teacher-led rate once again being larger. (Note that this is a borderline result, with a 0.003 difference between the critical p-value and that of the test statistic.)

Individual Subject and Interaction contribution rates for teachers and students were examined in an attempt to determine whether these differences in contribution rates could be attributed to a particular type of discourse (see Table 28 through to Table 31).

TEACHER	**Teacher-centred**	**Teacher-led**	**Student-centred**
Content	3.8093	5.9780	1.7361
Activity	0.5201	0.7634	1.3798
Technology	0.2563	0.0033	0.0605
Activity-Content	0.6259	0.6389	0.4370
Activity-Technology	0.2388	0.3578	0.7963
Activity-Content-Tech.	0.0170	0.0152	0.0527
Content-Technology	0.0170	0.0098	0.0231
Task sentiments/attitudes	0.5051	0.5925	0.5075
Unrelated/Unclassifiable	0.1042	0.2479	0.1040
Total	**6.0936**	**8.6068**	**5.0969**

Table 28 – Average of rates of teacher contribution by Subject type for different activity designs

TEACHER	**Teacher-centred**	**Teacher-led**	**Student-centred**
Independent Question	0.6139	1.3470	0.6472
Independent Statement	4.4281	4.3598	2.7264
Question Response to Question	0.0361	0.0453	0.0182
Question Response to Statement	0.1191	0.1926	0.0734
Statement Response to Question	0.2433	0.4138	0.2859
Statement Response to Statement	0.6360	1.8457	0.9239
Question Response to Action	0.0000	0.0000	0.0091
Statement Response to Action	0.0170	0.4026	0.4128
Totals	**6.0936**	**8.6068**	**5.0969**

Table 29 – Average of rates of teacher contribution by Interaction type for different activity designs

STUDENT	Teacher-centred	Teacher-led	Student-centred
Content	0.0899	0.4367	0.6482
Activity	0.0279	0.0344	0.2069
Technology	0.0019	0.0092	0.0119
Activity-Content	0.0032	0.0193	0.1543
Activity-Technology	0.0208	0.0280	0.0516
Activity-Content-Tech.	0.0000	0.0000	0.0012
Content-Technology	0.0000	0.0016	0.0000
Task sentiments/attitudes	0.0113	0.0439	0.0436
Unrelated/Unclassifiable	0.0057	0.0126	0.0362
Total	**0.1607**	**0.5858**	**1.1538**

Table 30 – Average of rates of per-student contribution by Subject type for different activity designs

STUDENT	Teacher-centred	Teacher-led	Student-centred
Independent Question	0.0051	0.0246	0.1402
Independent Statement	0.0297	0.0773	0.2866
Question Response to Question	0.0103	0.0369	0.0225
Question Response to Statement	0.0032	0.0163	0.0515
Statement Response to Question	0.0903	0.3442	0.3465
Statement Response to Statement	0.0164	0.0742	0.2692
Question Response to Action	0.0000	0.0043	0.0044
Statement Response to Action	0.0057	0.0082	0.0329
Totals	**0.1607**	**0.5858**	**1.1538**

Table 31 – Average of rates of per-student contribution by Interaction type for different activity designs

Statistical analysis was performed to determine whether there were significant differences in rates for any of the Subject or Interaction types. These tests yielded the following results:

1. There was a significantly lower mean rate of teacher Content textual discourse contribution per minute for the student-centred as opposed to the teacher-led activity design (with respective averages of 1.736 and 5.978 sentences per minute, ref. Appendix B Statistical Test 23). This illustrates the teacher delegation of responsibility for Content discussions to the students for the student-centred design.
2. There was a significantly higher mean rate of per-student Content textual discourse contribution for the student-centred as opposed to the teacher-centred activity designs (with respective averages of 0.648 and 0.090 sentences per minute, ref. Appendix B Statistical Test 24). This indicates the increase in student ownership over content in the student-centred as opposed to teacher-centred activity designs.
3. There was a borderline significantly lower mean rate of per-student Content textual discourse contribution for the teacher-centred versus teacher-led activity designs (with respective averages of 0.090 and 0.437 sentences per minute, ref. Appendix B Statistical Test 24). Once again, the teacher-centred activity design inhibits the rate of student Content textual-discourse contribution.
4. There was a significantly higher mean rate of teacher Independent Questions for the teacher-led as opposed to student-centred activity design (with respective averages of 1.347 and 0.647 sentences per minute, ref. Appendix B Statistical Test 25). In the teacher-led activity design the teacher attempts to involve students by positing

questions, whereas in the student-centred activity design there is less need because students are automatically involved by the nature of the task.

5. There was a significantly higher mean rate of teacher Independent Statements for the teacher-led as opposed to student-centred activity type (with respective averages of 4.360 and 2.726 sentences per minute, ref. Appendix B Statistical Test 25). In the student-centred activity design the teacher does not need to make as many directive and instructive comments.
6. There was a significantly lower mean rate of per-student Statement Response to Questions for the teacher-centred as opposed to student-centred activity types (with respective averages of 0.090 and 0.346 sentences per minute, Appendix B Statistical Test 26). Students are seldom responding to questions in the teacher-centred activity design, whereas in the student-centred design they have the chance to respond to the questions of both the teacher and each other.

Note that for Statistical Test 23 through to Statistical Test 26 Bonforroni adjusted significance levels have been applied to account for the large number of comparisons being drawn.

The results of performing the quantitative analysis above should considered in light of the following qualifications:

- In each learning episode there was a range of affecting factors (such as student virtual classroom competencies, the specific details of the teacher implementation, the particular students involved in the learning episode and so on) that impact upon collaborations and thus comprise part of the error in this analysis.
- The sample is only a small subset of learning episodes in three particular semesters, by one teacher in one subject, and as such cannot be considered representative of all activity designs. The external reliability of extrapolating these results to other educational contexts needs to be carefully considered.

5.4.5 Rationale for not performing analysis between Iterations and between half semesters

Initially it was intended that the structured sampling process adopted in this study could be used to perform quantitative analysis of:

1. Differences in discourse between iterations (to gauge the efficacy of learning design refinements between semesters as part of the design research process)
2. Differences in discourse between the first half and the second half of each semester (to gauge developments in contribution types and rates over time).

Upon detailed review of the data an analysis of the difference in collaborations between iterations could not be performed because the number of episodes sampled in each iteration was both small and not random (and thus not representative). For instance, for the Topic 3 task analyzed a student-centred approach is used in Iteration 2 but a teacher-led approach is used in Iteration 3 (due to time restrictions). As well, teacher-centred approaches are used in Iteration 2 for both the Topic 9 and Topic 10 tasks. The sample allowed the effects of different learning designs to be measured, but the small number of learning designs sampled did not necessarily represent the approaches of the iteration from which they were drawn.

Differences between amount and type of collaboration for the first half and second half of semester lessons was critically influenced by the particular activities that were implemented. The "Debugging Cube", "Distinguish Program Features", "Write SoftDrinkCan" and "Applet Comprehension" tasks of the first half of each semester comprised entirely different activities and learning designs than the "Shallow versus Deep Copy", "RadioButton to ComboBox", "Nested Loop Array", "Adjust File Reader" of the second half of semester, and thus any statistical comparisons would be unduly exposed to the effect of intervening variables.

5.5 Consolidated Observations

Integrating qualitative observations from across the 24 learning episodes provides a point of comparison and contrast with the global quantitative results, allowing a more holistic understanding of teaching and learning in web-conferencing environments to be formed. The major interpretivistic themes that have emerged are presented below, along with specific supporting evidence from the learning episodes in which they have been observed (ref. Appendix B - Multimodal Discourse Analysis Summary of Data).

5.5.1 Design of the web-conferencing environment

There were several ways in which the design of the web-conferencing environment was observed to affect collaborations and learning. Firstly, the provision of a dedicated solution space in the Iteration 2 and Iteration 3 design revisions for the "Distinguish Program Features" and "Applet Comprehension Questions" tasks allowed Content to be separated from Activity- and Technology-related contributions. This meant that the negotiated solution could be reviewed without the extraneous cognitive load (van Merriënboer & Ayres, 2005) of separating it from coordinating collaborations. The dedicated solution space acted as a filter that alleviated the need for students to manually separate out this information.

Audio was observed to allow students to more easily contribute extended items of textual discourse than text-chat, often resulting in greater levels of contribution. Iteration 2 of the "Applet Comprehension Questions" task provided an example of how audio paired more effectively than text-chat with visual modes of communication such as note-pods and whiteboards. Using audio allows people to utilize their dual processing capabilities (Low & Sweller, 2005) and avoid split attention (Ayres & Sweller, 2005). Audio when paired with note-pods or whiteboards allows the multimedia principle (Fletcher & Tobias, 2005) and the modality principle (Low & Sweller, 2005) to be leveraged.

For instance, the whiteboard combined with audio to provide an effective "multimedia cluster" (Baldry & Thibault, 2006) for representing in Iteration 3 of the "Nested Loop Array Output" task. Students described their forming ideas and coordinated their actions using audio, at the same time as they represented their shared notional machine (du Boulay, O'Shea, & Monk, 1989) mental model on the whiteboard. The whiteboard made it possible for students to dynamically organize and represent their conceptions of how all parts of the system interrelated, which in turn allowed the teacher to assess the level of understanding they had achieved. The whiteboard was also able to facilitate this in Iteration 3 of the "Shallow versus Deep Copy" task. The visual representation afforded by the whiteboard offloads cognition to the environment, allowing shared understanding to be negotiated in a more cognitively efficient way than if audio alone was used. As well, the capacity to highlight information on the whiteboard using colour and size reduced the need for coordinating discourse.

Designing effective interfaces depended on the capacity to anticipate patterns of collaboration. If substantial text-chat collaboration was expected then increasing the size of the chat-pod will allow more conceptions to be displayed at once (as demonstrated in the transition from Iteration 1 to Iteration 2 of the "Debug Cube" task). Pre-designing the whiteboard interface for Iteration 3 of the "Shallow versus Deep Copy" task allowed the activity to be completed in far less time than the previous two iterations. On the other hand failing to anticipate how not having audio would impact on the student-centred screen-sharing activity for Iteration 2 of the "Write SoftDrinkCan" task compromised the effectiveness of collaboration and learning.

There are some cases in which the use of one multimodal cluster over another is highly context sensitive. For instance, whether a note-pod approach is more appropriate than a screen-share approach to group programming may depend on the extent to which students have acquired programming process knowledge (how to use the IDE), their level of web-conferencing collaborative competencies, and their capacity to manage distributed process loss. This is discussed in the Topic 10 Iteration 2 episode summary.

Subtle affordance attributes embedded in the web-conferencing tools can affect the nature of the discourse and hence the learning design applied. For instance, in Iteration 1 and 2 of the "Shallow versus Deep Copy" task, difficulty using the whiteboard tool led to unnecessary activity and technology discourse. This meant the students (and the teacher) were less able to focus on discussing the curriculum matter content (object) being studied.

5.5.2 Design and implementation of the activities

Similar learning designs were shown to result in similar patterns of collaboration across iterations (and thus across student cohorts). This is particularly notable in the "Debug Cube Program" task of Topic 1 where there were no significant differences in the Subject profile of student discourse between the three iterations using the same learning design. The fact that in Iteration 3 there were only two students using audio whereas in Iterations 1 and 2 there were 9 and 11 students respectively using text-chat still did not lead to a different collaborative profile. Similarly, the teacher-led approaches to implementing the "Write SoftDrinkCan" task in Iteration 1 and 3 led to significantly different collaborative profiles to the student-centred approach of Iteration 2, but not to each other.

Student-centred activity designs allow students to evidence they have achieved a relational level of task understanding (for instance, Iteration 3 of the "Shallow versus Deep Copy" task, and Iteration 2 and 3 of the "RadioButton" to "ComboBox" task). When students are required to collaboratively sequence and combine all aspects of a problem solving task they demonstrate that they not only that they have acquired all items of knowledge associated with the curriculum matter but that they have an understanding of how the elements interrelate. As well, the conversations that occur while groups of students negotiate solutions under student-centred approaches allows the teacher to observe the process of students forming understandings, enabling more timely and appropriate feedback to be provided.

Teacher-led approaches only allow a multistructural level of understanding to be evidenced (for instance, all iterations of the "Debug Cube Program" task or Iteration 1 of the "RadioButton to ComboBox" task). When the teacher solicits items of information from students and uses those knowledge items to perform the problem solving process then students are not provided with the opportunity to represent all relations between the pieces of information.

Teacher-centred approaches at best revealed a unistructural student understanding. The low levels of student contribution prohibit their mental models from being extensively represented. Thus teacher-centred approaches are suitable for declarative tasks. Diagnosis of unistructural understanding is normally attempted by asking students for declarative responses to a single question. See for example Iteration 1 of the "Nested Loop Array" task.

The teacher dictated the amount of space that students are afforded and hence their degree of contribution to the learning episode. This was a pervasive theme. For instance, the highly transmissive approach in Iteration 2 of the "Shallow versus Deep Copy" task, in Iteration 1 of the "Nested Loop Array" task, and Iteration 1 of the "Adjust FileReader" task corresponded with low levels of student contribution. Similarly, in both the "Distinguishing Program Features" and "Applet Comprehension Questions" tasks the increased teacher dominance in Iteration 3 coincided with lower levels of student contribution than in Iteration 2. Note that the teacher domination of a whiteboard space can also reduce levels of student contribution, as exemplified in Iterations 1 and 2 of the "Shallow versus Deep Copy" task as compared to Iteration 3.

Student-centred approaches often required more time than instructive approaches, but increased the amount and changed the type of student contributions. For instance, for the "RadioButton to ComboBox" task the group programming learning designs of Topic 10 Iteration 2 and Iteration 3 resulted in a large number of independent questions and statements (indicating student ownership), and large amounts of student responses to other students (collaborative problem solving) as compared to the teacher-led programming design of Iteration 1. Similarly in the student-centred approach to the "Distinguishing Programming Features" task in Iteration 2 and Iteration 3 of Topic 2, the collaborative approaches take significantly longer than in Iteration 1 due to the overheads of coordinating activity and collaborative technology. However this also allows students to take more responsibility for the learning process, leading to more questions and responding to other people's questions. The rate of Content based contributions in both Topic 2 and Topic 10 increased as a result of implementing the student-centred activity design. The teacher's role changes from one of knowledge bearer to facilitator, as indicated by the shift from Content comments to a relatively higher proportion of Activity and Technology based comments (reference Topic 3, Topic 4, Topic 10).

The teacher could encourage greater student contribution. In Iteration 3 of the "RadioButton to ComboBox" the teacher's explication of their intention to leave the collaborative space to students corresponds to high levels of student collaboration. The teacher attempt to prompt student discussion by asking questions in Iteration 2 of the "Adjust FileReader" task appeared to encourage student contribution. However, as previously noted, engaging teacher-led approaches such as that in Iteration 2 of the "Adjust FileReader" task tend to result in more responsive discourse, whereas establishing student-centred approaches such as in Iteration 3 of the "RadioButton to ComboBox" task led to more independent and student directed learning.

Teacher preparation can also have a critical effect on collaboration. In the Iteration 2 of the "Nested Loop Array" task the lack of teacher rehearsal and preparation leads to unanticipated problems regarding the way the debugger represented arrays, resulting in an inefficient presentation. By contrast, in Iteration 3 the teacher has learned from the mistake of using the debugger to illustrate the nested-array loop which improves the efficiency of the presentation (by moving straight to the whiteboard representation).

5.5.3 Types of tasks

Process based tasks allow the evolving nature of peoples' underlying mental models to be shared. When the teacher or students are performing and describing a process their understandings are made explicit. The "Debug Cube Program", "Write SoftDrinkCan", "RadioButton to ComboBox", "Adjust FileReader" tasks allowed students the opportunity to represent evolving components of their understanding, such as whether or not they could relate the computing concepts being addressed with the semantic and syntactic skills required to solve the programming problem. Making this public gave the teacher the opportunity to support the formation of students' mental models in places where deficiencies were evident. In contrast the "Distinguish Program Features", "Applet Comprehension Questions", and even "Shallow Versus Deep Copies" tasks focused on already formed understandings (not as developing processes on concrete tasks), and thus provided less opportunity for the evolving nature of students' mental models to be observed and addressed.

Authentic tasks appeared to engage greater levels of student interest. The "Write SoftDrinkCan" task and the "RadioButton to ComboBox" task resulted in several comments demonstrating student satisfaction upon completing the task. In contrast the "Distinguish Program Features" and "Applet Comprehension Questions" were more contrived and appeared to result in students completing the task because it had been prescribed.

