Chapter 6

Discussion and literature reflection

6.1 Introduction

Chapter 4 presented the data analysis and findings in response to the first research question, namely *What conjectures and principles are associated with an intervention that uses computer technology as an expert system shell to develop higher-order thinking skills in Foundation English Communications students at TUT?* Chapter 5 presented the data analysis and findings that resulted from an exploration of the students' experiences of working within the learning environment developed during the first part of the study.

What follows is a discussion of the findings applicable to this study together with an attempt to link these findings to the relevant literature. This discussion and literature reflection are organised under the following headings:

- Students left to discover information on their own.
- Practical application of understanding.
- Making connections with existing knowledge.
- Collaborating in groups.
- Representing understanding and knowledge.
- Designing a functional expert system.
- Developing a functional application.
- Exploring an ill-structured problem.
- Alleviating cognitive load.

6.2 Students left to discover information on their own

Many of the conjectures and principles formulated during this research involved students being left to discover information and arrive at a conceptual understanding of concepts applicable to the domain largely on their own. A limited amount of measured guidance was regarded as appropriate assistance or support for the learners during this process. This resonates with many ideas reflected in the literature concerning discovery learning and guided discovery learning environments.

In a pure discovery learning environment students are left to figure out solutions to challenges on their own with little or no guidance from an instructor (Prince & Felder 2007, p. 15). Students are principally responsible for finding or discovering the "properties of a domain" when working within a discovery learning environment (Gijlers & De Jong 2005, p. 265). These properties are not made available to the students in a "direct manner" (ibid.). The students are to use interpretation and experimentation to discover them (ibid). The environment provides very little structure within which the learning takes place and the students are encouraged to explore solutions through a trial and error approach (Prince & Felder 2007, p. 15). The idea that students consider their 'mistakes' to be an opportunity to gain an enhanced understanding of communications concepts is a significant component of the conjectures and principles that informed the design of the learning environment. The emphasis is not on correct answers or on definitive representations of understanding, but rather on individual explorations and constructive representation of knowledge. Students are encouraged to learn extra information beyond that which is made available by the lecturer through a challenging process of exploration and discovery. It has, however, been concluded that to allow students to struggle on their own for too long could become demoralising and counterproductive. The conjectures and principles formulated during this study were, therefore, more closely aligned to a guided discovery learning approach rather than to a pure discovery learning one.

In a guided discovery learning environment there is a measured amount of structure and the facilitator offers a calculated amount of guidance to the students (ibid.).

The characteristics, procedures and arguments associated with the principles and conjectures formulated as a result of this research often involved the inclusion of various resources that could be made available to the students during their exploration and discovery of information. Handouts that included terminology as well as step by step instructions and an interactive screen capture demonstration were designed and developed to serve as supporting resources. This is consistent with Veermans, Van Joolingen and De Jong's (2000, p. 233) assertion that support for "discovery learning aims at providing context and tools for performing learning processes essential for discovery learning".

The conjectures and principle formulated in this study presuppose that it is necessary for students to have a certain amount of foundational or fundamental knowledge if they are to function successfully within an environment that requires them to discover information on their own. Prior or existing knowledge has an important influence on knowledge development in a discovery learning process (Gijlers & De Jong 2005, p. 264). In a constructivist discovery learning environment students are encouraged to move away from a passive reception of information toward an active engagement with the subject domain. This could involve the establishment of an extensive application of skills that promote problem-solving and an exploration of unique experience (Castronova 2002, p. 2). These students are also encouraged to build on existing knowledge in order to gain a deeper understanding of information currently being explored (ibid.). New knowledge is constructed by an individual through experiences that allow that individual to "add new concepts to memory, subdivide existing concepts, or make new connections between concepts" (Edelson 2001, p. 358).

6.3 Practical application of understanding

The practical demonstration of understanding is an important aspect of the learning environment designed during this research and many of the principles and conjectures were formulated to facilitate this type of activity. Edelson (ibid.) suggests that being "able to retrieve and recite facts that are relevant to a problem" is of little use if a person is unable to "combine those facts to construct a solution to that problem". The students must learn how to use or operationalise "conceptual knowledge" (ibid.) if the knowledge is to be of any value.

6.4 Making connections with existing knowledge

The principles and conjectures formulated during this research often involved an exploration of the students' existing knowledge before new concepts were introduced. This could be done in the form of brainstorming exercises, paper-based exercises and general student group discussions. The context within which the learning takes place together with making linkages to existing knowledge is alluded to by Edelson (ibid.). He points out that connections that are constructed for subsequent retrieval when learning takes place are dependent on the context in which that learning takes place. The creation and elaboration of these indices or "contextual cues" are a decisive part of the learning process (ibid p. 357). This implies that a learning environment must assist the learner to create suitable "indices to knowledge structures" in order to enable the learner to "retrieve those when they are relevant in the future" (ibid.). Rote learning and the simple regurgitation of facts are characteristic of lower-order thinking while higher-order thinking typically involves combining prior or existing knowledge with new or recently acquired knowledge in order to find solutions to confounding problems (Zoller & Pushkin 2007, p. 155). An exploration of the way in which the students experience the learning environment has revealed that students occasionally found it frustrating to be expected to undertake task for which they felt they did not have the prerequisite knowledge. These feelings of frustration seemed partly the result of being encouraged to think like experts in order to create an expert system.

