Computers as cognitive tools: Do they really enhance learning?

Carole Steketee, Jan Herrington & Ron Oliver

Edith Cowan University

Abstract

Do computers, when implemented effectively, enhance learning? This question is the essence of the third phase of a Ph.D. study where computers were integrated as cognitive tools into a tertiary learning environment. The implementation framework was based on a social constructivist perspective of learning where discourse and collaboration were highly valued, and students were encouraged to distribute their learning between social, physical, symbolic and intellectual resources found within the learning environment. Using action-research methodology, this framework provided the catalyst for exploring how computers can be used effectively in tertiary education. It also permitted insight into the extent to which computers, when used as cognitive tools, can promote and foster cognitive processes that catalyse quality learning outcomes, the results of which are discussed in this paper.

The mediational nature of learning

Reviews of the literature into computer-based learning have revealed several common themes. One theme in particular is in relation to the theoretical perspective that appears to most effectively support computer technology in the classroom. Known as social constructivism, this perspective establishes learning as a social experience and posits that mediational tools (such as the computer) transform the ways in which individuals interact with one another and with their learning environment in general. This perspective, which is a derivative of Vygotsky's (1978) socio-culturalism, is the cornerstone of this study. Principles associated with Piaget's (1963) constructivism have also been drawn on to provide a richer understanding of how mental processes are supported by mediational devices.

The precise way in which computers mediate learning is not altogether clear in the literature, nor are existing interpretations agreed upon. While most theorists agree that computers 'support' cognition, it is their interpretation of 'support' that varies. These variances usually relate to claims that computers can either *amplify* or *augment* cognition. Advocates of the amplification perspective claim that computers support cognition by carrying out lower-order cognitive tasks, leaving the student free to carry out more complex cognitive tasks (Jonassen, 1992). Advocates of the augmentation perspective, however, claim that computers support cognition by offering students opportunities to construct more sophisticated representations of phenomena (Pea, 1985; 1993). Others argue that computers have a residual effect in the sense that they equip students with new tools of thought which can be accessed even when the computer is not present (Salomon, Perkins & Globerson, 1991; Underwood & Underwood, 1990). Whichever way, it is clear the technology is encouraging the student to activate thinking processes, to a greater or lesser extent.

Given that any one of these outcomes is possible depending on the capabilities of the applications being accessed, and the ways in which they are being used (Knuth & Cunningham, 1993), the 'amplification/augmentation/residual' argument becomes a superfluous one. In light of the fact that the computer *can* transform activity upon the world (Crook, 1994), perhaps a more pertinent concern is how to *cultivate* mediations between the computer and students such that opportunities to expand cognition are seized upon. With this in mind, an implementation framework was developed (and subsequently operationalised) within which the mediational powers of the computer could be potentially realised. This framework constituted the first and second stage of the study and is briefly described below.

A framework for a distributed learning environment

The framework was based on the notion of distributed learning, which is essentially an extension of social constructivsm. When learning is distributed, cognition is not solely an individual pursuit, but rather is shared amongst mediating resources found within the learning environment (Pea, 1993). A type of communal milieu is developed within which students, together with other students and resources, construct new knowledge and understandings. While the idea that learning is facilitated by cognitive resources is not new (Nickerson, 1993), distribution of cognition within the classroom environment is not such a natural phenomenon and, as such, a distributed learning environment needs to be engineered.

For this to occur, a complex combination of appropriate *teaching context characteristics* and *student characteristics* need to be in place to allow the necessary *process characteristics* to transpire (see Figure 1). The *teaching context characteristics* comprise a wide range of complex phenomena. Through the careful orchestration of tasks, curricula, teaching and assessment methods teachers effectively show students *how* to participate in distribution through the processes of collaboration, using resources and thinking strategically. Together, these factors convey messages to students about the type of learning that is desired and rewarded, which impacts upon *student characteristics*.

Student characteristics relate to students' perceptions of the learning environment and their roles within it. These perceptions influence the students' commitments to the distributive learning methods, as well as their acceptance of the responsibility they have for their own learning and the learning of others. Consequently, these perceptions affect the way students approach their learning, that is, the processes they adopt.

Process characteristics refer to students' use of resources as they endeavour to learn something new. Resources typically available within the classroom environment can be categorised as social, physical, symbolic and the student's intellect. While it is possible for students to pursue learning tasks drawing on perhaps only one resource (e.g., their prior knowledge), this study accedes with others (Derry, DuRussel & O'Donnell, 1998; Hewitt & Scardamalia, 1998; Lebeau, 1998) and argues that cognition is most powerful when it is distributed across a variety of resources.

Figure 1. Characteristics of a distributed learning environment

Consequently, this framework was the catalyst for the introduction of a computerised concept-mapping tool into a fourth year Bachelor of Education unit. Through its implementation, a collaborative learning community was established where the task of learning was distributed between the students, the computer and other resources that mediated the learning process. The methodology and research design is outlined below.

Methodology

Given that the learning environment was based on the belief that classrooms are knowledge building communities, where resources collectively contribute to cognitive activity, the methodology needed to acknowledge the indivisible nature of the classroom in this instance. While the computer was a focal point of this study, it was acknowledged that its success depended on many other interdependent variables within the learning environment. In relation to this, Salomon et al. (1991) write, "no computer technology in and of itself can be made to affect thinking. One needs to consider both theoretically and practically, the whole social & cultural milieu…" (p. 3).