5.5.4 Semiotic representations in the web-conferencing system

Teacher guidance and modelling regarding how content could be represented using the technology allowed more effective collaboration and learning. This is in alignment with Laurillard's (2002) recommendations that students need to be shown semiotic representations in the given domain of study and be provided with opportunities to interpret and apply them in the learning environment. For instance, in Iteration 3 of the "Shallow versus Deep Copy" exercise the teacher's representation of the shallow copy on the whiteboard provided a model of an object for students to interpret. Requiring students to represent the deep copy provided the opportunity to apply the representational forms, which in turn immediately allowed the teacher to ascertain whether students had acquired a complete understanding of the concept.

The whiteboard provided an effective tool for students to dynamically represent their conceptions of how a program functions. In Iteration 3 of the "Nested Loop Array" task the whiteboard was again used, this time for students to dynamically represent their "notional machine" (du Boulay, O'Shea, & Monk, 1989). The teacher provided guidance about appropriate ways to represent array elements, counters, and output. The guidance allowed students to represent their understanding in a more efficient way than they had initially intended, and in a way that conformed to standard representational approaches in the field. By applying the semiotic representations to dynamically represent the nested array output, the teacher could once again diagnose whether or not students had achieved a relational level understanding, and if not, had the opportunity to provide remedial support based on the misconceptions that the students had revealed.

Screen-sharing is a "cognitively efficient" (Salomon, 1994) modality to share programming process information. Using screen-sharing to demonstrate the "Debugging Cube Program" task of Topic 1 allowed students to see the operations required to edit, compile and debug programs. The underlying thinking behind these processes could also be shared, offering students a "cognitive apprenticeship" (Collins, Brown, & Holum, 1991). This is particularly important at the beginning of the subject when students are unfamiliar with these processes. However, as students acquire these understandings and no longer need to have them demonstrated, a not-pod provided a more equally accessible mode for students to collaboratively engage in the program writing process.

5.5.5 Interacting using the web-conferencing system

New patterns of engagement were possible using the web-conferencing system which are not possible in face-to-face environments. The most frequently applied of these was the way in which one person (normally the teacher) can be providing an audio commentary while other people (students) can simultaneously be making comments, posing questions and responding to the questions of others. For instance, this was observed in the screen-sharing teacher-led programming approach for the "Debugging Cube Program" task as well as Iteration 1 and Iteration 3 of the "Write SoftDrinkCan" task. Part of the success of the teacher-led programming approach was that the teacher could leverage the multimedia principle (Fletcher & Tobias, 2005) and modality principle (Low & Sweller, 2005) by using audio and the visual screen-share, while student suggestions and questions could be provided using the non-interfering text-chat.

A number of teacher techno-pedagogic tactics were applied to promote more efficient communication and integration of the collaborative modalities. For instance, there were numerous instances of following audio questions with typed prompts in the text-chat in order to emphasize the question and provide a marker in the text-chat discourse that indicated the start of a new thread (see for example, Iteration 1 of the "Distinguish Program Features" and "Applet Comprehension Questions" tasks). There were also instances of highlighting program code to 'signal' (Mayer, 2005b) the focus of discussion, thus avoiding extraneous cognitive load. This was most prevalent in the three iterations of the "Adjust FileReader" activity.

The teacher's technological competencies critically impacted collaboration in the web-conferencing environment. For instance, because in Iteration 1 of the "Debugging Cube Program" the teacher was not aware that minimizing the web-conferencing browser window would cause student text-chat comments to pop-up in mini windows, the text-chat area was kept visible thus doubling up its display in the screen-share. Not understanding the operation of the "synch" button meant that in some instances students did not see the same part of the document to which the teacher was referring or could scroll forward to the solutions (see Iteration 1 of Topic 4 – "Applet Comprehension Questions"). Other instances of forgetting to screen-share (Iteration 2 of the "RadioButton to ComboBox" task) and locking a student from the using the audio "talk" button by enforcing screen-share (Iteration 3 of the "Adjust FileReader Program") were detrimental to collaboration and learning.

More sophisticated teacher technological skills were required to manage group-work in the web-conferencing environment. The teacher needed to understand how to use multiple rooms, toggle between rooms, and direct communications to particular students or group or to the whole class. Examples of this in action are provided in Iteration 2 of the "Identify Program Features" and "RadioButton to ComboBox" tasks. The teacher also requires the confidence to troubleshoot technical problems associated with the web-conferencing system as they arise for students. Achieving this level of technological fluency can then underpin spontaneous redesign of interfaces to meet the changing collaborative needs of the episode at hand (both by the teacher and students). For instance, in Iteration 2 of the "Identify Program Features" task the teacher rearranges the main classroom to facilitate better comparison and contrast of group-work solutions.

Student technological competencies in the virtual classroom were also observed to impact upon the effectiveness of collaborations. The most notable example of this was in Iteration 2 of the "Write SoftDrinkCan" task where not knowing that minimizing the browser window causes text messages to pop up led to inefficient transitions between screen-sharing the IDE and returning to the web-conferencing environment. Similarly in Iteration 3 of the same task students and the teacher discussed the mechanics of using the "full-screen" screen-sharing mode. In such cases the number of Activity and Technology based comments increases, meaning students focus is distracted from Content.

Audio appeared to be a more efficient collaborative modality in small group situations where all participants are contributing approximately equal levels of discourse. For instance when audio was used in Iteration 3 of Topic 10, the per-student rate of contribution was 2.4 comments per minute. When the same learning design with text-chat was used in Iteration 2 the per-student rate of contribution was only 0.5 comments per minute. Audio allows 'tightly coupled' (Neale, Carroll, & Rosson, 2004) collaborations to be used to negotiate meanings. Using audio in small groups is more effective because there is less likely to be interference between contributions (the fact that only one person can contribute at any one time using audio is less concern with fewer people because there is more space per person).

In contrast, text-chat appears an effective medium for conducting large group discussions or respondent communications where one participant (such as the teacher) is playing a dominant role. The fact that students' use of audio in the teacher-led Iteration 3 of the "Debugging Cube Program" task made no observable difference to the type of contributions that were made as compared to Iteration 1 and Iteration 2, indicated that using audio during an episode where the teacher was leading discussions made no observable difference to discourse. The textual discourse of the teacher-led programming episodes of Iteration 1 and Iteration 3 of the "Write SoftDrinkCan" programming were similar in terms of amount of discourse and Subject-Interaction profile, even though text-chat was used in Iteration 1 and audio was used in Iteration 3. Text-chat has far less limitations in terms of space per person, and so is more effective for allowing everyone to contribute in large group collaborations. It should be noted that text-chat also requires less technological overhead (setting up, troubleshooting, volume control, monitoring and so on).

An ongoing question in using the web-conferencing system to facilitate group programming was whether to use a communal note-pod solution space (for instance, as in Iteration 2 and Iteration 3 of the "RadioButton to ComboBox" task), or whether to make one student share their screen of the IDE and have other students provide programming directions (for instance, as in Iteration 2 of the "Write SoftDrinkCan" task). Using the note-pod approach allows all students to have equal access to the solution space, as well as to copy and paste several lines of program code at once. On the other hand groups can run into version control problems if several students copy and paste code between a note-pod and their IDE.

As well, scrolling on the note-pods is not synchronized between participants, the identity of the editor is not automatically known, and there is no way to highlight specific lines of code. The last three features contribute to "distributed process loss" (Neale, Carroll, & Rosson, 2004) and need to be considered when providing guidelines for students regarding how to perform the task.

5.5.6 Coordinating problem solving

A general pattern of collaboration was observed across episodes whereby the Subject of discourse changed as the learning episode progressed (for example, refer to Iteration 3 of the "Distinguishing Programming Features" task or Iteration 3 of the "Write SoftDrinkCan" task). Broadly speaking, Activity contributions were used first to introduce the episode. This was followed by some brief Activity-Technology comments to describe how the activity would be mediated using the web-conferencing system. Then Activity-Content statements were used to indicate who was to perform the different components of the task. Only once the activity and technology components of the task had become embedded as protocols of the community in the learning context could discourse focus purely on Content.

Teacher management of activity (and technology) can allow students to focus on content. For instance, the teacher-led programming approach adopted in Iteration 1 and Iteration 3 of the "Write SoftDrinkCan" task allowed a focus on content because the teacher was coordinating activity and operating the technology. Note that the approach was still able to encourage interaction, but the interaction was mainly responsive. The student-centred programming approach of Iteration 2 resulted in a significantly higher level of activity related textual discourse. Allocating roles and explaining the approach to contribution in Iteration 3 of the "Applet Comprehension Questions" avoided much of the coordinating discussion that students required in Iteration 2.

Tasks can engage more student collaboration by requiring a negotiated solution. Requiring a group solution to Iteration 2 and Iteration 3 of the "RadioButton to ComboBox" exercise resulted in higher levels of collaboration. On the other hand the "Applet Comprehension Questions" task could have been designed to involve more negotiation as a way to foster collaboration, for instance by asking students to rank the points they provided in descending order of importance.

5.5.7 Engaging collaborative learning patterns in the web-conferencing environment (Activity-Content-Technology)

Establishing collaborative patterns enabled more efficient learning episodes. Ensuring a means of negotiation is fundamental to engaging distributed cognition approaches to learning (Hollan, Hutchins, & Kirsh, 2000). Two ways in which this occurred include:

- Rules of engagement could overcome some of the distributed process loss that the community would otherwise have experienced in the web-conferencing environment. For instance, in Iteration 3 of the "RadioButton to ComboBox" and "Applet Comprehension Questions" tasks students were taught to append their initials at the end of note-pod contributions allowing their identity to be immediately revealed. This avoided the need for unnecessary activity based statements, again allowing a focus on Content.

- Applying learning designs that provide students with spaces to collaboratively negotiate solutions allows them to effectively develop their mental models in a shared sense. Examples of learning designs where collaborative spaces enabled such approaches to be engaged include Iteration 3 of the "Shallow versus Deep Copy" task and Iteration 3 of the "Nested Array Output" task.

Establishing effective patterns of collaborative learning in the web-conferencing environment allowed tasks to be instantiated without the need for unnecessary Activity and Technology based discourse. For instance, adopting the established collaborative pattern of teacher-led programming required relatively low levels of teacher and student activity or technology related discourse, allowing a focus on Content. The design led to a reasonable level of student engagement and teacher interaction (for instance, see Iteration 1 of the "RadioButton to ComboBox" task). On the other hand when the teacher requires the class to share short pieces of declarative knowledge then using text-chat to implement a question-response approach provided an appropriate approach (for instance, Iteration 1 of the "Distinguish Program Features" task).

5.6 Summary of the Multimodal Discourse Analysis

The multimodal discourse analysis provided descriptive statistics of teacher and student use of the web-conferencing environment. The subject of discourse, the interactive nature of collaboration, and the different modalities used to perform actions were able to be deconstructed in order to characterize the nature of teaching and learning in the virtual classroom.

Differences in collaboration between teacher-centred, teacher-led and student-centred activity designs were detected using quantitative analysis. Levels of student discourse increased under student-centred techniques. Responsibility for discussing content and directing the learning episode was devolved from the teacher to the students. The capacity of audio to enable more extensive and tightly coupled contributions during group-work was also highlighted.

The qualitative observations from the multimodal discourse analysis included the way in which provision of dedicated solution spaces enabled students to more effectively share their mental models, how teacher management of activity and technology enabled students to focus on content, how authentic and problem based tasks stimulated greater student engagement, and how virtual classroom competencies has a critical impact upon learning. The differing utility of different modalities for representing was also observed, including whiteboards for the representation of dynamic concepts, and screen-sharing for dynamically representing processes.

The analytic lens provided by the multimodal discourse analysis facilitated qualitative understandings that would not have been derived unless the coding scheme was applied. For instance, the general evolution of the subject of textual discourse from Activity to Activity-Technology to Activity-Content to Content highlighted the way in which Activity and Technology discourse underpins successful Content discussions. As well, the prevalence of various types of Subject-Interaction contributions and techno-pedagogic tactics was able to be gauged.

Student-centred approaches enabled students to demonstrate a relational level of understanding as opposed to teacher-centred approaches which often restricted students to demonstrating at most a unistructural understanding. Teacher guidance on how to represent concepts was observed to support the speed and ease with which students could demonstrate their mental models. Establishing familiar patterns of collaboration allowed students to engage more quickly with the content because they did not need to conduct any coordinating activity or technology related discourse.

The results of the multimodal discourse analysis are synthesized with the design-based research findings in the next chapter in order to provide an integrated set of implications from the combined study. On this basis a set of techno-pedagogical patterns are proposed. They describe how to form and apply multimodal clusters based on the type of task and level of student understanding being developed and assessed. By proposing a set of techno-pedagogical patterns for teaching and learning in the web-conferencing environment, teachers have the opportunity to select from a set of established and tested approaches, the rationale of which is based upon educational theory. This represents the output of the entire design-based research process. Applying these patterns with students allows "functional specializations" (Jewitt, 2006) to develop, which in turn enables students to more immediately engage with the curriculum matter rather than unnecessarily spend time discussing activity and technology related matters.

5.7 Corpus Contribution Summaries

TEACHER	Topic 01 Iteration 1	Topic 01 Iteration 2	Topic 01 Iteration 3	Topic 02 Iteration 1	Topic 02 Iteration 2	Topic 02 Iteration 3	Topic 03 Iteration 1	Topic 03 Iteration 2	Topic 03 Iteration 3	Topic 04 Iteration 1	Topic 04 Iteration 2	Topic 04 Iteration 3	Topic 09 Iteration 1	Topic 09 Iteration 2	Topic 09 Iteration 3	Topic 10 Iteration 1	Topic 10 Iteration 2	Topic 10 Iteration 3	Topic 11 Iteration 1	Topic 11 Iteration 2	Topic 11 Iteration 3	Topic 12 Iteration 1	Topic 12 Iteration 2	Topic 12 Iteration 3	Totals
Actions – adjusting VC interface to better facilitate communication	0	0	3	0	10	0	0	3	6	0	0	0	1	2	0	0	2	1	0	3	2	0	1	1	35
Actions - broadcasting doc with Qs or As or content	1	0	2	3	3	1	0	0	0	0	0	0	1	0	0	1	0	0	2	2	1	0	0	0	17
Actions - highlighting text with cursor to emphasize	2	0	5	0	0	1	0	0	0	0	0	0	0	0	0	4	0	1	0	7	4	31	7	14	76
Actions - moving information between resources and pods	3	1	3	0	3	0	1	0	0	0	0	0	0	0	0	2	2	1	0	1	4	0	0	0	21
Actions - moving of people between layouts and rooms	0	0	0	0	5	1	0	2	0	0	2	1	0	0	0	2	12	2	0	0	1	0	0	0	28
Actions - note-pod non-textual discourse conts	0	0	0	0	2	7	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	10
Actions – recording lesson	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0	0	0	0	0	0	6
Actions - screen-share modelling programming	27	23	24	0	0	0	35	0	48	0	0	0	0	0	0	60	11	29	0	37	17	8	9	4	332
Actions - unrelated task	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	15
Actions - whiteboard adding to and editing	0	0	0	0	0	0	0	0	0	0	0	0	17	20	0	0	0	0	0	0	17	0	3	1	58
Textual Discourse – audio contribution sentences	68	59	76	68	86	217	157	137	178	73	49	43	75	43	40	126	140	60	30	59	234	34	90	53	2195
Textual Discourse - note-pod textual Subj-Int conts	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Textual Discourse - text-chat pod contribution	0	1	0	6	5	2	0	2	0	4	10	2	1	0	1	0	0	0	0	0	1	0	2	1	38
Textual Discourse – collaborating by typing text comment in IDE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	101	84	113	77	118	233	193	144	232	77	61	46	95	65	41	195	187	96	32	109	281	73	112	74	2839

Table 32 – Summary of TEACHER Contributions (Actions and Textual Discourse) by media and type