6.5 Collaborating in groups

Group collaboration is an important aspect of the learning environment designed during this research. Students were encouraged to share understanding and offer support during the exploration and discovery of concepts and information. If students are to investigate a domain within an environment that is based on discovery learning successfully, measures should be in place to support "working in collaborative groups" (Van Joolingen *et al.* 2005, p. 672). This would encourage higher achievement and lead to a deeper exploration of the subject domain. By collaborating in groups students are more likely to engage in a dialogue that contributes to meaningful learning. This dialogue is characterised by the "asking and answering of questions, reasoning and conflict resolution" (ibid. p. 682). The concept *critical thinking* often suggests the comparing and contrasting of ideas, the classification and evaluation of information, and the evaluation of bias (Zoller & Pushkin 2007, p. 157). An exploration of the students' experiences of the learning environment has revealed that collaborating in groups often led to vigorous debate and discussion which in turn resulted in the generation of differing ideas. Students were exposed to various convergent points of view and were encouraged to explore their own ideas more deeply when defending these to the other group members. The dialogue that resulted from group member collaboration also seemed to result in a form of reflection as individual students were often forced to revisit and modify their ideas due to the interaction with fellow group members. The construction of collective or shared knowledge is the decisive objective of collaborative learning. Van Joolingen *et al.* (2005, p. 683) argue that this objective has two important "consequences for the tools in collaborative discovery learning". These are:

- Shared knowledge must be explicitly represented or externalised so that learners can examine the object that is being discussed and explored.
- The tools used should accommodate or allow for the integration of the students' multiple perspectives.

Students typically found the learning environment to be more challenging than they expected it to be and considered the group collaboration to assist in addressing some of these challenges. They were able to share ideas and explore concepts collectively. There were, however, some students who found the group collaboration to be an obstacle to learning as they experienced what they considered to be unnecessary resistance to their ideas and often found that there were students who were not contributing constructively to group activities.

Socio-constructivist learning is based on the idea that learners build an understanding of a subject domain by "working on authentic tasks in realistic settings" (ibid. p. 672). A socio-constructivist learning environment involves peer collaboration and learner-regulated task performance (ibid.).

6.6 Representing understanding and knowledge

An important part of the learning environment is concerned with the externalisation of understanding and knowledge. Many of the principles and conjectures formulated involve characteristics, procedures and arguments that are a factor in enabling learners to represent their understanding by drafting flow diagrams and through the development of a functional expert system. Lee and Nelson (2005, p. 3) propose that complex cognitive processes, such as problem solving, are enhanced and activated through the external representation of knowledge that could make use of symbols and objects. External representations have the potential to be an effective way of addressing complex problems as they help to clarify the fundamental statement of the problem, better its indistinct status to an "explicit condition", limit unnecessary cognitive activity and "generate multiple solutions" (ibid.). Furthermore, an external representation of understanding can be used as a means of clarifying or elaborating and individual's unique "conceptual understanding to others" as well as evaluating the learners' conceptual understanding (ibid.). An exploration of the way in which students experienced the learning environment has revealed that students were encouraged to think about the subject domain in broader terms through the process of representing their understanding. This seemed to be particularly true during the process of drafting an algorithmic flow diagram where the logic behind all conclusions reached needed to be traced and articulated. Any breakdown in logic inherent in the flow diagram is normally uncovered during the development of a functional expert system. This encourages students to, once again, reflect on the logic that was applied to the flow-diagram design and in so doing, explore the subject domain at a deeper level.

6.7 Designing a functional expert system

Closely related to the representation or externalisation of understanding is the idea of designing the functional expert system. This formed an important part of the learning environment and principles and conjectures were formulated to allow for design activities to be incorporated in the learning experience. Contact sessions that did not include computer technology were used as planning and design sessions. Students were encouraged to map out their proposed expert systems using flow diagrams, IF THEN statements and natural language in the form of questions and a selection of answers. The notion of design suggests the creative linking of relationships by collecting information and ideas to form a logical and innovative conception (Kimber, Pillay & Richards 2007, p. 64). The design process involves critical reflection and creative vision and is an important means of "engaging students in knowledge construction" (ibid.). Design activities are suitable for "creating reflective representations of knowledge" and encourage the students to "develop deeper levels of learning" (ibid.). A more coherent and discerning knowledge structure is formulated when the relationship between ideas is articulated (ibid. p. 65).

The results of a study conducted by Kimber, Pillay and Richards (ibid., p. 78) indicate that the activity of design serves not only to apply computer technology "to the manipulation of ideas but also to foster deeper, more critical thinking about content" (ibid.).