STUDENT	Topic 01 Iteration 1	Topic 01 Iteration 2	Topic 01 Iteration 3	Topic 02 Iteration 1	Topic 02 Iteration 2	Topic 02 Iteration 3	Topic 03 Iteration 1	Topic 03 Iteration 2	Topic 03 Iteration 3	Topic 04 Iteration 1	Topic 04 Iteration 2	Topic 04 Iteration 3	Topic 09 Iteration 1	Topic 09 Iteration 2	Topic 09 Iteration 3	Topic 10 Iteration 1	Topic 10 Iteration 2	Topic 10 Iteration 3	Topic 11 Iteration 1	Topic 11 Iteration 2	Topic 11 Iteration 3	Topic 12 Iteration 1	Topic 12 Iteration 2	Topic 12 Iteration 3	Totals
Actions - adjusting VC interface to better facilitate communication	0	0	0	0	0	0	0	12	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	16
Actions - broadcasting doc with Qs or As or content	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Actions - highlighting text with cursor to emphasize	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2
Actions - moving information between resources and pods	0	0	0	0	11	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
Actions - moving of people between layouts and rooms	0	0	0	0	0	3	0	9	0	0	16	3	0	0	0	0	0	3	0	0	0	0	0	0	34
Actions - note-pod non-textual discourse conts	0	0	0	0	6	3	0	0	0	0	1	0	0	0	0	0	73	29	0	0	0	0	0	1	112
Actions – recording lesson	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Actions - screen-share modelling programming	0	0	0	0	0	0	0	74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74
Actions - unrelated task	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Actions - whiteboard adding to and editing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	17	0	8	0	33
Textual Discourse – audio contribution sentences	0	0	26	0	0	29	0	0	48	0	108	0	0	0	10	0	0	263	0	0	57	0	0	8	549
Textual Discourse - note-pod textual Subj-Int conts	0	0	0	0	39	28	0	0	0	0	69	15	0	0	0	0	0	0	0	0	0	0	0	0	152
Textual Discourse - text-chat pod contribution	27	22	0	35	182	8	44	145	0	35	54	6	39	8	11	64	147	0	1	12	0	4	31	0	875
Textual Discourse – collaborating by typing text comment in IDE	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Totals	27	22	26	35	238	72	44	250	50	36	248	24	40	8	29	64	220	296	1	12	74	4	39	9	1868

Table 33 – Summary of STUDENT Contributions (Actions and Textual Discourse) by media and type

	Topic 01 Iteration 1	Topic 01 Iteration 2	Topic 01 Iteration 3	Topic 02 Iteration 1	Topic 02 Iteration 2	Topic 02 Iteration 3	Topic 03 Iteration 1	Topic 03 Iteration 2	Topic 03 Iteration 3	Topic 04 Iteration 1	Topic 04 Iteration 2	Topic 04 Iteration 3	Topic 09 Iteration 1	Topic 09 Iteration 2	Topic 09 Iteration 3	Topic 10 Iteration 1	Topic 10 Iteration 2	Topic 10 Iteration 3	Topic 11 Iteration 1	Topic 11 Iteration 2	Topic 11 Iteration 3	Topic 12 Iteration 1	Topic 12 Iteration 2	Topic 12 Iteration 3	Totals
Teacher Comment on Self Understanding & Thinking	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Teacher Comment on Others' Understanding & Thinking	1	0	0	3	0	2	2	0	1	1	1	0	1	0	2	0	1	0	2	0	4	1	0	3	25
Student Comment on Self Understanding & Thinking	1	0	2	6	4	2	2	2	1	0	2	0	3	0	2	0	1	0	0	2	6	0	0	0	36
Student Comment on Others' Understanding & Thinking	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Totals	2	1	3	9	4	4	4	2	2	1	4	0	4	0	4	0	2	0	2	2	10	1	0	3	64

Table 34 – Summary of Metacognitive Statements by type per learning episode

	Topic 01 Iteration 1	Topic 01 Iteration 2	Topic 01 Iteration 3	Topic 02 Iteration 1	Topic 02 Iteration 2	Topic 02 Iteration 3	Topic 03 Iteration 1	Topic 03 Iteration 2	Topic 03 Iteration 3	Topic 04 Iteration 1	Topic 04 Iteration 2	Topic 04 Iteration 3	Topic 09 Iteration 1	Topic 09 Iteration 2	Topic 09 Iteration 3	Topic 10 Iteration 1	Topic 10 Iteration 2	Topic 10 Iteration 3	Topic 11 Iteration 1	Topic 11 Iteration 2	Topic 11 Iteration 3	Topic 12 Iteration 1	Topic 12 Iteration 2	Topic 12 Iteration 3	Totals
Audio repeating student text-chat to emphasize	5	3	0	0	0	2	4	0	0	10	0	3	2	0	0	4	9	0	0	0	0	0	5	0	47
Repeating own audio using text-chat to emphasize	0	1	0	7	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
Audio describing student actions to emphasize and focus	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	7
Audio repeating student audio to emphasize	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Highlighting text with cursor to emphasize	2	0	5	0	0	1	0	0	0	0	0	0	0	0	0	4	0	1	0	7	4	31	7	14	76
Totals	7	4	5	7	0	4	4	6	0	14	0	3	2	0	0	8	10	1	0	7	4	31	12	14	143

Table 35 – Summary of Teacher techno-pedagogic tactics by type per learning episode

Chapter 6 - Discussion

This chapter synthesizes results from the design-based research and multimodal discourse analysis to provide an integrated understanding of teaching and learning in web-conferencing environments. The influence of task type, activity design and the interface in engaging collaboration and learning are discussed. On this basis a framework for learning design in web-conferencing environments is proposed. Reflections on the research including implications of the study, limitations, and possible future directions are also provided.

6.1 Introduction

This study has provided an illustration and analysis of the nature of teaching and learning through web-conferencing environments, using both qualitative and quantitative techniques. Both the design-based research and the multimodal discourse analysis provided a characterization of using web-conferencing for educative purposes, and at the same time facilitated an investigation into how collaboration and learning were affected by the task, the (inter)activity design and the interface as a mediating tool. This analysis was based upon an Activity Theory perspective applied to the web-conference based learning environment, as illustrated in Figure 53.

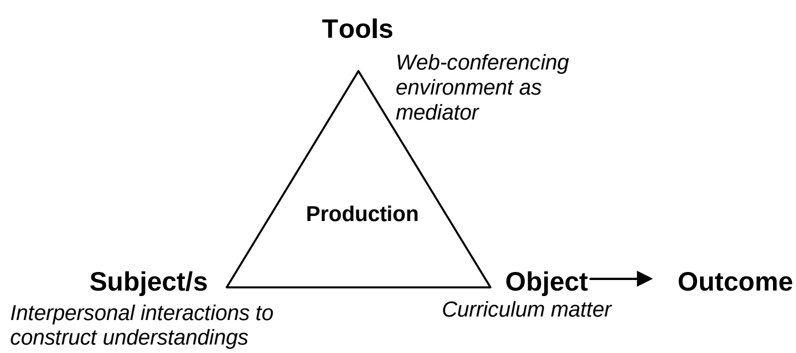

Figure 53 – Web-conferencing environment as mediating interactions between people and actions upon content to produce learning outcomes

After briefly evaluating the redesign strategies, findings from the design-based research and multimodal discourse analysis are triangulated to derive an integrated set of heuristics for design in web-conferencing environments. On this basis a framework of learning designs for teaching in web-conferencing environments is proposed. Summative remarks are also provided.

6.2 Evaluation of the Redesign Strategies

Combining the design-based research findings and the multimodal discourse analysis allows the effect of redesign strategies adopted between iterations to be evaluated, as follows:

- The analysis of the activity designs in the quantitative components of the multimodal discourse analysis revealed that student-centred activity designs led to greater rates of student contribution. The design-based research supported this finding. The qualitative analysis in the multimodal discourse analysis and the design-based research demonstrated how student-centred approaches led to greater revelation of mental models. This provides vindication of the approach to improving collaborations from Iteration 1 to Iteration 2.
- The analysis in this research study also indicated that
    a. the use of audio by students
        i. enabled more extensive and rapid contribution suitable for group-work situations (as evidenced by the multimodal discourse analysis)
        ii. reduced split attention where other forms of input into the web-conferencing interface are required, as opposed to text-chat (as evidenced by the design research and qualitative components of multimodal discourse analysis)
    b. an emphasis on dynamically adjusting the interface based on the representational needs of the conversation that was transpiring allowed for more effective sharing of meaning (as evidenced by the design-based research).

  This provides vindication of the approaches to improving collaborations from Iteration 2 to Iteration 3.

As such, the results of the design research and multimodal discourse analysis validate the efficacy of strategic refinements applied between iterations of the project.

At the same time as validating the strategic redesigns between iterations, this research has led to a number of other understandings regarding teaching and learning in web-conferencing environments. Key findings are summarized in the next section, which in turn form the basis of the formalized design framework for teaching and learning in web-conferencing environments that follows.

6.3 Heuristics for Design

Teaching and learning through web-conferencing environments is different from working in face-to-face environments because all interactions are necessarily mediated through the technology. Because the designer has the capacity to select the combinations of modalities that will be used to facilitate interaction and represent knowledge, they have a strong influence over the collaboration and learning that transpires. As well, the ability to dynamically design the environment affords new possibilities for teaching and learning.

This section describes heuristics for design that have been generated from the results of this research. These heuristics attend directly to the questions raised in Chapter 1. Observations have highlighted the interdependency of the task, activity design and interface in the construction of effective learning environments. Thus applying a holistic approach to learning design requires an integrated consideration of the three aspects. As such, the results below are not categorized by task, activity or technology, as in many cases they involve an integrated application of all three elements.

6.3.1 Different modalities afford different possibilities for representing

The different representational possibilities afforded by different modalities have been primarily harvested from the technology observations of the design-based research results, but were also validated by qualitative observations reported in the multimodal discourse analysis. Subsequent sections provide links back to substantiating evidence in the results chapters, however since the modality results in this section were repeatedly evidenced throughout the results chapters, specific links have not been provided. While many of the observations may seem intuitive, the consolidated set of empirically derived results provides educators with a resource that informs the process of designing with synchronous modalities.

6.3.1.1 Text-chat

Text-chat affords the potential to share short pieces of declarative information. Many people can contribute this information simultaneously, and respond to each other simultaneously. This makes text-chat efficient in large group discussions so that people do not have to wait for everyone else to contribute before making a comment. The text-chat then allows different students' contributions to be compared and contrasted. Because the information is automatically sequenced, non-editable and navigable the discourse can be reviewed at the preferred pace of the learner, either during or after the lesson.

6.3.1.2 Audio

The audio modality affords the opportunity to contribute more extensive descriptions more rapidly than text-chat. Because audio contributions cannot be made simultaneously they are better suited to small group discussions or situations where one person (such as the teacher) is dominating the collaborative space. In small group situations the pace and ease of audio contributions affords more tightly coupled interactions, supporting the formation of negotiated meanings. Audio information needs to be processed in working memory at the time of broadcast and cannot be reviewed at the students preferred pace during the lesson.

6.3.1.3 Note-pods

Note-pods can provide an equally accessible solution space for organizing textual information. Note-pods afford an ease of contribution, only requiring typing or copy-paste skills. Large amounts of information can be shared at once, and formatting can be preserved. The information is automatically sequenced, and can be edited, copied and deleted. This makes it suitable for collaborative authoring. Disadvantages of note-pods include that only one person can type in each at a time, the identity of the contributor is unknown, and scrolling can lead to split focus if large amounts of text are being shared in the one pod. These imply the need for the community to establish contribution rules in order to overcome distributed process loss.

6.3.1.4 Screen-sharing

Screen-share allows process based information to be represented. Sequences of actions can be shared, allowing students to see the steps required to solve a problem. This sharing of information in a form which closely resembles that in which it will be reapplied promotes cognitive efficiency through transfer appropriate representation. Authentic, concrete tasks can be attempted using screen-sharing, which can then form the basis for the development of abstractions in the domain. Because students observe the problem solving process being performed (either by the teacher or their peers) they may not only acquire content knowledge but also more generic problem solving skills. By modelling processes such as editing, compiling, and debugging computer programs the teacher can offer students a cognitive apprenticeship.

6.3.1.5 Whiteboard

The whiteboard allows several items of information to be organized and interrelated, which makes it suitable for representing conceptual knowledge. Both visual and textual information can be represented. The whiteboard also allows pieces of information to be highlighted, as well as offering the potential to compare and contrast information without splitting attention between multiple files or pods. The solution space afforded by the whiteboard can be accessed equally by all participants, making it suitable for collaborative meaning making. On the other hand, contributions to the whiteboard can take more time than for the text-chat or note-pods because people need to choose the placement, form and style of their contribution. Because the whiteboard affords the evolving representation and interrelation of information it is suitable for representing dynamic mental models, such as students' notional machine.

6.3.2 Designing multimodal clusters according to multimedia learning principles can improve cognitive efficiency

Different modalities not only offer different individual possibilities for representing, but also different possibilities in combination as multimodal clusters. The design of effective multimodal clusters was observed to rely upon application of multimedia learning principles. Examples include:

- Student use of text-chat while the teacher uses audio enables many-to-many student collaborations to occur that do not interfere with the teacher's (or other student's) explanations and instructions. This was noted as part of the Iteration 1 technology observations for the design-based research (see Vignette 1).
- Use of audio (rather than text-chat) in combination with visual modalities (such as note-pods or whiteboards) allows dual processing capabilities to be utilized. This is in accordance with the modality principle; performing collaboration using text-chat along with other visual modalities can result in split attention. See Iteration 3 of the design-based research or Iteration 2 of the "Applet Comprehension Questions" task for the Multimodal Discourse Analysis.
- Using diagrams to embellish audio explanations to support clearer formation of mental models (multimedia principle, see Vignette 6 and Vignette 10 of the design-based research results for illustrative examples). Using diagrams rather than just audio descriptions allows cognition to be offloaded to the environment (see Vignette 13 and Vignette 23).

These results validate the use of multimedia learning principles (Mayer, 2005a) for designing interfaces. Using multimedia learning principles allows the functional load imposed by multimodal clusters to be reduced. Providing effective representations in the shared cognitive space lowers the load on peoples' working memory. Collaborative solution spaces facilitate joint negotiation of meaning, and cognitive load balancing amongst participants. These effects are portrayed by both Vignette 13 and Vignette 23.

When designing multimodal clusters it is also important to avoid split attention caused by the physical (and temporal) separation of related information. For instance, compare and contrast activities with information on separate layouts force students to store chunks of knowledge in working memory while they perform their evaluations (Vignette 14 as opposed to Vignette 15). Not including task descriptions in the interface may require students to split their attention between physical resources and their computer screen (an interface design issue described in Iteration 2 of the design-based research).

As well, multimodal clusters should avoid incorporating unnecessary pods that may occupy otherwise useful space or cause people to communicate ineffectively (redundancy principle). For instance, Vignette 15 illustrates how including a redundant whiteboard in a multimedia cluster designed for a group-work textual analysis task resulted in the inefficient use of the whiteboard to conduct textual collaborations, and also compromise the amount of space available for more useful tools.

6.3.3 Tactics can be applied to reduce distributed process loss in the web-conferencing environment

While web-conferencing environments support distributed cognition through the discursive modalities and shared solution spaces they afford, there are several ways in which distributed process loss can occur. These include:

1. not knowing who is present in the virtual classroom
2. not knowing who is making contributions
3. not knowing what other participants are experiencing
4. not knowing where the focus of attention should be directed.

In order to appreciate who is present in the virtual classroom the attendance pod should be made long enough for the full list of room occupants to be read, or otherwise as long as possible. This is illustrated in Vignette 2. Students may be "logged in" to the virtual classroom but not engaged at their computer, so requests for peoples' contribution may be required to determine their presence. Regular student contributions can be elicited as part of applying the interpretation, application and feedback phases of Laurillard's (2002) Conversational Framework.

When using the note-pods or whiteboards the identity of the contributor is not made explicit and often not implied by the context. This can cause distributed process loss because other participants do not know where to direct comments, thus often needing to ask who made contributions before proceeding. Expressed in terms of Activity Theory, establishing rules of contribution amongst the community can reduce unnecessary coordinating collaborations. For instance, encouraging students to append their initials at the end of textual contributions immediately allows the identity of the contributor to be revealed. This was exemplified by Iteration 2 and Iteration 3 of the "RadioButton to ComboBox" task in the multimodal discourse analysis, and discussed as an approach to coordinating collaborative problem solving in Iteration 3 of the design-based research results. Students can be encouraged to use different colours when making whiteboard contributions to differentiate their contributions (as illustrated by Vignette 14). Once these protocols become part of the communicative culture they require little effort to implement and allow more efficient collaboration.

Not every person receives the same virtual classroom transmission. Different permission levels, screen sizes, individual user settings and network connections mean that different people may see or hear different information at different times. However a shared understanding of the environment is necessary for effective interaction (Luff et al., 2003). This requires a level of monitoring and maintenance not needed in face-to-face contexts. The teacher may need to check that a (high bandwidth) screen-share is being received, that people can see a particular question in a document being broadcast, that audio levels are appropriately set and that people can access the required pods. Students should be encouraged to report any communication issues immediately. The quality with which transmissions were monitored and managed was observed to critically impact on the efficiency and effectiveness of learning episodes, as discussed in Iteration 1 and Iteration 2 of the design-based research results. This is also exemplified in Iteration 3 of the "Write SoftDrinkCan" task in the multimodal discourse analysis.

Highlighting is critical for overcoming distributed process loss because unlike face-to-face contexts the focus of attention cannot be ascertained from the gaze or body positioning of others. In-built web-conferencing tools such as the pointer tool can be used to facilitate this. When performing a screen-share selecting the text in question allowed a section of text to be emphasized, indicating the subject of focus. In the case of note-pods and whiteboards, sometimes audio commentary provides the most effective means of directing attention to a particular resource or piece of information. In order to emphasize particular items of text-chat the teacher may choose to repeat student comments using audio. The teacher may also choose to repeat their own audio contribution using text-chat to highlight the importance of the comment and provide a marker in the text-chat transcript from which student responses can follow. The multimodal discourse analysis coding scheme detected the extent to which these effects were utilized within learning episodes, and qualitative analysis during the design-based research and the multimodal discourse analysis identified the efficacy of the approaches.

6.3.4 Student-centred designs allow student involvement to be increased and mental models to be more fully revealed

In this study, activity design provided the major mechanism through which the teacher could increase student involvement. The student-centred activity designs in the multimodal discourse analysis resulted in a 618% higher rate of per-student textual discourse contribution than teacher-centred designs, and 97% more than teacher-led designs (ref. Statistical Test 22). In student-centred activity designs there were lower rates of teacher Content contribution than in teacher-led episodes, indicating that responsibility for learning content had genuinely been devolved to the students. Student-centred activity designs also resulted in significantly higher rates of per-student Content contribution than teacher-centred designs (ref. Statistical Test 24), indicating an assumption of responsibility for learning by students. Because students were discussing curriculum matter more extensively in student-centred designs their mental models were more fully revealed than for more teacher dominated approaches (as exemplified in Iteration 3 of the "Shallow versus Deep Copy" task, and Iteration 2 and 3 of the "RadioButton" to "ComboBox" task from the multimodal discourse analysis). This provides greater insight into the accuracy of student schema and the form of remediation that may be required.

Teacher-led activity designs also had collaborative utility. The multimodal discourse analysis indicated that teacher-led activity designs had a greater average rate of teacher and per-student contribution than teacher-centred designs, even when the longer sentence length for teacher-centred designs was taken into account. A significantly greater rate of per-student Content contribution was also observed in teacher-led as opposed to teacher-centred activity designs (ref. Statistical Test 24). This provides evidence to favour teacher-led activity designs over teacher-centred designs for engaging interactive learning. However teacher-led approaches such as prompting students for contribution using questioning resulted in students being more responsive and less directive in their learning, as demonstrated by the correlation tests in the multimodal discourse analysis. Design based research observations identified how teacher-led activity designs limited students to demonstrating at most a multistructural level of student understanding because the teacher was performing some of the sequencing and intermediary aspects of the problem solving process (for instance, under the "instructed-teacher" approach represented in Vignette 5 or the "question-response" approach of Vignette 1).

Teacher-centred approaches appeared more suitable for the transmission of information when student mental models were not yet formed. In this study teacher-centred approaches incurred less activity and technology discursive overhead and as such were often adopted in order to save time. These effects are discussed in the activity design sections of the design-based research results, and illustrated in Vignette 3 and Vignette 11. Because students rarely contributed during more teacher-centred approaches the capacity to assess the level of their mental model development was restricted. Students typically provided brief responses to declarative questions, usually allowing at most a unistructural level of understanding to be gauged (see Vignette 4).

Successful learning may depend on having a balance of all types of interactions. However the efficacy of episodes where authentic student contributions are not made every two or three minutes should be carefully considered. In such circumstances it is not possible to ascertain student engagement, correctness of pitch, or level of understanding, particularly because of the lack of non-verbal cues such as body language in web-conferencing environments. Providing students with the space to contribute requires a movement from teacher-centred towards teacher-led and student-centred approaches. This shift can occur within learning episodes, as illustrated by Vignette 13.

6.3.5 The teacher is the major influence upon the types of interaction and collaboration that transpire

The teacher is responsible for setting the collaborative expectations of learning episodes conducted in the web-conferencing environment. In situations where there was limited space there appeared to be a trade-off between the number of teacher and student contributions. This was a pervasive theme identified in all iterations of the design-based research and quantified by the multimodal discourse analysis. In this study, if the teacher dominated discourse and activity then students were likely to assume a more passive role. On the other hand, if the teacher established the expectation that students contribute then levels of student involvement generally increased. Explicit teacher direction explaining the collaborative intentions of the activity was observed to align collaboration with expectations. Specific examples of this were discussed as part of the consolidated observations of the multimodal discourse analysis.

Different teaching styles and learning designs led to different patterns of interaction. As an example, the multimodal discourse analysis revealed how independent questions by the teacher were typically followed by several statement responses to questions by students, a little bit like a Socratic dialogue. Increasing the rate of teacher independent questions did not significantly improve rates of student contribution, but did alter the interactive nature of discourse by increasing the rate of student statement responses to questions (ref. Statistical Test 19, Statistical Test 20). By reflecting on the types of interaction chains that arise from different educational designs teachers can adjust their approaches. For instance, Socratic dialogue may be desirable in some circumstances but if a teacher wishes to support the development of student control decisions in their subject they may prefer students to adopt a student-centred activity design (providing more opportunity for students to ask independent questions).

Providing collaborative space (both virtual and temporal) appears to be a key to promoting collaboration in web-conferencing facilitated learning. In some of the student-centred and teacher-led activities there was sufficient space for the students and the teacher to be contributing simultaneously in an integrated fashion. The "teacher-led programming" and "question-response" approaches discussed in the design-based research results exemplify this. These approaches enabled Laurillard's (2002) Conversational Framework to be efficiently and effectively applied. With adequate collaborative space students' mental models could be more fully revealed, and as a result the teacher could conduct more accurate assessment and provide more appropriate feedback (several examples have been discussed throughout the results, for instance see Iteration 3 of the "Shallow versus Deep Copy" task in the multimodal discourse analysis, or Vignette 23 of the design-based research). In many cases this increase in collaborative space was due to the interface design, for instance allowing the teacher to be communicating using audio while students were responding simultaneously using text-chat. Thus, although activity design was observed to be the most significant influence upon collaborations, interface design (and task type, as described below) can have a direct impact.

6.3.6 Effective management of activity and technology enables students to concentrate on the task content

Establishing effective collaborative patterns was observed to improve the effectiveness of interactions. Since interactions in technology-based learning designs occur across all aspects of Activity, Content and Technology, management across all of these dimensions is required as follows:

- Content: clear explanation of the curriculum-based exercise/s to be covered (task specification)
- Activity: allocating roles, stating learning objectives such as process above solution, explaining how students are to interact with each other (coordinating collaboration)
- Technology: ensuring students have the technological competencies to complete the task (virtual classroom competencies)
- Activity-Technology: ensuring students know how to use the technology to interact (technology based collaborative patterns)
- Content-Technology: students are aware of how to represent content using the technology (patterns of representation)

- Activity-Content: students are able to coordinate their activity regarding the content (content based collaborative patterns)
- Activity-Content-Technology: students can synergistically integrate Activity, Content and Technology to collaboratively evolve representations of concepts (distributed cognitive tool).

Observations to support these claims are found in the activity design, coordinating collaborative problem solving and representing content using technology sections of the design-based research. The coordinating collaborative problem solving section of Iteration 3 discusses how the teacher's approach to implementation had evolved throughout the design-based research process. Vignette 16 provides an illustrative example of such effects in practice.

Failure to provide adequate management of activity and technology related aspects of a learning episode may require students to hold unnecessary non-content based discussions. On the other hand, pre-empting areas where students will require explicit instructions on how an exercise should be performed can allow them to concentrate upon subject matter. This is discussed in the coordinating problem solving section of the multimodal discourse analysis results, and exemplified by the more content focused student collaboration in Iteration 3 of the "Write SoftDrinkCan" and "Applet Comprehension Questions" tasks as compared to Iteration 2.

In this study a common sequence of collaboration for the subject of textual discourse within student-centred learning episodes was as follows:

1. Activity – describing and defining the task that students were required to perform
2. Activity-Technology – discussing how the task should be completed using the collaborative technology
3. Activity-Content – working on the task and coordinating roles between people
4. Content – roles and technology use are defined so that students can make purely Content based textual discourse contributions.

Examples of this trend are illustrated in Iteration 3 the "Write SoftDrinkCan" and "Distinguish Program Features" episodes of the multimodal discourse analysis. While the trend is general, it does serve to illustrate the cascading prerequisites for Content collaborations to occur. In order for students to concentrate exclusively on curriculum matter students need to have first understood the activity, clarified how the technology will be used to facilitate collaboration, and coordinated task roles between them. By efficiently defining patterns of collaboration at stages 1 to 3 the teacher can fast-track students through to stage 4 so that they may focus their discussions purely on Content, thus promoting more efficient learning.

In cases where specific or potentially novel conceptual representations are required to complete an activity, providing guidance on how to use the technology to share those representations can lead to more efficient collaboration and learning. For instance, in Iteration 3 of the "Shallow versus Deep Copy" task the fact that a representational form had already been provided for a shallow copy meant that students did not need to spend time discussing how to depict objects and references. Guidance on how to represent array elements in Iteration 3 of the "Nested Array Loop" allowed students to share their notional machine without needing to first invent a semiotic system.

6.3.7 More authentic tasks promoted involvement and allowed a full range of understanding to be assessed

More authentic programming tasks (such as those that required students to solve a problem or meet a design specification) encouraged collaboration. The more ill-structured and complex character of authentic tasks required students to collaborate in order to solve them (for instance, see Iteration 2 and Iteration 3 of the "RadioButton to ComboBox" task examined in the multimodal discourse analysis). Such process based tasks often resulted in students asking more specific and detailed questions as opposed to tasks that dealt entirely with abstractions, encouraging more accurate formation of mental models.

Tasks that were more authentic in nature were also observed to promote heightened levels of student interest. This was observed in terms of the amount of collaboration that transpired, the quality of collaboration, and the enthusiasm students expressed (as discussed and exemplified in the Task Observation sections of the design-based research results). The situated nature of authentic tasks allows students to embed their practice in contexts resembling those in which knowledge will be required, therefore facilitating transfer.

More authentic tasks incorporate all stages of the action-process-object cycle, allowing the evolving nature of students' underlying mental models to be shared. Authentic tasks require students to work on a concrete problem, thus engaging their declarative and procedural knowledge. As students attempt to apply learning from other episodes to the current context and develop abstractions from their problem solving attempts, conceptual thinking is engaged. Performing this in a public space using teacher-led or student-centred activity designs allows the abstraction process to be shared by all participants. Thus the level of understanding at the declarative, procedural and even conceptual level is made visible. This is observed in Vignette 21 of the design-based research, as well as Iteration 2 and Iteration 3 of the "RadioButton to ComboBox" task.

Because more authentic tasks are more likely to reveal all levels of knowledge they allow the teacher to adjust the lesson to meet student needs. Throughout this study tasks that built upon student partial attempts to solve a problem coincided with greater levels of student engagement (as noted in task results from all iterations of the design-based research). Feedback and discussion could focus upon areas where students demonstrated weak or incorrect mental models. The pitch of tasks could be accurately set at the appropriate level for student understanding.

Note that there was no direct evidence to suggest that the level of knowledge (Anderson & Krathwohl, 2001) being addressed affected the levels or quality of collaboration. If students were allowed to determine the direction of the lesson then either declarative, procedural or conceptual tasks were able to promote engaging discussion. However the quality of the task was observed to influence the level of involvement. For instance, the design of the task requiring students to abstract "inheritance", "dependency", and "association" relationships from computing code promoted greater levels of mental model formation and collaboration (see Vignette 12).

6.3.8 Virtual Classroom Competencies underpin effective collaborations in web-conferencing environments

Student virtual classroom competencies were observed to have a critical impact on collaborations. For instance, in Iteration 2 of the Topic 3 "Write SoftDrinkCan" group programming exercise, students' unfamiliarity with and lack of understanding of the screen-sharing facility in the web-conferencing environment substantially compromised collaborations. Other examples of virtual classroom competencies impacting upon the effectiveness and efficiency of collaborations (collected from the "interactions using the conferencing system sections" of the design-based research) include:

- not being aware of how to use the scroll or full-screen button to increase the size of desktop broadcasts
- not understanding how to use the whiteboard tools
- not knowing how to upload files to broadcast documents they had prepared
- not understanding the mechanics of broadcasting the screen
- inadvertently communicating using private text-chat instead of public

Observations from the design-based research indicated how students often required several reminders about how to use the web-conferencing facilities to best effect. A gradual and on-demand approach to developing student virtual classroom competencies allowed skills to be more familiar to students at the time of application. The level of student competencies increased as more student-centred designs were applied.

Of more impact than student virtual classroom competencies upon discourse and learning were teacher competencies. For five of the twenty-four episodes analyzed as part of the multimodal discourse analysis, insufficient teacher virtual classroom competencies critically impacted upon the effectiveness of collaborations and the educational quality of the sequence. The teacher is not only required to make more advanced use of the interface during learning episodes, but is also responsible for providing troubleshooting support when students experience technical problems. Examples of the teacher misunderstanding or misusing the virtual classroom (drawn from the "interactions using the conferencing system sections" of the design-based research) include:

- Not understanding functionality – not understanding how the access privileges of students will affect access to tools such as the synch button and the whiteboard, not understanding that minimizing the browser window would cause student text-chat to appear in mini-bubbles
- Not appreciating the student view – forgetting that different screen sizes will affect the amount of solution documents seen, setting audio too loud or soft, forgetting to broadcast the desktop when conducting a screen-share explanation, forgetting that students cannot make text-chat contributions when full-screen mode is being used, forgetting that turning the "synch" button off may prevent students from seeing the relevant parts of the solution
- Mistaken use – posting private messages instead of public messages through the text-chat, forgetting to minimize the web-conferencing browser window during a screen-share so that student text messages will be provided in pop-up windows, responding to student audio problems using audio, unintentionally leaving the microphone on during mid-lesson breaks

- Poor group-work room management – not knowing whether students can login to multiple rooms, not knowing how audio functions in multiple rooms, not switching layouts for different group-work interface designs
- Design errors – not being aware of note-pods on two separate layouts being linked and then replacing the contents with the wrong information, designing a group programming interface using screen-sharing and text-chat so that the IDE operator had no direct way to communicate with their peers

The gradual way in which these skills develop was notable, with critical errors still being made right up to the last lesson of Iteration 3 (as discussed in the design-based research results for this iteration). While the instances of teacher not understanding how to use the web-conferencing tools were quickly overcome once identified, accidental misuse of the technology was more persistent. Understanding of the web-conferencing system also underpinned the capacity to spontaneously redesign the interface based on the changing collaborative and representational needs of the learning episode. To this extent developing teacher virtual classroom competencies is a critical mechanism by which teaching and learning through web-conferencing environments can be improved.

6.3.9 The capacity to dynamically redesign web-conferencing environments affords new possibilities for supporting conversational approaches

In conversational approaches the direction of discourse is negotiated (Laurillard, 2002; Waite, Jackson, & Diwan, 2003). This means that the collaborative requirements of the interface may change based on the interpretations, actions and feedback of participants. There were several instances where the web-conferencing environment was redesigned during learning episodes in order to meet changing collaborative and representational needs (for instance, see Vignette 2, Vignette 9, Vignette 21, and Vignette 23). The capacity to spontaneously adjust the interface based on the type of information that needs to be shared offers students and teachers the ability to more efficiently apply Laurillard's Conversational Framework (2002).

For instance, in response to student questioning regarding coordinate systems, integrating a whiteboard into the interface for Iteration 3 of the Applet Drawing activity allowed the teacher to communicate visual information (ref. Vignette 23). The whiteboard lessened the potential for cognitive overload caused by students attempting to relate too many pieces of information in their working memory. The collaborative space was shared, allowing student understanding to be assessed through their contributions to the whiteboard. In accordance with Laurillard's (2002) Conversational Framework, based on students' actions on a description of the world the teacher was then able to provide feedback. Cognitive efficiency was promoted through using a modality that most appropriately matched the information being communicated. If the interface had not been dynamically redesigned based on the changing collaborative needs, the Conversational Framework (Laurillard, 2002) would not have been as effectively mediated.

Students were an excellent source of redesign ideas, often contributing suggestions and adjusting the interface themselves when given the opportunity. For instance, in an Iteration 2 and Iteration 3 of a student-centred programming activity to combine two Circle Applets, students decided to enlarge the note-pod of the main program. Once the other programs are integrated into the main program they become obsolete, and enlarging the combined program allows a more complete view of the code. Resizing pods allows their relative level of importance in the shared cognitive process to be represented.

Other examples of redesigns observed throughout the design based research included whiteboard use for dynamically representing array functioning, resizing text-chat pods to allow greater amounts of contributions to be reviewed, and incorporating two note-pods into the main room interface so that group-work solutions could be copy-pasted for easy comparison and contrast. In each case the adjustment of the web-conferencing tools allowed more efficient mediation of activity and representation of content.