6.8 Developing a functional application

The expert system designs formulated in the form of flow-diagrams, IF THEN statements and natural language during the non-computer integrated sessions were converted into functional expert systems during contact sessions in the computer laboratory. This often encouraged the students to revisit the logic of their designs and seemed to allow them to gain a deeper understanding of the concepts incorporated in them. It often became apparent to the students that their expert system designs were not functioning as inference engines that drew conclusions from available facts but were rather designed to aggregate options selected by a potential user. The development activities using CourseLab as an expert system shell facilitated this realisation as it forced them to examine both the reasoning behind the expert system design as well as the utility of the application that they were developing closely. Computer technology that has the capacity to support the creative management and expression of ideas embraces the constructivist position concerning the active building of meaning (ibid., p. 62). Computer technology used in this way enables knowledge to be constructed and reconstructed "progressively, repeatedly and with ease, complementing metacognitive processes visually and electronically" (ibid.). It, therefore, develops into a significant mechanism that supports the "generative learning process" (ibid.).

6.9 Exploring an ill structured problem

An aspect of the learning environment developed during this research involved students engaging with an ill structured open-ended problem. The principles and conjectures formulated regarding problem interaction and problem development revolved around situating the problem in a realistic context, ensuring the emergence of appropriate learning points, providing an appropriate measured amount of guidance and ensuring that the problem statement did not contain an obvious solution. These principles and conjectures resonate notably with many of the characteristics of problem-based learning.

A characteristic of the problem that the students were asked to engage with was that it should be presented to them in the form of a brief rather than a specific scenario with an implied solution. The principles and conjectures regarding problem development clearly indicated that the problem statement should involve more of a conceptual predicament than an exercise that encouraged the students to search for a definitive answer. Problems are distinct from simple exercises in that they require more than simply "knowledge and the application of knowledge" but are conceptual dilemmas that may involve a number of cycles of "interpretation, representation, planning, deciding, execution, evaluation and re-evaluation" (Zoller & Pushkin 2007, p. 155). Jonassen (2011, p. 107) states that ill structured problems "are the kind of problems that are encountered in everyday practice". These problems typically have a variety of possible solutions, imprecisely defined "goals and constraints", "and multiple criteria for evaluating solutions" (ibid.). The productive and meaningful interaction with problems therefore calls for the application of higher-order thinking skills and typically leads to a modified level of understanding rather than merely a resolution to the dilemma (Lyle & Robinson, 2001 p. 443). When endeavouring to "solve ill-structured problems" that lack, by definition, clearly defined solutions "the best evidence of problem solving ability can result from construction of arguments to support the solution that is selected" (Jonassen 2011, p. 107).

As mentioned in section 4.5.4, the principles and conjectures formulated during this research encouraged the students to collaborate in groups in order to explore a solution to the conceptual dilemma presented to them. An investigation into how students experienced the learning environment has revealed that the group work initiated significant debate that often led to the exchange of ideas and the clarification of concepts through a process of comparing and contrasting these ideas. Students were often made to defend their ideas vigorously or attempt to persuade other group members that their ideas were valid. This encouraged them to formulate logically constructed propositions and often led to the amendment of ideas. In a problem-based learning environment students usually work in groups to explore an "ill-structured open-ended real-world" problem (Prince & Felder 2007, p. 15). Students need to use their own resourcefulness to redefine the problem clearly. This involves figuring out "what they need to know and what they need to determine, and how to proceed to determine it" (ibid.). They are encouraged to devise and assess alternative solutions, present a logical argument for the adoption of that solution, and carefully consider the lessons learnt through this evaluation process (ibid.).

The conjectures and principles involved the facilitator being available to offer guidance to students while they were in the process of engaging with the ill structured problem. This guidance should be in the form of guiding questions rather than direct answers. The facilitator should be sensitive to the connotative aspects of the feedback obtained from students and use this to assess the type of guidance that the students may need. The facilitator is responsible for guiding the students toward obtaining information that the students themselves have identified as necessary to a proper engagement with the problem (Prince & Felder 2007, p. 15). Problem-based learning may not be suitable for gaining knowledge quickly but Prince and Felder (ibid) suggest that concepts discovered or constructed in a problem-based learning environment are retained for a longer period of time.

The principles and conjectures formulated during this research place emphasis on designing the problem statement in a way that would allow for the subject domain to be properly investigated. When interacting with a suitable problem, the students will be encouraged to explore appropriate subject content as well as the fundamental principles and concepts associated with the domain (ibid., p. 11). The problem must embody these concepts and engage the student in a process of reflection that leads "to higher-order learning" (ibid.).

A characteristic of the principles and conjectures related to the problem formulation involved situating the problem within a realistic setting that had real world relevance. Hannafin, Land and Olivier (1999, p. 119) use the term *open learning environments* to refer to a learning situation that presents the learner with "complex, meaningful problems that link central concepts to everyday experience" (ibid.). An open learning environment is concerned with examining "higher order concepts, flexible understanding" and allows for a variety of individual perspectives. There is a link between cognitive understanding and context. An open learning environment also stresses the importance of errors during the process of establishing a deeper understanding of concepts and proposes that meaningful learning often evolves from initial, imperfect beliefs (ibid.).