6.4 Web-Conferencing Learning Design Framework

6.4.1 Techno-pedagogic patterns

The intention of design-based research is to develop design principles for supporting teaching and learning (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2004; Sandoval, 2004; The Design-Based Research Collective, 2003). The analysis conducted in this study as summarized in the discussion above implies a framework of learning designs based on the level of student mental model development and the level of knowledge being addressed. The framework outlines how the web-conferencing environment can be designed to effectively mediate desired types of activity for different levels of knowledge. The patterns of meaning making have been described as techno-pedagogical patterns, where a techno-pedagogic pattern is a pedagogical pattern based on technology as a mediator for collaboration and thinking.

Techno-pedagogic patterns have been distinguished from pedagogic patterns in that the technology is essential to implementing the pedagogy, and as such their descriptions highlight how the technological affordances are leveraged to implement the approach. Applying particular techno-pedagogical patterns allows them to be more easily adopted in subsequent learning episodes. They form a functional specialization that becomes familiar to students (and the teacher), hence reducing the amount of activity and technology related discussion required to utilize them.

Table 36 contains thumbnail summaries of the techno-pedagogic patterns that comprise the web-conferencing learning design framework. Some of the patterns such as the "Question-Response" and the "Instructed Teacher" were used from the first iteration of this study, while others such as the "Teacher-led Representation" and the "Student Representation" did not evolve until the end of the design research process. These nine patterns are not an exhaustive set of learning designs for teaching in web-conferencing environments, but rather an essential collection of standard approaches which can form the basis of a teachers' design repository. They reflect the accumulated understanding derived by the end of the three iterations analyzed in this study.

If students have no or weakly formed understanding of content matter then a teacher-centred approach allows fundamental mental model forming information to be transmitted. If students have acquired an understanding of individual items of information then a teacher-led approach allows students to learn other knowledge chunks and observe how the pieces may be synthesized. If students understand components of knowledge then student-centred group-work approaches allows them to collaboratively interrelate knowledge by negotiating solutions with their peers. While it is acknowledged that amongst a class or even within an individual student the level of knowledge cannot be precisely defined at a single level, this fading approach to scaffolding provides a general framework for considering the level of teacher control in a learning episode.

	Declarative	**Procedural**	**Conceptual**
Unistructural **(Teacher-Centred)**	**Fact-Share** The teacher uses audio and pre-prepared artifacts to provide students with factual knowledge. Students comment using text-chat if required.	**Modelling Process (e.g. Programming)** The teacher uses audio and screen-sharing to describe how to perform a process. Students comment using text-chat if required.	**Explanation** Teacher uses audio and pre-prepared diagrams (either on documents or whiteboard) to explain concepts. Students comment using text-chat if required.
Multistructural **(Teacher-Led)**	**Question-Response** The teacher uses audio and visual stimulus to prompt students for responses to questions. Students use text-chat to respond (or audio for more extensive individual responses)	**Instructed Teacher** The teacher uses audio and screen-sharing to prompt students for directions about how to perform a process. Students use text-chat to respond (or audio for more extensive individual responses)	**Teacher-Led Representation** The teacher uses audio to guide students through the construction of a conceptual representation on the whiteboard. Students use audio but may choose to use text-chat to contribute thoughts while the teacher is speaking.
Relational **(Student-Centred)**	**Collaborative Definitions** Students use note-pods and audio to collaboratively compose sets of definitions or factual information. The teacher uses audio to address the class or a particular group (or text-chat to address individuals).	**Collaborative Process (e.g. Programming)** Students use note-pods with audio to collaboratively perform a constructive process (e.g. write a computer program). The teacher uses audio to address the class or a particular group (or text-chat to address individuals).	**Student Representation** The students use a whiteboard and audio to collaboratively construct a conceptual representation. The teacher uses audio to address the class or a particular group (or text-chat to address individuals). A note-pod may be used instead of a whiteboard if the information is textual rather than visual.

Table 36 – Design Framework for Teaching in Web-conferencing Environments

The interfaces afford representation of mental models at the level of knowledge being addressed. With teacher-centred approaches the text-chat modality allows students to contribute factual information to demonstrate a unistructural understanding. With teacher-led approaches the more numerous and extensive contributions that students are encouraged to make allow them to demonstrate a multistructural understanding. The collaborative space afforded to students under student-centred designs allows them to complete all aspects of the problem solving process, and hence demonstrate a relational understanding.

The nine learning designs are described in the following sub-sections as techno-pedagogic patterns. The educational context, influencing forces, proposed solution, advantages and limitations of each design is explained in accordance with recommendations for pedagogical pattern specification (Derntl & Botturi, 2006; Haberman, 2006; Pedagogical Patterns Project, 2006). As well, the technology design rationale is specifically described to explicate the way in which the affordances of the technology have been utilized to mediate collaboration and learning. References to example learning episodes that adopted similar designs have been provided, for illustrative purposes.

6.4.2 The "Fact-Share" learning design

Context: Students may have little or no understanding of items of factual information, or a set of factual information may need to be covered quickly.

Forces: In order to build procedural and conceptual understanding students need to consolidate their understanding of declarative knowledge. This knowledge needs to become automatic. Such definitions often need to be accurately covered in a time effective manner.

Solution: The teacher uses audio and pre-prepared artifacts to provide students with definitions of the factual knowledge. Students comment or ask questions using text-chat if required.

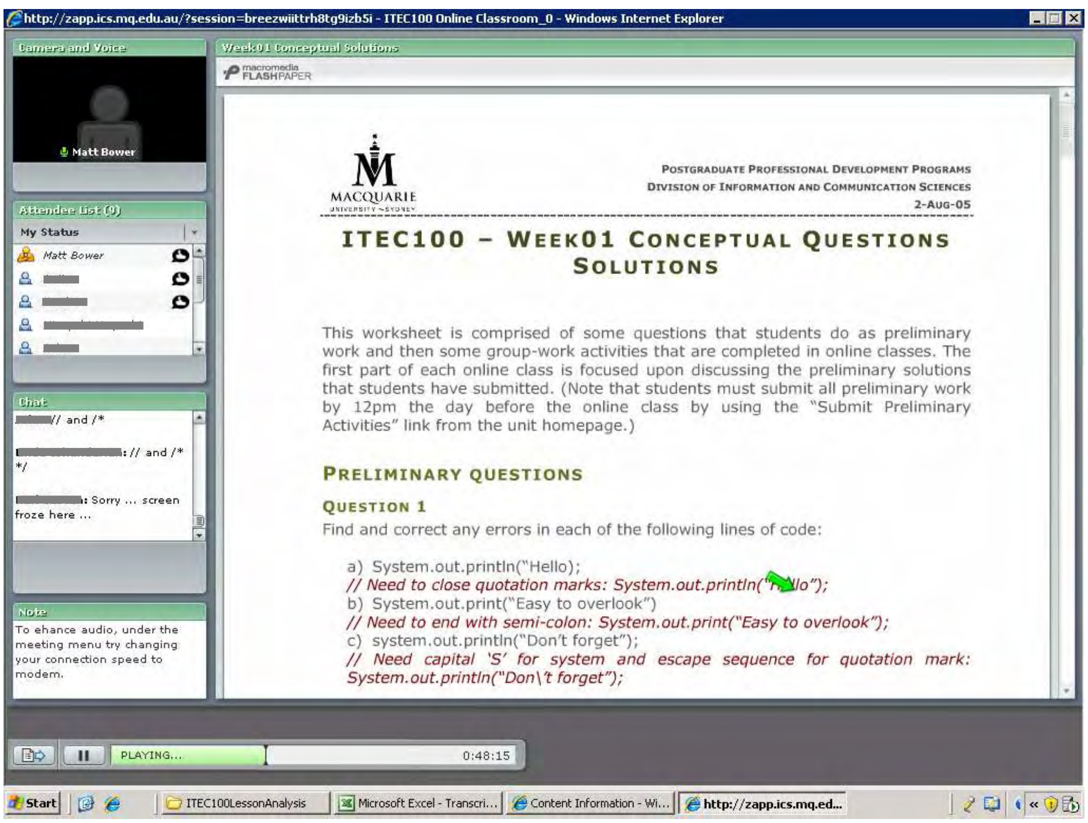

Figure 54 – Example of the "Fact-Share" learning design

Technology Design Explanation: The teacher uses audio to increase the pace of in-sequence explanation. The pre-prepared artefact promotes time efficient delivery. The small text-chat pod is congruent with the lower level of student involvement associated with teacher-centred approaches. The small text-chat pod also allows the pre-prepared artefact to occupy all but the left hand column of the interface, signalling it as the focus in the learning episode. The use of a pointer tool (such as the green arrow) may be used to highlight specific items of information being discussed.

Advantages/Disadvantages/Considerations: The use of pre-prepared artifacts and the transmissive nature of delivery can mean this approach is time efficient. Students still have the opportunity to ask questions if required, however the teacher-centred approach limits the level of student input and thus the level of understanding that they can demonstrate. The duration of the "Fact-Share" learning design may be short, and as such designing an entirely different layout may not always be warranted. This may mean that the "Fact-Share" approach may at times be applied using interfaces that serve other purposes, and may therefore contain other tools such as note-pods or file-share pods.

Example: The "Fact-Share" learning design was adopted at the beginning of Iteration 1 Topic 1 to quickly cover some syntactic concepts associated with programming in Java (see Figure 54 above). The teacher can show students common syntactic errors and provide them with model solutions.

6.4.3 The "Question-Response" learning design

Context: Students may be forming declarative knowledge and the teacher may desire to engage students at the same time as assess the accuracy of their understanding.

Forces: The teacher may wish to apply an approach that requires more student involvement than the "Tell" design, but still retain control over the pace and direction of the learning episode. A large number of short factual student responses may be required at once.

Solution: The teacher uses audio to prompt students for responses to declarative questions. Pre-prepared visual stimuli may be used to support audio stimuli, in accordance with the multimedia learning principle (Fletcher & Tobias, 2005). Students use text-chat to respond (or audio for more extensive individual responses).

Technology Design Explanation: The increased size of the text-chat pod allows more students' contributions to be reviewed at once and signals to students an increased emphasis upon their input (as compared to the "Tell" learning design). The teacher still uses audio as it allows rapid coordinating and explanatory contributions to be made whenever necessary. The movement of the chat-pod from the left hand column to along the bottom of the screen allows the attendee pod to be elongated, so that many (if not all) participants can be seen. This enables the participation of students to be more easily monitored.

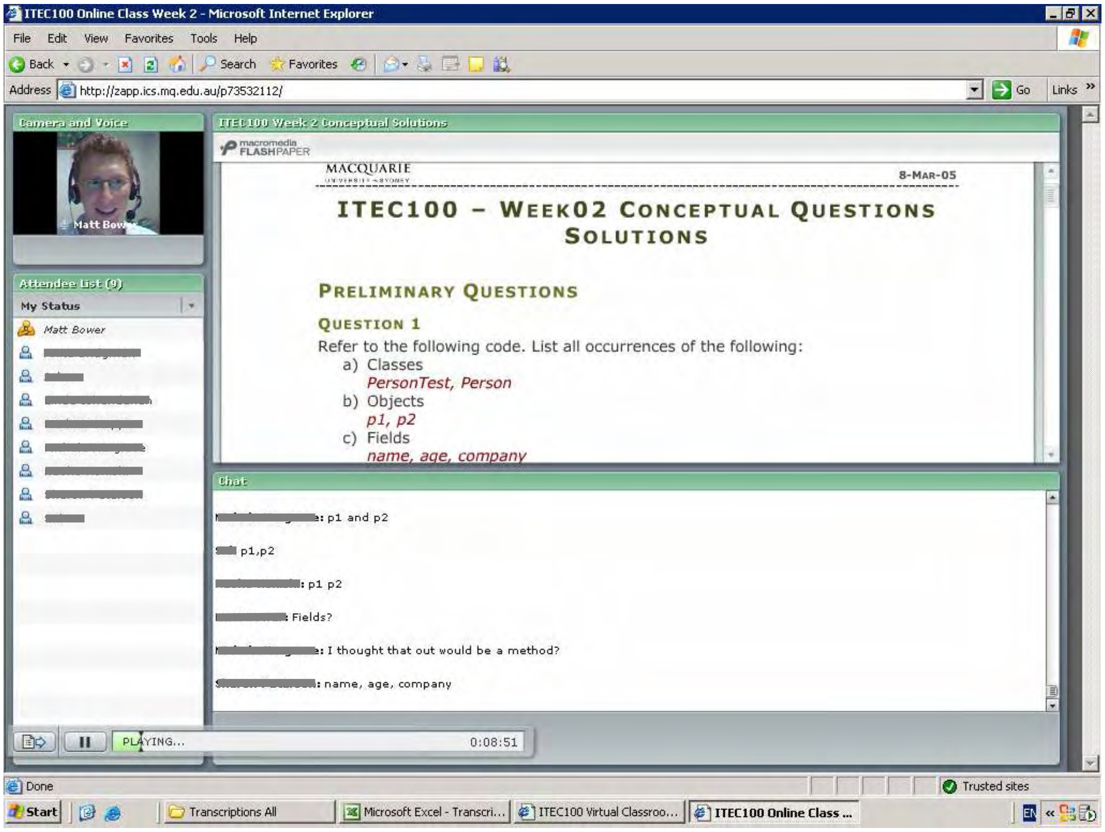

Figure 55 – Example of the "Question-Response" learning design

Advantages/Disadvantages/Considerations: Advantages of the "Question-Response" approach include:

- it requires little explanation as students are familiar with the approach from their face-to-face learning experiences
- many student responses can be harvested in a short space of time without interfering with one another (in the case of text responses)
- student responses are captured in text for easy review, comparison and contrast
- responses do not interfere with the commentary of the teacher (in the case of text responses).

However, because students are not required to interrelate or apply the pieces of information it is not possible to determine whether they have achieved more than a multistructural understanding of the curriculum matter to which the declarative knowledge refers.

Teachers should monitor whether all students are participating. Note that even though some students may not be contributing they may be intently engaged in the 'vicarious' learning (Bandura, 1977) that the "Question-Response" approach affords.

Example: The "Question-Response" learning design was used in Iteration 1 of Topic 2 (see Figure 55). Students were required to identify different types of identifiers (objects, classes, methods etc) in a program. Students could all simultaneously contribute declarative responses to the several factual questions that the teacher posed.

6.4.4 The "Collaborative Definitions" learning design

Context: Students may have acquired individual items of factual knowledge. Allowing them to direct a task involving a set of declarative knowledge may consolidate their understanding, promote automaticity, and allow them to abstract the underlying concepts.

Forces: An equally accessible solution space is required to allow collaboration. Declarative information should be easily represented. No complex interrelation of information is required.

Solution: Group-work rooms providing a note-pod solution space is provided allowing students to easily create sets of declarative information. Students use audio to coordinate co-construction of the solution.

Technology design: The solution space (in this case on the right hand side of the interface) is large enough to accommodate all of the declarative information that students contribute. Stimulus learning resources are placed in the interface, obviating the need to refer to external documents and thus averting split attention (Ayres & Sweller, 2005). Using audio (as opposed to text-chat) allows students to effectively discuss activity and negotiate content while they are contributing to the textual solution space (Low & Sweller, 2005).

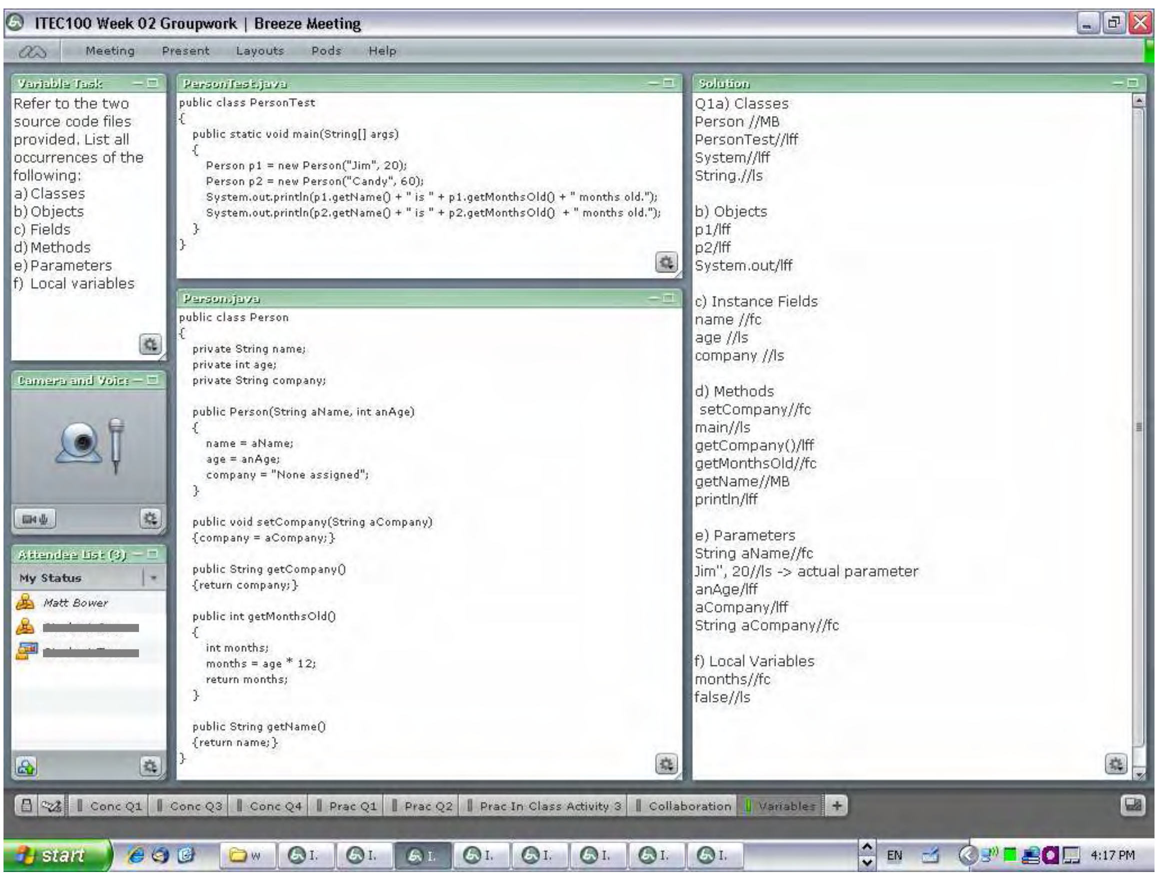

Figure 56 – Example of the "Collaborative Definitions" learning design

Advantages/Disadvantages/Considerations: Students are actively engaged in tightening their declarative definitions rather than passively receiving information from the teacher. The teacher is able to immediately assess whether the group's factual responses are accurate. Observing several correct pieces of declarative knowledge that relate to the same curriculum matter allows the teacher to assess whether students have accurately abstracted the underlying concept.

The "Collaborative Definitions" learning design may be slower to implement than the teacher-led "Question-Response" approach since students are required to coordinate activity. A group leader may be appointed to address this. Distributed process loss (Neale, Carroll, & Rosson, 2004) caused by not knowing the identity of the contributor to a note-pod can be overcome by creating a communal rule that students append initials after their line of text.

Example: In Iteration 2 and Iteration 3 of Topic 2 students created a list of all the classes, objects, fields, methods, parameters and local variable references in a program. The lists of declarative information students provided allowed the teacher to gauge the extent to which students had abstracted the concept of how each of these references were represented in computer programs. An example is illustrated in Figure 56.

6.4.5 The "Modelling Process" learning design

Context: Students may have little or no understanding of how to perform the steps required to complete a process. For example, students may not be able to use an IDE to write and run a computer program.

Forces: Observing others allows procedural knowledge to be demonstrated in contexts similar to that in which the skills will be required (Bransford, 1979). Using dynamic visual modalities allows process based information to be communicated in a way that requires minimal encoding and recoding, thus promoting cognitive efficiency (Salomon, 1994).

Solution: The teacher broadcasts the desktop to demonstrate how to perform a process. Audio descriptions overlay the visual transmission in accordance with the modality principle (Low & Sweller, 2005). Students comment using text-chat, if required.

Technology Design Explanation: Using audio allows the teacher to make rapid contribution of explanatory discourse. The large screen-share signals that the broadcast is the central focus of the learning episode, as well as allowing a visual representation with higher resolution. Using audio and visual modalities together leverages students' dual processing capabilities (Low & Sweller, 2005). The small text-chat pod provides more space for the screen-share pod, and indicates less emphasis on student contribution.

Advantages/Disadvantages/Considerations: The "Modelling Process" learning design is useful to introduce new processes because not every underlying step has to be explicated; students can learn by observation. This promotes more effective learning. As well, the audio explanation combined with a demonstration allows teachers to offer students a "cognitive apprenticeship" (Brown, Collins, & Duguid, 1989). The non-interfering nature of the text-chat and audio modalities allows students to make comments without interrupting the teacher's audio transmission.

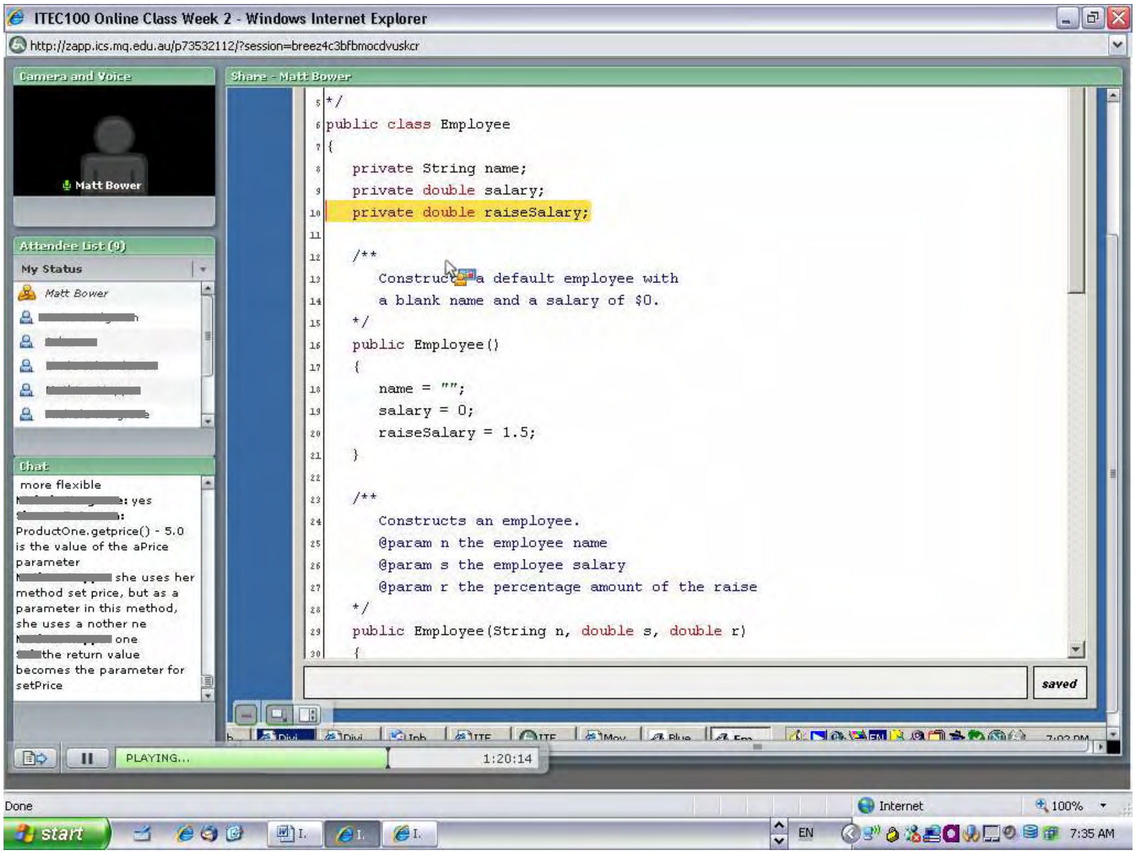

Figure 57 – Example of the "Modelling Process" learning design

In the "Modelling Process" learning design students are passive observers in the activity, with no opportunity to practise the skills that they apprehend in the discourse (i.e., there is limited potential to engage conversational approaches). As such the level of student understanding and engagement is difficult to ascertain. Regularly prompting students to indicate understanding or to ask questions may be useful for gauging correctness of pitch and appropriateness of instruction.

Example: The "Modelling Process" learning design was used in Iteration 1 of Topic 3 to demonstrate an approach to writing an "Employee" class that could raise an employee's salary by a user specified proportion (see Figure 57).

6.4.6 The "Instructed Teacher" learning design

Context: Students have individual items of process knowledge but may need to see how to sequence and integrate that knowledge as an entire process.

Forces: The teacher may want students to contribute more than in the "Modelling Process" pattern so that their level of understanding can be more accurately gauged and their level of activity can be increased. However, the teacher may wish to retain control over the learning episode in order to manage its pace and direction. Items of information related to solving the problem or performing the process may need to be contributed by students (such as lines of computer code).

Solution: The teacher uses audio and screen-sharing to prompt students for directions about how to perform a subject related process (for instance, write a computer program). Students use text-chat to contribute suggestions and offer lines of text. Students may use audio for more extensive individual responses. The teacher retains control over the pace and direction of the lesson, and is able to interject at any time with commentary or clarifying explanations. Student engagement is encouraged by delegating them responsibility for solving the problem. Engagement can also be promoted through the authentic, meaningful tasks that this learning design can encompass.

Technology Design Explanation: The text-chat pod has been made larger to accommodate more frequent and substantial contributions by students. Text-chat once again allows the students to contribute while the teacher is talking. Having the text-chat pod along the bottom of the screen rather than in the left hand column provides more space for the attendee pod, allowing student participation to be more easily monitored. The small note-pod in the bottom left corner can be used for ancillary notes, but also allows students to copy-paste multi-line text contributions (for instance, computing code) in a manner that preserves formatting. If the teacher wants the students to be able to work with the files on their own machine then a file-share pod may in some cases be included in the bottom-right hand corner of the interface.

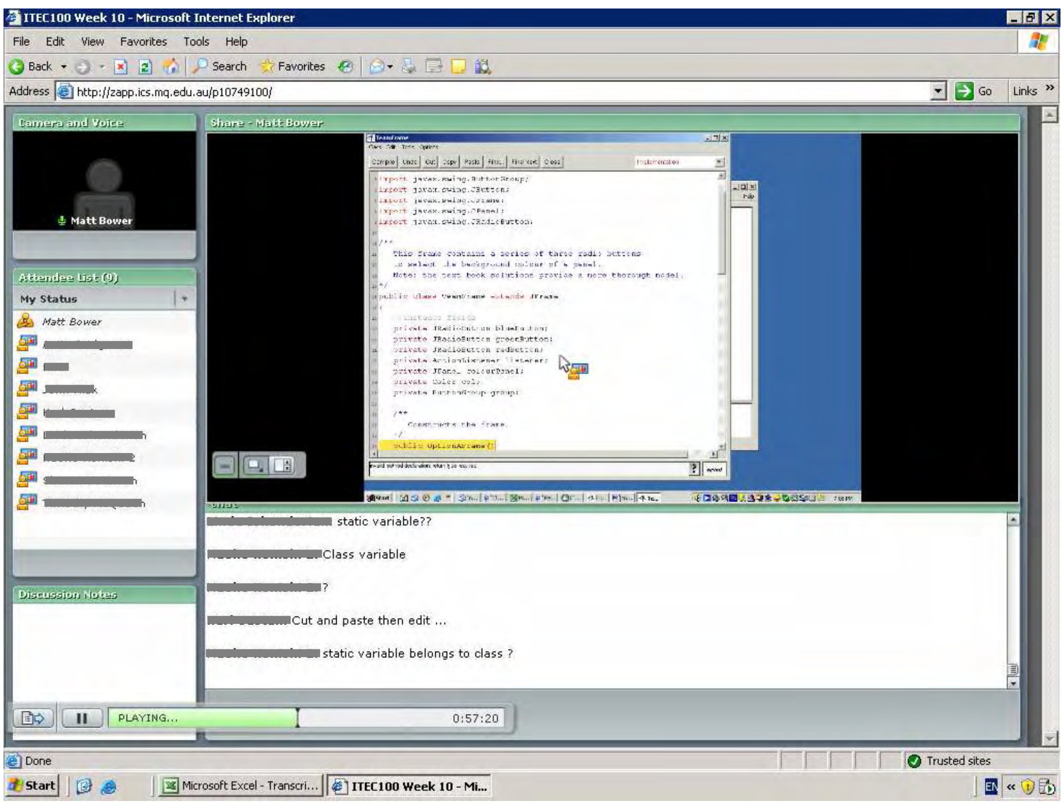

Figure 58 – Example of the "Instructed-Teacher" learning design

Advantages/Disadvantages/Considerations:
Advantages of the "Instructed Teacher" approach include:

- The dynamic, visual modality allows large amounts of process knowledge to be shared in 'cognitively efficient' form (Salomon, 1994).

- The approach affords process based distributed cognition (Hollan, Hutchins, & Kirsh, 2000), where students can combine their knowledge in a collaborative space.
- The conversational framework (Laurillard, 2002) can be engaged by virtue of the bidirectional flow of information between the teacher and students.
- Because the teacher coordinates aspects of the technology and activity the students can concentrate on the curriculum matter content of the task.
- Practical and authentic tasks provoke concrete and relevant questions that would be less likely to arise when attempting more conceptual or declarative tasks.
- The approach allows the possibility for weaker students to learn vicariously (Bandura, 1977).
- Students reveal aspects of their mental models through their suggestions.

Because the learning design is centred around a moderate level of teacher input and an emphasis on process, the level of teacher engagement and knowledge addressed can easily be adjusted based on the understanding that students demonstrate. For instance, if the students show low levels of process knowledge the teacher can easily transition into the "Modelling Process" design pattern if required. As well, the teacher may take the opportunity to support the development of abstractions by directing discussion towards more conceptual ideas, or tend to weaknesses in declarative knowledge such as items of syntax. Thus this learning design has the greatest potential to integrate a variety of activity (teacher-centred, teacher-led, student-centred) and knowledge levels (declarative, procedural, conceptual).

However, under the "Instructed-Teacher" design students can demonstrate at most a multistructural level of understanding. The teacher ultimately performs the process and can "fill in gaps" either to be time efficient or because student understanding is incomplete. Students do not demonstrate that they can complete the entire process, only that they have several component parts of the knowledge required to solve the problem. As well, although this design allows students to learn vicariously, there is also the possibility that some students disengage as others dominate the problem solving process.

Example: The "Instructed-Teacher" learning design was used in Iteration 1 of Topic 10 in order to adjust a computer program so that the background colour of a panel was set by a drop-down menu instead of radio-buttons (see Figure 58).

6.4.7 The "Collaborative Process" learning design

Context: Students have acquired the fundamental skills underpinning performing the process (for instance, operating software applications such as the IDE) and require practice in applying curriculum-based knowledge to solve authentic problems.

Forces: The active engagement of students is desired. Equal access to the solution space is required in order for the process to be truly shared. The curriculum content relating to solving the problem is more important than the operational skills underpinning performance of the process. Knowledge may need to be integrated from ancillary resources.

Solution: Provide students with note-pod solution spaces to collaboratively engage in the problem solving process. Students use audio to interact with one another. The teacher uses audio to direct commentary to all groups or individual groups, and uses text-chat to address individuals.

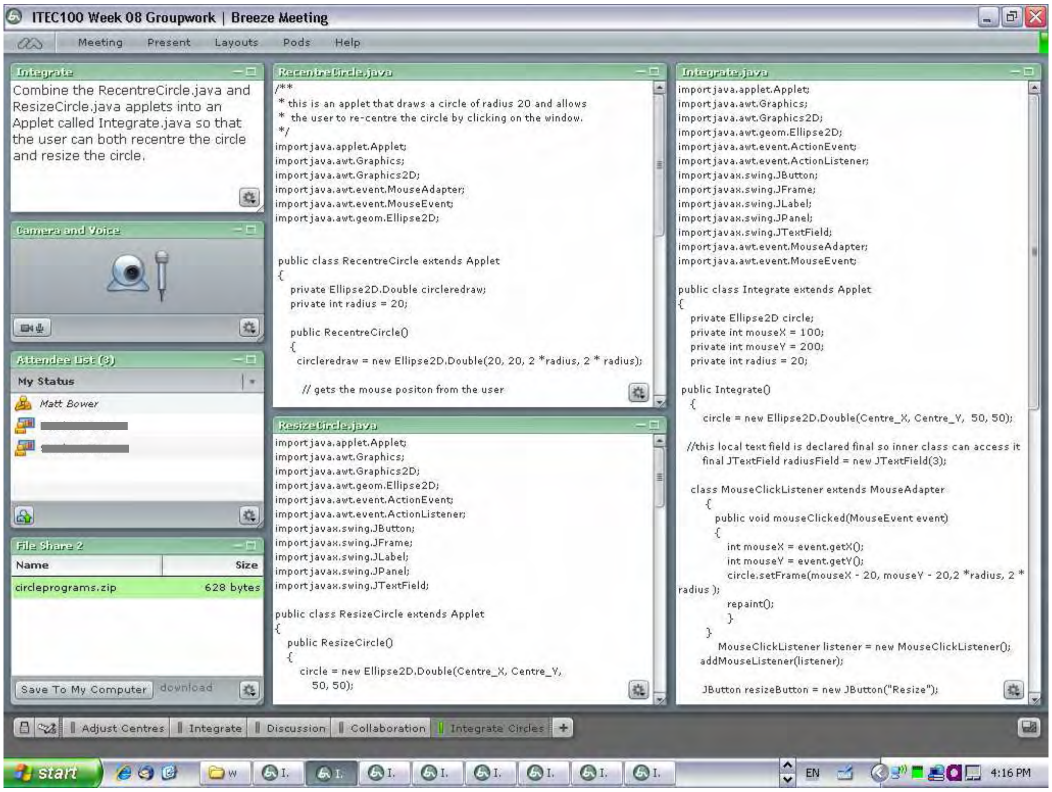

Figure 59 – Example of the "Collaborative Process" design

Technology Design Explanation: The large note-pod solution space (in this case on the right hand side of the interface) allows all students equal authoring access. The solution space is elongated to allow students to see as much of the text at once as possible. Ancillary resources are provided in the solution space (in this case middle column) to avoid split attention caused by needing to refer to external documents. The task is placed prominently in the top-left corner. Providing a clear task description in the interface is important for student-centred learning design because the teacher is not leading the activity. A file-share pod containing a zip file of the entire project is provided (bottom- left corner) so that students can download and work on the code on their own machine if required, either during or after the episode. Audio allows students to negotiate and discuss content with their peers at the same time as they contribute to the solution space.