6.10 Alleviating cognitive load

An aspect of the scaffolding provided to the students involves presenting the students with examples of the various concepts explored in the learning environment as well as progressing from simple explanations and instances to more complex ones. This resonated with some of the principles associated with cognitive load theory.

Cognitive load theory is primarily concerned with the learning of complex or difficult cognitive undertakings during which learners are commonly " overwhelmed by the number of information elements and their interactions that need to be processed simultaneously before meaningful learning can commence" (Paas, Renkl & Sweller 2004, p. 1). Central to cognitive load theory is the assumption that human cognitive structures consist of a working memory that has limited capacity when handling new information and a long-term memory that has unlimited capacity for storing schemas of information (ibid., p. 2). Cognitive load theory focuses on techniques for "managing working memory load" so that information can be passed efficiently onto long-term memory (ibid.). Three types of load are identified in cognitive load theory; these are intrinsic, extraneous and germane. The "number of information elements and their interactivity" determine the intrinsic cognitive load (ibid.). This is the "intrinsic nature of the learning task" itself and it cannot be altered by the type of instructional intervention used (Van Merrienboer & Sweller 2005, p. 150).

Extraneous cognitive load can be altered by instructional intervention as it is comprised of the "load that is not necessary for learning" (ibid.). Extraneous cognitive load is also referred to as ineffective load as it is the product of "information and activities that do not contribute to the process of schema construction" (Paas, Renkl & Sweller 2004, p. 2). Germane cognitive load is considered effective load as it is load that enhances learning as it results in "resources being devoted to schema acquisition and automation" (ibid.).

The conjectures and principles formulated during this research contained characteristics, procedures and arguments that were directed at allowing the students to progress from simple tasks to more complex ones. Examples of flow-diagrams that represent very simple decision structures were initially presented to the students in order to explain the basic symbols used to represent understanding in this way and to introduce them to the logic behind using flow-diagrams. The flow-diagrams became progressively more complex, involving multiple decision structures and partially completed diagrams. By progressing from simple tasks to more complex ones the intrinsic cognitive load associated with a particular undertaking can be reduced. The extraneous aspects of this undertaking can be reduced by initially "providing the substantial scaffolding of worked examples" (ibid., p. 3). These can be followed by "completion problems and then full problems" (ibid.). Paas, Renkl and Sweller (ibid., p. 3) suggest that using worked examples, as an alternative to attempting to solve comparable problems, is a widely accepted and well-known technique aimed at reducing cognitive lead. Jonassen (2011, p. 102) supports this when he proposes that the "most common method for supporting schema construction is the worked example". He goes on to suggest, "It is doubtful that worked examples are effectively applicable to very ill-structured problems" (ibid.). The scaffolding provided by using worked examples can be reduced or faded by successively removing parts of the solution to the problem until eventually only a complete problem or completely unsolved problem remains (Paas, Renkle & Sweller 2003, p. 3).

6.11 Chapter summary

This chapter presented a discussion of the findings applicable to this research and an attempt has been made to link these findings to the relevant literature.

Chapter 7

Summary, conclusion and recommendations

This enquiry followed a design-based research approach in order to design and develop a learning environment that uses computer technology in the form of an expert system shell to facilitate higher-order thinking skills in first year Foundation English Communications Skills students at TUT. Design principles were formulated in the form of conjectures and principles that intended to serve as a guide or reference for those undertaking similar activities under similar circumstances. These conjectures and principles are presented in a descriptive manner and in the form of advice or recommendations that include characteristics, procedures and arguments. Once the design of the learning environment was substantively complete, Foundation English Communication Skills students were exposed to the learning environment based on these conjectures and principles and their experiences related to working within it were explored.

This chapter provides a summary of the problem that gave rise to the research as well as the research design. A summary of the research findings is presented by outlining the conjectures and principles formulated during the design phase of the research and by summing up the findings that resulted from an exploration of the students' experiences. The relevance of these research findings is discussed with particular reference to the South African context. The chapter concludes with recommendations for future research and concluding remarks.

7.1 Summary of the problem that gave rise to the research

A review of the literature (Fisk & Ladd 2005; Stephen, Welman & Jordaan 2004; Thanosoulas 2001; McLaughlin 1999; Bothma, Botha & Le Roux 2004; Jaffer, Ng'ambi & Czerniewics 2007; Scott & Yeld 2008; Legotlo *et al.* 2002; Van der Berg & Louw 2006; Howie 2003; Ngidi & Qwabe 2006 and Schlebush & Thobedi 2004) indicates that many South African students enter higher learning institutions academically under-prepared. This under-preparedness is the result of inadequate schooling. Teachers often seem to have poor content knowledge and interact with learners in a poorly mastered language. This makes the teachers reluctant to engage with the students in a manner that encourages higher-order thinking. These teachers are more inclined to teach answers and, therefore, encourage students to learn by rote. This schooling background often leads students to expect to be provided with solutions to problems without applying any cognitive effort when they enter higher learning institutions.