Advantages/Disadvantages/Considerations:
Students are able to easily access and contribute to the solution space. Audio allows rapid exchange of information between students. Using audio with the visual (textual) modality takes advantage of dual processing capabilities (Low & Sweller, 2005). The group-work approach allows more collaborative space per person. Engaging in a concrete and authentic problem solving process stimulates questions and discussion that are helpful to students' practice. Having students responding to student questions heightens the level of engagement and ownership of their learning. A relational level of understanding can be assessed by virtue of running a groups' program; if students have been able to perform all of the steps to solve the problem they have demonstrated they understand how all of the curriculum matter knowledge items interrelate.

To overcome distributed process loss (Neale, Carroll, & Rosson, 2004) caused by not knowing the identity of the contributor, a communal rule requiring students to append their initials to any contribution may be established. Audio should be used to indicate the focus when discussing specific parts of the solution. Students should be encouraged to be wary of version control issues if they are copying and pasting code to and from their IDE. The "Collaborative Process" design can take longer than teacher dominated approaches. Appointing a group leader may be useful to help coordinate activity.

Example: In Iteration 2 and Iteration 3 of Topic 8 students used a note-pod solution space to collaboratively construct a program that both resized and re-centred a circle (based on two programs that perform each of these functions in isolation). See Figure 59.

6.4.8 The "Explanation" learning design

Context: Students have little understanding of a concept. They need to know how items of knowledge interrelate

Forces: The teacher needs to present and inter-relate several pieces of information underpinning a concept in a time efficient manner.

Solution: The teacher presents a pre-prepared document or whiteboard diagram and uses audio to deliver an explanation. Students can use text-chat to ask questions or provide short declarative responses.

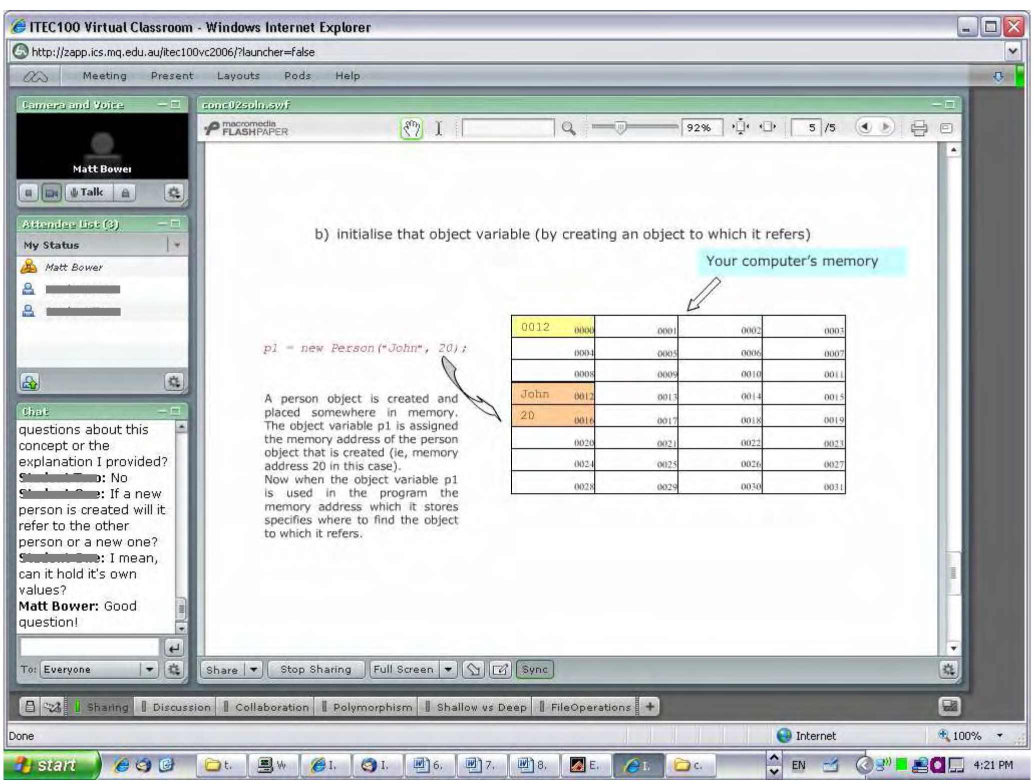

Figure 60 – Example of the "Explanation" learning design

Technology Design Explanation:
The majority of the interface is dedicated to the presentation of the pre-prepared resource (document or diagram). This signals the central role of the resource in the learning episode. All relevant information can be incorporated into the same space, averting "split attention" (Ayres & Sweller, 2005). Using audio for teacher commentary allows extensive rapid contribution of discourse. Ideally unnecessary pods are removed.

Advantages/Disadvantages/Considerations:
Teacher audio complements the visual modality of the pre-prepared resource according to both the modality principle (Low & Sweller, 2005) and multimedia principle (Fletcher & Tobias, 2005). If students have questions or comments they can post them using text-chat, which does not interfere with the teacher's audio explanations. Pre-preparing the visual resource enables more time efficient delivery.

On the other hand, it is easy for students to disengage under the "Explanation" learning design because little or no action is required on their part. The teacher's conceptual explanations can be of extended duration, and if students make no contribution then the correctness of pitch and level of student attention is difficult for the teacher to monitor.

Example: In Iteration 1 of Topic 2 the teacher provides a simplified explanation of how objects are laid out in memory so that students may develop the concept of a "reference". A whiteboard is used in Iteration 3 of Topic 2 to invoke the "Explanation" design, when the teacher explains polymorphism by first having placed all programming code on one page (thus avoiding split attention). An example of this approach is represented in Figure 60.

6.4.9 The "Teacher-Led Representation" learning design

Context: Students have individual pieces of knowledge underpinning a concept but have not resolved how all items of information are interrelated.

Forces: Many items of information may need to be interrelated. The conceptual nature of the subject matter requires operation at the level of description of the world (Laurillard, 2002). Semiotic forms are required to represent curriculum-based concepts.

Solution: The teacher guides students through representing a concept (often a dynamic one) on the whiteboard. The teacher uses audio. Students use audio or text-chat, depending on the size of the comment that they are making and the number of people in the episode.

Technology Design Explanation: The whiteboard provides a solution space that can be equally shared by the teacher and the students. Visual and textual information can be organized and interrelated in the one area, allowing more flexible representation than other modalities and avoiding split attention (Ayres & Sweller, 2005). Using text-chat allows many students to provide suggestions at once. Using audio enables discourse to occur during whiteboard operation without splitting attention. As well, the combination of a visual and auditory modality allows both the modality principle (Low & Sweller, 2005) and multimedia principle (Fletcher & Tobias, 2005) to be leveraged. Students have the opportunity to dually process and encode the information (Pavio, 1986). Other pods such as the file-share pod can be incorporated in order to share relevant resources.

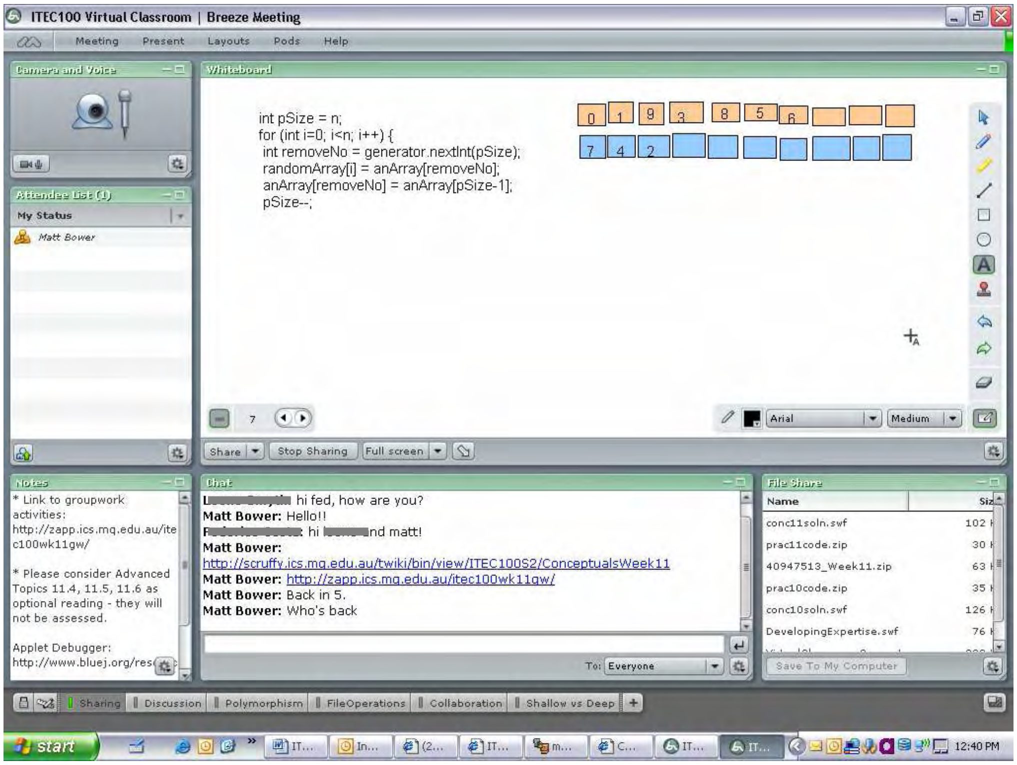

Figure 61 – Example of the "Teacher-Led Representation" learning design

Advantages/Disadvantages/Considerations: Advantages of the "Teacher-Led Representation" approach include:

- Students must apprehend representational forms and are provided with guided practice in applying those semiotic representations.
- The teacher can provide support and modelling regarding how knowledge can be appropriately represented, thus expediting the exercise.
- The approach engages a discourse between students and the teacher where students' mental models are revealed and the teacher can provide feedback (in accordance with the Conversational Framework, Laurillard, 2002).
- The teacher retains control of the direction and pace of the episode while still affording students the opportunity to engage with activity.
- Students can participate in the evolving description of dynamic models.

In order to contribute to the conceptual representation students need to be confident in the use of the whiteboard tool, otherwise unnecessary activity and technology discourse may occur. The process of evolving a conceptual representation on the whiteboard provides a clear model, but can be slow. Students can evidence a multistructural level of knowledge, but because the teacher guides the process students do not indicate a complete understanding of all aspects of the concept in a "relational" sense (Biggs & Collis, 1982).

Example: In Iteration 3 of Topic 11 the "Teacher-Led Representation" approach is used to demonstrate how a piece of code allows random permutations of the first ten non-negative numbers to be formed using two arrays. The code is placed in the solution space and the teacher and students discuss how to represent the notional machine and emulate the program execution on the whiteboard (see Figure 61).

6.4.10 The "Student Representation" learning design

Context:

Students have an understanding of the main knowledge that comprises a concept. Co-constructing a shared representation allows them to evidence their understanding and consolidate their knowledge.

Forces:

Equal access to the solution space is required for students to collaboratively create a shared representation. Flexible representation is required to enable visual and textual information to be organized and interrelated. As students are actively engaged with negotiating and constructing the representational form a non-interfering discursive media is preferable. Greater individual contribution is desirable to allow students more opportunity to represent their understanding and be involved in discussions.

Solution:

Groups of students co-construct conceptual representations on a shared whiteboard. The students use audio and the teacher can broadcast audio to all rooms, individual rooms, or send text-chat to individuals.

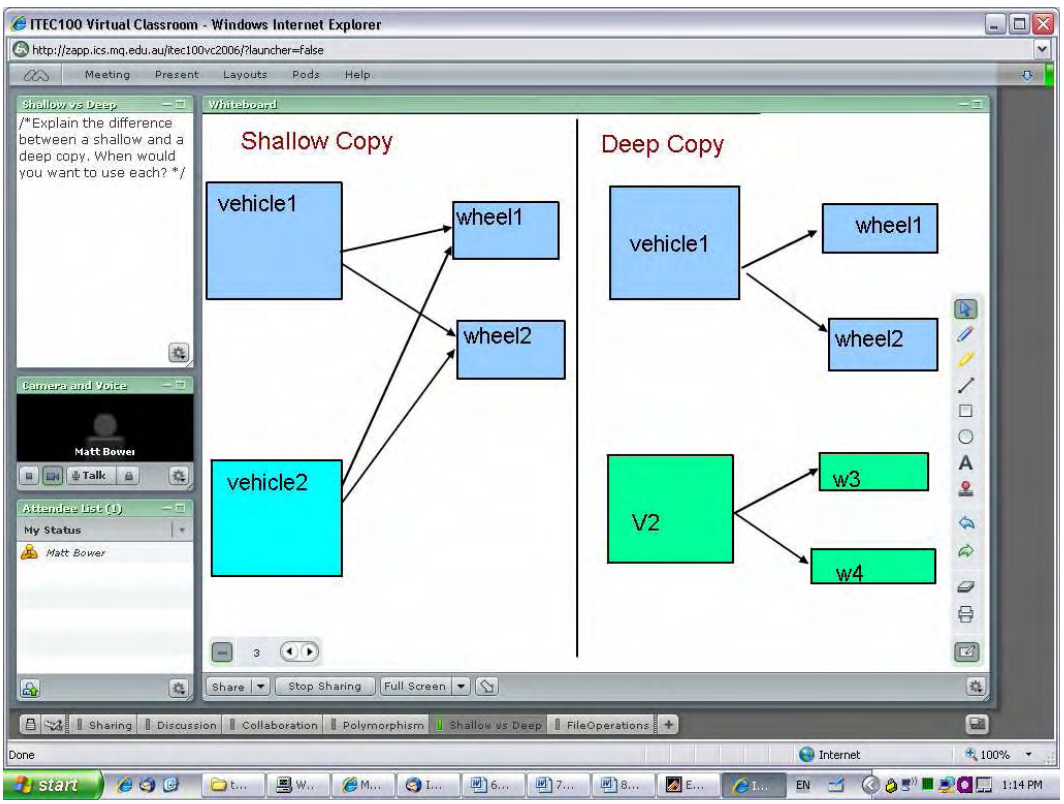

Figure 62 – Example of the "Student Representation" learning design

Technology Design Explanation:

The whiteboard occupies the majority of the interface to allow clear representation of many items of information. The task is provided in the interface (top-left corner), avoiding split attention (Ayres & Sweller, 2005) that may have been caused by referring to external documents. It is important for task prescription to be clearly defined because in student-centred approaches the teacher is removed from the activity. Having students use audio leverages the inherent advantages of the modality principle (Low & Sweller, 2005). The interface may contain an exemplar representation, allowing students to represent their own conceptions without the need to invent a semiotic system. Ideally redundant pods are removed.

Advantages/Disadvantages/Considerations:
Through negotiated construction of representations students are exposed to the mental models of others, allowing them to compare and contrast schema. Students are able to be more actively involved than in teacher-centred or teacher-led approaches, allowing their mental models to be more fully revealed. The interface provides a flexible means of organizing and interrelating information. Using audio for group-work allows rapid contribution of extensive student discourse at the same time as the visual modality of the whiteboard is being used. Because students build the representations without teacher intervention it is possible to assess whether a relational level of understanding has been achieved. The teacher can provide scaffolding if required, which may be targeted at the class, group, or individual level.

Disadvantages of this approach include that although the representations are clear, they can take considerable time to construct. Providing students with exemplar representations may be used to increase the efficiency with which students build their own.

Example: In Iteration 3 of Topic 9 students represent the difference between a shallow copy and a deep copy on a whiteboard. Using audio allows them to discuss how the concept should be represented. The way in which students represent the output of series of if-then-else statements in Iteration 3 of Topic 5 provides another example of this learning design. An example of this is represented in Figure 62.

6.4.11 Implementing the designs

Successful implementation of the designs requires that teachers address the issues relating to distributed process loss, virtual classroom competencies, task management, collaborative space creation and dynamic design that have evidenced themselves during this study.

Distributed process loss is particularly relevant for student-centred-learning designs, where students are responsible for coordinating activity. Establishing communal rules of engagement such as appending initials after note-pod contributions and encouraging students to be explicit about the part of a resource upon which they are focusing can help overcome distributed process loss.

Virtual classroom competencies underpin successful collaboration in the web-conferencing environment. A structured introduction to the system and providing students with access to the environment outside lesson time enables students to develop their skills and confidence. A staggered rather than an all-at-once approach to developing student virtual classroom competencies prevents technology training from overshadowing learning of the curriculum matter at the beginning of a subject and allows skills to be taught at a time closer to their use.

In this study collaborative efficiency was achieved when learning episodes were effectively managed. Clearly prescribing the task and its objectives, how people are expected to collaborate, and how the technology can be used to represent conceptions allow students to concentrate on the curriculum matter. Failing to define these elements can mean that students conduct unnecessary discourse relating to coordination of activity and the use of technology which distracts them from focusing on the content to be learned.

In determining the amount of collaborative space that students are afforded, the teacher is the major influence over the level of student involvement. The movement from transmissive to more interactive (conversational) and student-centred approaches can be supported by more collaborative interface designs and more holistic tasks, but begins with the teacher's determination to hand over collaborative space to the students. This involves the conscious decision not to dominate communications and to encourage student participation.

As students have greater influence over the direction of learning, dynamic adjustment of the interface may be required. Teachers should be aware of the need to change the interface so that information can be communicated in cognitively efficient forms. Students as end users should be encouraged to suggest changes to the interface, and in the case of student-centred activities make adjustments themselves. In this way web-conferencing environments can enable more effective implementation of conversational approaches.

These issues illustrate that teaching effectively in web-conferencing environments is not as simple as transferring face-to-face approaches. The affordances of the web-conferencing platform allowed a new range of learning designs (pedagogical patterns) to be applied and also impose several constraints that need to be managed. Salmon (2000) notes that introducing technology into teaching and learning without adequate support and training is likely to result in "meager and unsuccessful" outcomes (p. 55). Given the inherent complexity of teaching using web-conferencing systems it would appear that substantial professional development is appropriate. Development of virtual classroom competencies, techniques for overcoming distributed process loss, approaches to managing learning episodes, provision of collaborative space and how to apply dynamic designs provide suitable foci for web-conferencing teacher education programs.

6.5 Reflections on This Study

Having responded to the research question (and its corresponding sub-questions) and having developed a situated framework for teaching and learning using web-conferencing, this study draws to a close. However, before concluding, it is appropriate to reflect upon this study in the broader context of technology-based learning. The following sections consider the efficacy of the methodology that was adopted, suggest potential implications of this research for general e-learning design and practice and present possibilities for future work in light of the limitations of this study.

6.5.1 Reflections on the methodology

Analyzing the data using both the design-based research and multimodal discourse analysis provided a means for establishing validity in cases where similar results were derived using both methods. For instance, the critical influence of activity design on interactions, the way in which teacher management of task enabled students to focus on content, and how teacher questioning changed the nature of student contribution rather than increasing it were all validated through triangulation of the methods. Having the more objective multimodal discourse analysis confirm findings in the design-based research was particularly important to validate that a degree of impartiality was achievable when the researcher was also the designer and practitioner.

As well, in several instances the multimodal discourse analysis was able to provide results that the design-based research could not, and vice versa. For instance, the discourse analysis provided objective measures of differences in contribution rates for different types of activity designs (for the data analyzed). On the other hand the design-based research was able to detect a greater range of effects across the entire dataset, such as the types of virtual classroom competencies that impacted upon the success of lessons.

The design-based research allowed the whole dataset to be analyzed and the researcher's subjective observations to be incorporated into the analysis. It underpinned the development of strategic design improvements. This in turn led to a greater understanding of web-conference based learning and the development of a design framework. The multimodal discourse analysis provided a tool with which to conduct etic investigation. It enabled descriptive statistics to be calculated and objective intertextual analysis to be performed. Thus synthesizing the design-based research and multimodal discourse analysis not only increased dependability but also allowed a greater range of results to be achieved than would have been possible if only one or other of the methods was applied. This supports the notion that mixed methods research can provide an effective means of improving the reliability and sensitivity of technology-based learning research.

6.5.2 Implications of this study for technology-based learning design

This study has addressed a current gap in the technology-based learning field by deriving a theoretically based and empirically grounded design framework for teaching and learning in web-conferencing environments. While this advances the field of teaching and learning using web-conferencing, the outcomes of this study are also relevant to teaching and learning using other online technologies, as described below.

The varying utility of modalities under different learning circumstances that was observed in this study can be directly applied to other learning contexts. Text-chat is useful for sharing short pieces of declarative information in circumstances where many people may want to contribute simultaneously. Audio is suitable for more rapid and extensive contribution by a single participant, or when more tightly coupled interactions are required in small group situations. Note-pods (or synchronous text areas) afford group sequencing of information and are thus appropriate for collaborative authoring. Screen-sharing allows process-based desktop operations to be shared in a cognitively efficient manner. Whiteboards are suitable for collaborative concept representation due to their ability to visually interrelate several items of knowledge that participants contribute. Understanding the circumstances under which different modalities are appropriate accelerates the design process.

Technology-based learning design cannot and should not simply be considered as transplanting face-to-face approaches to online environments – there are clever ways in which tools can be used in combination to improve cognitive and communicative efficiency beyond that possible (or practically achievable) in face-to-face environments. In this study examples included having multiple student contributions using text-chat at the same time as the teacher was speaking, or multi-student collaborative authoring using text areas and audio. The capacity for educators to determine the mode/s of communication (audio, chat, drawing on whiteboards) that can or cannot be used by participants allows clusters to be designed in ways that transcend the face-to-face environment by targeting the particular cognitive and collaborative requirements of the learning episode. There are undoubtedly other possible successful clusters using different combinations of learning technologies that have not yet been discovered or reported.

Because there is almost inevitably some contextual information loss when interacting using technology, additional strategies for managing collaborations in online learning environments will almost certainly be required. In this study specific approaches were applied such as tagging text contributions to help ensure the identity of the contributor was known, or signalling the focus of attention using audio and visual highlighting. Educators need to be aware of the potentially crippling effect of distributed process loss, and apply these and other tactics (as appropriate for the learning environment being used) in order to reduce its impact.

Teachers should utilise the more contribution-oriented technologies that have evolved out of the Web 2.0 movement to engage more interactive and collaborative learning – in this study having students represent their understandings in a shared space increased the quantity of their contribution, and improved the capacity for the quality of their mental models be gauged. In the web-conferencing environment the interactive and collaborative learning design increased student contribution by 97% and 618% respectively. Providing collaborative space using other technologies may potentially reap similar results. More contribution-oriented learning episodes tended to reveal the quality of student mental models and hence allowed more appropriate feedback and remediation to be offered (either by the teacher or peers). This effect may be expected in other technology-based learning environments.

Thus given the proliferation of blogs, wikis, discussion boards, and synchronous communication tools such as Skype, there is little excuse in the contemporary era for limiting learning design to transmissive approaches. As in face-to-face classes, teachers using online technologies may be tempted to dominate learning episodes by exhaustive efforts to demonstrate what they know about their subject. However successful teaching and learning depends on students' effortful engagement with the curriculum matter. Given the advantages of interactive and collaborative learning in terms of mental model development and assessment, the new age of online learning design must be about student contribution.

The management framework for attending to the Content, Activity and Technology (and combinations thereof) components of the web-conference based learning episodes that was presented in this study can be applied to other online learning environments. In this study providing clear specification about how students should interact and represent their understandings avoided the need for students to conduct unnecessary coordinating conversation, thus allowing them to focus on the curriculum matter being addressed. However interactive and collaborative learning designs in other environment will also require students to engage with a task and with each other through the mediating tools, and so explicit instructions on how to coordinating activity between them, represent their knowledge, and leverage the technology can be used to accelerate the learning process. Specific approaches to managing these aspects of the learning episode will obviously vary instance by instance depending on the subject matter being considered, the collaborative design that has been selected, and the mediating technologies being used.

There is no reason to suggest that the heightened levels of engagement and interest associated with the more authentic online learning tasks in this study would not occur in other environments. More holistic and relevant tasks promoted discussion on all levels of knowledge, which in turn allowed mental models to be more effectively assessed. Prescribing authentic tasks that students perceive as applicable in their work or life in accordance with guidelines outlined by Herrington, Oliver & Reeves (2002) is an useful design principle for improving learning in any environment.

Developing student and teacher technological competencies is a direct way to improve the ability of participants to collaborate and learn using technology. In the web-conferencing environment not being aware of how to use the tools, mistaken use of the tools, or sub-optimal use of the tools, was repeatedly observed to compromise the effectiveness of learning episodes. Overcoming those misunderstandings allowed participants to immediately interact and collaborate more effectively. In all other technology-based learning environments students and teachers inevitably need to use the tools at their disposal to interact, and understanding how to most effectively apply the affordances of tools can only serve to improve their ability to collaborate. As such, developing technological capacities appears a direct way of improving the efficiency of learning in online environments, especially in those that afford greater flexibility and functionality.

As students and teachers become more familiar with contribution-based learning technologies and acquire an improved understanding of how their affordances can be leveraged to educational advantage, dynamic design may become a central concern of the technology-based learning field. In this study the capacity to dynamically redesign the web-conferencing environment based on the evolving collaborative requirements of the episode support more effective mental model development by allowing information to be represented and shared in more cognitively efficient forms. However learning needs invariably change no matter what the learning environment, and as such educators using other suites of technologies should appreciate how they can redesign their environment based on the impending learning needs. In this study a framework to support dynamic design of the web-conferencing environment was proposed based on the level of mental model development to be addressed and the level of task knowledge under scrutiny. Support dynamic design in other environments will require frameworks specific to those contexts. This represents a research and development agenda for the technology-based learning field.

6.5.3 Possibilities for Future Work

There were several limitations placed on this study in order for an in-depth analysis to be conducted. As such, there are many ways in which this research could be expanded, relating to the scope, analytic perspective, coding approaches and methodology adopted in this study. The potential to study the transferability of this research to other technology-based learning environments is also discussed below.

6.5.3.1 Increasing the scope

This research has investigated one learning domain (introductory programming), one web-conferencing system, one teacher, and a small cohort of students. Applying the approaches adopted in this study to other learning domains would allow the effect of the subject matter to be better understood. For instance, to what extent do the principles of design developed in this research extend to more humanities-based subjects such as anthropology or literary studies? There may be different design principles required in these less logico-deductive subjects.

Different web-conferencing systems have subtly different affordances. Educational institutions are required to evaluate these technologies for selection purposes. Web-conferencing system developers attempt to design their software to meet educational needs. Currently there is only anecdotal situated evidence to suggest how affordances of these systems should be designed signaled to best satisfy learning needs. Research in this area would serve both educators and web-conferencing system developers.

In order to conduct an in-depth qualitative investigation only one teacher and a small cohort of students was studied. Thus there is the potential to conduct a similar study on other students, a larger cohort of students, and different teachers. The results of such studies could add to the reliability of this research. The effect of individual participants may also be particularly relevant to consider in conjunction with the learning domain being researched – since both the teacher and the students in this study could be assumed to be relatively technologically savvy by virtue of the computing course they had selected, individuals studying other domains may find learning through the web-conferencing environment more challenging. Researching a larger and less homogenous cohort, may uncover a larger range of issues relating to teaching and learning using web-conferencing.

6.5.3.2 Alternate analytic perspectives

Sociological and ethnographic aspects of learning through web-conferencing environments were not incorporated into this study – the emphasis was on how students constructed their understanding. Post semester student feedback was an extensive aspect of the research conducted during this study, and involved surveying and interviewing students about their experience of learning through the web-conferencing system. However, because the emphasis of this investigation was upon the actual activity students conducted in the environment in order to collaborate and learn, students' individual experiences and perceptions were not highlighted. Analysis and explication of these aspects of teaching and learning in web-conferencing environments is left to form the basis of publications in other arenas.

6.5.3.3 Alternate coding approaches

There are possibilities for expanding the approach to coding applied in the multimodal discourse analysis. For instance, the Content category could be further deconstructed into declarative, procedural and conceptual knowledge, allowing the influence of task, activity and technology upon level of knowledge to be analyzed in more depth. As well, the Subject-Interaction profile of actions was not coded because their meaning and reason is less explicit than for textual discourse. However, attempting to code non-textual contributions (such as drawing on the whiteboard) could allow the way in which different modalities contribute to discourse and meaning making to be better understood. As well, future work could investigate the use of graphs, colours and symbols to represent sequences of Subject-Interaction discourse, enabling visual analysis to be conducted.

6.5.3.4 Methodology

In this study qualitative approaches were used to evaluate the effectiveness of mental model development and sharing, and quantitative approaches were used to measure the extent of contribution, however the impact of different web-conferencing designs upon objective measures of learning was not gauged. Quantitative approaches could be used to gauge the relative effectiveness different modalities and multi-modal clusters, based on the measures of learning performance. Similarly future studies could apply more objective approaches to evaluating the effect of virtual classroom competencies, strategies to managing learning episodes and tactics for overcoming distributed process loss.

6.5.3.5 Other technology-based learning contexts

Future research could investigate the transferability of the results of this study to contexts other than web-conferencing. Do interactive and collaborative learning designs in other environments result in similar gains in contribution as in this study? What sorts of tactics are required to overcome distributed process loss in other contexts? Do similar types of technological competencies impact upon learning in other environments? Does task authenticity improve engagement in all technology-based learning situations? Understanding the similarities and differences in results for different environments will allow more general heuristics for design to be proposed.

6.5.3.6 Emerging frameworks for dynamic learning design

As the technologies at educators' disposal become more flexible, frameworks to guide dynamic design will become more important. The field of technology-based learning is continually evolving, and if teachers are expected to move to new technologies and rapidly redesign the environment for more successful learning then frameworks will be needed to support this practice. In each instance the development of such frameworks will require an analysis of the affordances of the technologies, of the types of activity desired and of the types of knowledge being addressed, as was the case in this study. The development of dynamic design frameworks for a variety of technologies will allow the field to determine more general principles for dynamic technology-based learning design.

6.6 Concluding Remarks

The pursuit of designing web-conferencing environments for learning is informed by multimedia learning principles. The interface effects interaction and collaboration by determining the cognitive efficiency with which modalities mediate the exchange of mental models. However the interface is merely a facilitator and does not in itself encourage interaction and collaboration. It is more accurate to say that a poor interface will constrain interaction and collaboration than to say a good interface will encourage it.

Authentic, meaningful tasks support the abstraction of concepts. By engaging in a holistic problem solving task students are able to apply their declarative knowledge, practise their procedural skills and develop their conceptual understanding. The concrete and situated nature of problem solving tasks stimulates questions that may not have arisen if more abstract or factual tasks were attempted. The skills developed in situated, authentic tasks are directly relevant to students becoming practicing experts in a field.

However, on the basis of the episodes analyzed in this study, the greatest impact upon the quality and quantity of interactions and collaboration is the activity design that the teacher establishes. By providing students with appropriate virtual and temporal space to participate, the rates and types of contribution were significantly affected. Collaborative learning approaches not only increased the rate of student contribution and led to more student directed learning, but also provided students with the critical opportunity to more completely share their mental models.

A balance of teacher-centred, teacher-led, and student-centred approaches appears useful to efficiently provide content, scaffold learning, and activate students (respectively). This study has observed the value of all three approaches, but has focused upon determining means and effects of moving from transmissive approaches towards engaging more interactive and collaborative learning. It is through the exchange of descriptions of the world that students evolve their schema. Discursive processes allow the teacher to gauge student understanding, provide feedback and appropriately adjust the direction of the lesson. The capacity to flexibly adjust the web-conferencing environment to cater to the changing collaborative requirements of the episode enables discursive processes to be more effectively engaged.

Teaching and learning in web-conferencing environments is affected by a number of complex and interacting variables, and analysis is inevitably affected by context. As such, detailed descriptions of observations and methods have been provided to allow decisions regarding the validity and generalisability of results to be drawn. This study has, however, determined ways in which factors such as the interface design, task type and activity design influenced teaching and learning in a particular educational context. On this basis a learning design framework has been proposed that relates interface design with the level of interactivity desired and the task type being addressed. It is intended that the analytic lens, observations and analysis conducted in this study at the very least support practitioners to more effectively engage interactive and collaborative learning in web-conferencing environments.