Computer technology has become an increasingly ubiquitous part of educational environments and is typically used as a medium of instruction. A review of the literature (Jonassen 2006; Hokanson & Hooper 2000; Jonassen & Reeves 1996) however, indicates that computer technology does not perform the role of a teacher very effectively and does not facilitate higher-order thinking when performing this function. When computer technology is used as a cognitive tool to model understanding, however, students are encouraged to engage constructively with the subject domain. Designing an expert system as a cognitive tool requires that students demonstrate or externalise the reasoning of a human expert and encourages them to engage in higher-order thinking.

There seemed to be insufficient understanding of the characteristics of a learning intervention that uses technology in the form of an expert system shell to facilitate higher-order thinking in Foundation English Communications students at TUT. It was within this context that it was considered appropriate to explore the following questions:

- What conjectures and principles are associated with an intervention that uses computer technology as an expert system shell to develop higher-order thinking skills in Foundation English Communications students at TUT?

- How do foundation students at TUT experience a learning environment based on conjectures and principles formulated to use computer technology in the form of an expert system shell in order to achieve higher-order thinking skills?

7.2 Outlining the research design

The design of the first part of this study was based on design-research and involved placing a prototype of the design of a learning environment before a design team that was comprised of experienced lecturers and instructional designers. This learning environment was improved and refined through a cyclic process until it was considered substantially ready to be implemented in an authentic, real world educational setting. After each of these design sessions a focus group interview was conducted in order to obtain opinions, ideas and suggestions from the design team. These interviews were recorded and then transcribed verbatim. The modification and refinement of the prototype or tentative learning environment was based on a provisional or formative analysis of the focus group transcripts. A more comprehensive grounded theory analysis of the focus group interview transcripts was conducted in order to discover and formulate design principles. These design principles were expressed in the form of conjectures and principles and followed a format that outlined the characteristics, procedures and arguments allied to these conjectures and principles.

In order to explore how students experienced the implementation of the learning environment designed during the first part of this study, four separate focus group interviews were conducted with a sample randomly drawn from the student population that was exposed to the intervention. The focus group interviews were transcribed and then analysed using the grounded theory technique of coding, sorting and memoing.

7.3 Summary of the conjectures and principles

Conjectures and principles were formulated from a grounded theory analysis of nine of the ten focus group interviews conducted with the design team. Even though the conjectures and principles all concern the characteristics, procedures and arguments associated with the research question discussed in section 7.1 their focus differed at times and can be separated into the following clusters:

- The students' initial exposure to the learning environment.
- The students discovering information and concepts on their own.
- Designing the expert system on paper.
- Creating subject domain awareness in the students.
- Creating an awareness of the relationship between a conceptual understanding and a representation of that understanding.
- The students' hands-on development of a functional expert system.
- The students' engagement with the problem statement.

A summary of these conjectures and principles is now presented by initially describing their more salient features and then an attempt is made to separate these conjectures and principles into their respective characteristics, procedures and arguments by using a table.

7.3.1 Initial exposure

Face to face facilitation supported by a printed handout that contains a step by step guide to developing a functional expert system is characteristic of the students' initial exposure to a learning environment that uses computer technology as a cognitive tool to facilitate higher-order thinking. The face to face facilitation should preferably be the medium used to demonstrate a worked example of a functional expert system. A printed handout that corresponds to the steps used or explained in the demonstration should complement this demonstration. The face to face facilitation would allow any concerns that the students might have to be addressed timeously and it was more practical as it proved to be impossible to anticipate every concern that the students might have if a more static medium of instruction was used. The printed handout would allow the students to follow the demonstration more comprehensively and would serve as a reference when they began the development of an expert system on their own. Table 7.1 provides a summary of the characteristics, arguments and procedures associated with the conjectures and principles concerning the students' initial exposure to the learning environment.

Table 7.1 Summary of conjectures and principles concerning the students' initial exposure to the learning environment

Characteristics	Procedures	Argument
• Face to face facilitation • Printed handout to support face to face facilitation	• Demonstration involving worked examples. • Complemented by a printed handout containing a step by step guide to support understanding.	• Just-in-time support through face to face interaction. • Handouts serve as a supporting instrument to enhance understanding as well as a reference to be used later.

7.3.2 Students discovering concepts for themselves

A number of characteristics that filter through the learning environment developed during this study involve allowing or encouraging students to discover information by themselves. This is achieved by providing them with basic or fundamental information, restricting them to the exploration of concepts in manageable chunks, allowing them to struggle unaided for a limited period of time and encouraging them to consider their mistakes to be part of the learning process. These characteristics resonate with many of the properties of a guided discovery learning environment, which allows for a regulated or balanced amount of assistance from the facilitator and for resources to be made available to the students when they need it. The provision of basic or fundamental information allows for linkages to be made between existing information and new information and helps to prevent students from becoming disorientated and discouraged. Allowing students to struggle on their own for a limited period of time enables them to discover information beyond that which they are being taught and to learn from their mistakes. By monitoring the students' progress, the facilitator is able to prevent the students from encountering an irreconcilable impasse and ensures that the learning objectives are achieved. Table 7.2 provides a summary of the conjectures and principles related to the students discovering concepts on their own by separating these conjectures and principles into their characteristics, procedures and arguments.

Table 7.2 Summary of design principles concerning the students' discovering information on their own

Characteristics	Procedures	Argument
• Students encouraged to discover information on their own.	• Providing students with basic / foundational information. • Allowing students to struggle on their own for a limited period. • Encouraging students to view mistakes as part of the learning process. • Allowing students to explore concepts in manageable chunks. • Monitoring students' progress.	• Build linkages to current knowledge. • Prevent students from becoming discouraged. • Identify when students need assistance.

7.3.3 Designing the expert system on paper

Formulating questions and flowcharts are some of the activities included in the learning environment that involves designing an expert system in order to represent understanding. These activities are preceded by exercises that assist the students in becoming familiar with the flow-diagram symbols and then encouraging them to plot the logic of their expert systems on paper in the form of a flow diagram. This would have the effect of reducing the cognitive load involved in designing the system, as students would not have to be limited or distracted by the challenges involved in using the expert system shell software. This would also give them the opportunity to articulate their understanding of the expertise the expert system is designed to imitate. Table 7.3 provides a summary of the conjectures and principles related to designing the expert system on paper by separating them into their characteristics, procedures and arguments.

Table 7.3 Summary of conjectures and principles concerning the students' designing their expert systems on paper

Characteristics	Procedures	Argument
• Flowchart representation of expert system logic. • Formulation of questions in natural language.	• Familiarise students with flowchart symbols. • Use non-laboratory contact sessions for design. • Encourage students to plot the expert system on paper first.	• Reduces cognitive load. • Articulates understanding of expertise. • Enables students to compare and contrast understanding with group members.

7.3.4 Creating subject domain awareness

The characteristics associated with creating an awareness of the subject domain involve exploring the students' current understanding, paper-based exercises, providing suitable support and using video clips to conceptualise learning. The students' current understanding can be explored through discussion and brainstorming sessions, where the facilitator allows the student group to lead or guide the discussion. Paper-based completion exercises, multiple-choice test items and open-ended questions could also facilitate the exploration of the domain and allow the students to gain insight into various concepts associated with it. Support could be provided by avoiding assumptions regarding the students' understanding and allowing them to ask questions freely. Examples would make concepts less abstract and alleviate the cognitive load associated with conceptual understanding. Video clips depicting realistic communication situations could be used to situate the learning in a realistic or authentic setting. Learning points and conceptual understanding could be rooted in these realistic situations. Paper-based exercises and group discussions could reference these realistic situations to reinforce conceptual understanding. It is, however, important to allow the students to discover concepts themselves and for the facilitator to adopt a more constructivist approach during class discussions. Table 7.4

provides a summary of the conjectures and principles related to creating domain awareness by separating them into their characteristics, procedures and arguments.

Table 7.4 Summary of conjectures and principles concerning creating domain awareness

Characteristics	Procedures	Argument
• Exploration of students' existing knowledge. • Using paper-based exercises. • Providing support. • Using video clips depicting realistic situations.	• Brainstorming, group discussion and paper-based exercises involving multiple choice test items, completion exercises and open-ended questions. • Make use of examples. • Allow students to ask questions freely, clarify concepts and adopt a constructivist approach to allow students to discover learning points on their own. • Showing video clips to students to situate learning in realistic settings that they can reference during discussions.	• Exploring the students' current understanding would allow the facilitator to gain insight into where to pitch explanations and instruction. • Examples would make the learning points less abstract and alleviate cognitive load. • Allowing students to discover learning points on their own would facilitate a deeper understanding of concepts associated with the domain.

7.3.5 Creating an awareness of the relationship between conceptual understanding and a representation of that understanding

The conjectures and principles associated with the representation of understanding involved the following:

- Activities designed to bridge the gap between conceptual understanding and a representation of that understanding.
- Formulating appropriate questions.
- Formulating inferences.
- Modelling understanding through the development of a functional expert system.

To bridge the gap between conceptual understanding and a representation of that understanding seamlessly, a flow-diagram representation of a group discussion involving a communication situation could be drafted immediately after or as the discussion takes place. This would allow the students to view the flow-diagram as an authentic and reliable representation of their understanding and enable them to relate to the logic or utility behind this form of representation. Due to the possibility that the representation of understanding using an algorithmic flow-diagram may place high cognitive demands on the student, owing to unfamiliarity with the flow-diagram symbols and logic, it would be useful initially to draft questions and answers to these questions. These can them be converted into a flow-diagram. The formulation of inferences is an important component of the students' representation of understanding. These inference formulations should be carefully monitored by the facilitator to ensure that they are not merely an aggregation of answers to various questions. An important component of the students' modelling of conceptual understanding involves the development of a functional expert system. This development would encourage them to explore their conceptual understanding of the subject domain more comprehensively. Table 7.5 provides a summary of the conjectures and principles related to the representation of conceptual understanding by separating them into their characteristics, procedures and arguments.

Table 7.5 Summary of conjectures and principles concerning the students' representation of conceptual understanding

Characteristics	**Procedures**	**Argument**
• Bridging the gap between conceptual understanding and a representation of that understanding. • Formulating questions and answers. • Formulating inferences. • Developing a functional expert system.	• Creating contiguity between discussion and representations of that discussion. • Encouraging students to formulate questions in order to probe for understanding. • Explaining to students the distinction between the aggregation of options and making inferences based on options selected.	• Contiguity allows students to appreciate the logic involved in representing understanding. • It encourages students to consider the representation to be a true reflection of their understanding. • An inference is a conclusion drawn from available facts and constitutes the display line or the output of the

Table 7.5 Summary of conjectures and principles concerning the students' representation of conceptual understanding (continued)

Characteristics	Procedures	Argument
.		functional expert system.

7.3.6 Students' development of a functional expert system

The students were encouraged to represent their understanding of Communications concepts through the development of a functional expert system. The following characteristics are associated with this component of the learning environment:

- Orientation to the learning environment
- Group collaboration
- Relating the development to the flow-diagram representation
- Becoming familiar with how to use the expert system shell
- The students' active participation in the development process
- Reflecting expert system logic

Face to face facilitation, worked examples and group collaboration are components of the students' orientation to the learning environment that requires them to develop a functional expert system. Face to face facilitation allows the facilitator to provide the students with prompt support. Worked examples lessen the cognitive load by making concepts less abstract and group collaboration allows for peer support and the exchange of ideas. By basing the development of a functional expert system on the flow-diagrams formulated by the students, the students are encouraged to revisit their ideas and conceptual understanding and explore them at a deeper level. Familiarity with the development environment (expert system shell) is important and the facilitator must not assume that the students have sufficient knowledge in this regard. It is important for facilitators to monitor the students' development and to ensure that this development reflects expert system logic by making inferences and not merely aggregating options selected. This can be done by asking questions and allowing students to explain or explicate the logic on which their development is based. Table 7.6 provides a summary of the conjectures and principles related to the development of a functional expert system by separating them into their characteristics, procedures and arguments.

Table 7.6 Summary of design principles concerning the students' development of a functional expert system

Characteristics	Procedures	Argument
• Orientation measures. • Collaborating in groups. • Relating expert system development to flow-diagram representation / design. • Familiarity with the expert system shell. • Active participation. • Reflecting expert system logic.	• Face to face facilitation. • Using worked examples. • Peer collaboration. • Encourage students to base development on flow-diagram design. • Assumptions regarding the students' ability to use the development software must be avoided. • Pose questions to gauge level of understanding.	• Timely response to students' concerns. • Lesson cognitive load. • Peers support one another. • Students are encouraged to explore their understanding more deeply when they revisit flow-diagram design.

7.3.7 Students' engagement with the problem statement

The students' engagement with the problem statement is an important part of the learning environment developed during this study. The following characteristics are associated with the students' engagement with the problem statement that formed part of the learning environment:

- Preferably situated in a real-life or authentic setting.
- Presented to the students in the form of a brief and not a detailed description of a scenario with an obvious or implied solution.
- The ill structured problem must be designed in such a way that allows for the specific concepts to emerge.
- The facilitator must be on hand to provide prompt support.

Presenting the problem statement to the students in the form of a brief that contains a conceptual outline that can be applied to a variety of situations allows the problem to be open-ended in nature. The problem would then accommodate a variety of possible solutions and would give the students the space to explore their understanding at a deeper level. The facilitator must be on hand to provide support but must do so by posing thought-provoking questions rather than imposing his or her own ideas on the student. Table 7.7 provides a summary of the conjectures and principles related to the students' engagement with the problem statement by separating them into their characteristics, procedures and arguments.

Table 7.7 Summary of conjectures and principles concerning the students' engagement with the problem statement

Characteristics	Procedures	Argument
• Situated in a real world / authentic setting. • Formulated in the form of a brief rather than a detailed scenario. • Must not have an obvious solution. • Must be designed to allow learning points to emerge. • The facilitator must be on hand to provide guidance.	• Design in the form of a brief that outlines a concept and not a particular situation. • Concepts should be applicable to an authentic setting. • The facilitator must monitor the students' engagement to ensure that learning points emerge and that they do not reach an irreconcilable impasse. • The facilitator should pose questions to stimulate thinking.	• Allow the students to explore their own understanding and gain a deeper conceptual grasp of subject matter. • The open-ended nature of the problem will allow for multiple solutions. • The facilitator should not impose his ideas on the students.

7.4 Summary of student experiences of a learning intervention based on conjectures and principles formulated to use computer technology in the form of an expert system shell in order to achieve higher-order thinking skills

Two sets of focus group interviews (four in total) were conducted with the two student groups that were exposed to the learning environment that was based on the conjectures and principles formulated during the design phase of the research. The aim of these focus group interviews was to explore the students' experiences of this environment. What follows is a summary of these experiences as discovered from a grounded theory analysis of transcripts of the focus group interviews.

The exploration of students' experiences of creating flow-diagrams to represent the logic of their proposed expert systems has revealed the following:

- The students were encouraged to think about communication in broader terms.
- They were challenged to think logically about the domain.
- The students were encouraged to reflect on their understanding of the domain when revisiting their flow-diagram design after each development session.
- The articulation of their understanding provided insight into some of the functional aspects of the subject domain.

An exploration of the students' experiences of collaborating in groups within the learning environment formulated as a result of this study revealed the following:

- Group member interaction often resulted in rigorous discussion.
- Group member interaction encouraged the exchange of ideas and exposed students to differing points of view.
- Group member collaboration encouraged students to defend their own points of view, which served as a form of reflection.
- Comparing ideas and defending points of view encouraged critical reflection.
- Group member collaboration allowed students to tackle the ill structured task more successfully.

- Group member interaction occasionally resulted in frustration when it was felt that some group members were being counterproductive or not making a contribution.

The exploration of the students' experiences of learning in an open-ended environment and engaging with an ill structured problem revealed the following:

- Students considered the experience to be more challenging than expected.
- Students sometimes felt bewildered and out of their depth.
- Students often found peer support to be helpful.
- Students sometimes felt that they did not have the required skills to be successful in the environment.
- Students felt that they were required to venture outside their comfort zones and seemed to see this in a positive light.

7.5 Relevance of the study

Scott *et al.* (2007, p. 37) point out that there is unlikely to be a meaningful increase in the number of "well prepared candidates for higher education" in the near future and that progress made in the school sector cannot be confidently relied on to address issues related to the students' under-performance at higher education institutions. Regardless of the limited number of "well-prepared candidates" who enter higher learning institutions, a priority should be placed on realising the "potential and facilitating the successful performance in the existing student intake" (ibid., p. 29). It should, therefore, be one of higher education's main concerns to enhance its own ability to address issues related to the students' under-preparedness (ibid., p. 37). Technology clearly has a role to play in dealing with these concerns. Jaffer *et al.* (2007, p. 141) point out that to improve the typical South African student's potential for success at higher learning institutions a "re-conceptualisation of how educational technologies are applied" is required.

This study presents design principles related to a learning intervention that uses technology as a cognitive tool in the form of an expert system shell in order to develop higher-order thinking skills. The study also offers insight into how students experience a learning environment based on these principles.

The design principles are presented in the form of conjectures and principles that provide suggestions, proposals, assumptions, suppositions and arguments that aim to inform or give substance to a learning environment that endeavours to assist students to acquire higher-order thinking skills with reference to a particular domain. This is particularly relevant to the South African context where students often enter higher learning institutions unable to engage meaningfully with subject matter. The conjectures and principles formulated in this study may serve to facilitate a better understanding of ways in which instructional designers and lecturers can make use of or exploit computer technology to allow or encourage students to engage with subject content in more meaningful ways. This set of conjectures and principles would then function as a model or set of guidelines on which similar endeavours under similar circumstances could be based.

7.6 Significance of the study

Though many of the conjectures and principles formulated during this study are based on a rediscovery of well-established theories and conventions, the context of the study is significant and unique. The problem that motivated the study is the under-preparedness of students for the cognitive demands of higher education and the inability of conventional educational computer technology to address this concern adequately. This study offers a singular insight into a combination of strategies aimed at using computer technology as a cognitive tool to foster higher-order thinking skills in Foundation Communications Skills students at TUT. It also presents a distinctive insight into how these students experienced the learning environment that was based on the conjectures formulated to use technology as a cognitive tool.

7.7 Suggestions for further research

This close and enduring association with and investigation into the use of computer technology as a cognitive tool has uncovered many opportunities for ongoing research. What follows are some suggestions for further research that have become apparent during this study.

- What are the design principles for using computer technology as a cognitive tool in other forms or applications besides expert systems? A few other forms are the following:
    - Mind mapping software
    - Word processing software
    - Data bases
    - Spreadsheets
    - Graphics applications
    - Screen capture applications
    - Web development applications
    - Content management systems
    - Virtual worlds
    - CAD applications
- What are the design principles for combining various types of computer application in order to use them as cognitive tools?
- Formulating design principles that would allow students the freedom to choose the type of application to use as a cognitive tool in a learning environment.
- Using computer technology as a cognitive tool in a learning environment across different domains, for example, Communications Skills and Engineering.
- Identifying the obstacles to using computer technology as a mind tool in an educational environment.

- Formulating design principles for using technology as a cognitive tool over a social network.

Ongoing studies regarding using technology as a cognitive tool to engage students in more meaningful learning could develop from the conjectures and principles formulated in this study.

7.8 Conclusion

This study adopted a design-based research approach to formulate design principles in the form of conjectures and principles related to a learning environment that uses technology as a cognitive tool. What emerged from a grounded theory analysis of the data was not a definitive list of principles but rather a collection of conjectures that could be clustered in certain ways. These were presented in a descriptive format in order to more accurately reflect the essence of the conjectures and principles that emerged from the data. It is hoped that this would provide a useful insight for those who wish to employ educational technology as a cognitive tool to encourage students to explore a subject domain at a higher cognitive level. The study also explored how students experienced a learning environment that was based on the conjectures and principles formulated. This exploration provided an encouraging insight into the value of using technology as a tool that supports the development of understanding and of allowing students the freedom to discover principles for themselves.