Consequently, qualitative methodology was used given that its principles are more in tune with, and capable of capturing and expressing, the emergent cognitive activity within a distributed learning environment. It was also thought that qualitative approaches would be more sensitive to the nuances characterising social situations and more likely to provide results that were rich, descriptive and a genuine reflection of the participants' perspectives. More specifically, the procedures associated with *action research* were followed given that the problem being investigated was within the social setting of the researcher's own class. As such, the researcher for this study was also the teacher.

Procedure

At the commencement of the unit, students were familiarised with the principles of distributed cognition and were also taught how to use *Inspiration 5.0*, an electronic concept-mapping tool. Concept-mapping software was chosen due to the interrelated nature of the concepts and topic modules within the unit. Each class was based on collaborative group work and whole class discussions, the understandings from which were then built into a concept-map that each group created for the five modules that made up the unit. When the students worked on their maps it was always in response to a specific objective that was either defined by the group or the teacher. A significant aspect of a distributed learning environment is that tasks are authentic and have a genuine purpose (Brown, Ash, Rutherford, Nakagawa, Gordon & Campione, 1993).

The collaborative groups were comprised of three students and one computer, the composition of which remained the same throughout the semester. Four of these groups were observed to assess the effects the computer had on their learning. On three separate occasions, these groups were audiotaped as they constructed their concept-maps and completed class activities. Although not the sole source of data, the transcripts from these class activities were the primary focus of analysis.

Framework for analysis

The environment within which this study was staged promoted a view that learning is an active mental process of distributing cognitions to others and across a range of contextual resources. It was expected, therefore, that assessment of any emergent learning should subsume these social constructivist perspectives. Consequently, the literature was reviewed in an attempt to identify models that recognised socio-cognitive processes and the shared construction of knowledge structures. While not developed specifically for co-constructed knowledge, Biggs and Collis' (1989) SOLO Taxonomy (Structure of the Observed Learning Outcomes), Marton, Dall'Alba & Beaty's (1993) conceptions of learning and Jonassen and Tessmer's (1996) outcomes-based taxonomy were useful in that they reflected the fundamentals of social constructivism and were descriptive enough to enable an analysis of the data.

In attempting to decide which of these three models would be the most suitable analytical tool for the purposes of this study, all three were combined to develop a thorough set of learning characteristics. Given that group discussion was the primary source of data, these merged learning characteristics were then translated into corresponding discourse which ultimately constituted the analysis tool. As indicated in Table 1, each level of discourse was described in terms of the types of socio-cognitive processes which were characteristic of the knowledge category it was derived from.

Table 1. Analysis framework **-** Merger of learning characteristics and their corresponding discourse

SOLO Taxonomy **(Biggs & Collis, 1989)**	**Conceptions of Learning** **(Marton et al.,1993)**	**Learning Outcomes Taxonomy** **(Jonassen & Tessmer, 1996)**	**Corresponding discourse**
Prestructural: Students engage the task but have difficulty in interpreting its requirements. Responses are illogical or irrelevant.	**Increasing One's Knowledge:** Students accumulate or absorb pieces of unrelated knowledge.		**Prestructural discourse:** Statements that are illogical, irrelevant, incorrect or incoherent. Statements about related declarative knowledge that are isolated from any other information. Statements that are indicative of memory recall or recognition of isolated declarative knowledge.
Unistructural: Students are able to interpret task requirements, but only in terms of a 1:1 relationship between a selected concept and the information supplied by the task	**Memorising and Reproducing:** Students rote learning information in order to recall pieces of knowledge.	**Declarative knowledge**: Students can recall, recognise and paraphrase declarative knowledge, albeit unstructured or inadequately structured knowledge.	
Multistructural: Students successfully relate task requirements to a number of appropriate concepts. However, interrelationships are not usually made.	**Using Knowledge for a variety of purposes:** When required, students use knowledge and skills that have been accumulated. Application, in this sense, does not presuppose understanding.	**Structural knowledge (basic)**: Students can identify the relationships between one or more basic facts related to a task.	**Foundational discourse:** Statements that are indicative of a developing understanding – groups can identify more than one relevant concept and will endeavour to (either successfully or unsuccessfully) relate these concepts together. Statements show consistency and congruence with expert perspectives.
Relational: Students successfully select a number of concepts and identify the relationships between them. These interrelationships are used to form generalisations, which are consistent with the task data.	**Understanding:** Students use strategies that enable them to search for the meaning inherent in concepts.	**Structural knowledge (complex):** Students demonstrate that they have acquired a range of diverse and interrelated semantic networks in relation to tasks.	**Relational discourse:** Statements are indicative of the formation of a diverse, complex semantic network of interrelated concepts. Knowledge of these relationships is articulated freely and effectively to others. A range of strategies are employed to facilitate deep level understandings of material and explanations are logical, coherent and speedy.
		Mental models: Knowing what, when and why of a particular concept. The foundations for ampliative learning.	
Extended Abstract: Students are able to select a wide range of concepts appropriate to the task requirements, and to interrelate these through the use of abstract universal principles not directly detailed in the task data. Students can formulate hypotheses and deduce from these that certain events are likely to follow. They can successfully introduce analogues not embodied in the data to explain principles.	**Seeing things in a different way:** Having understood the inherent meaning of a concept or concepts, students are able to look at it from a number of different perspectives.	**Situated Learning**: Students can successfully transfer knowledge of concepts and problems to authentic and diverse contexts.	**Extended abstract discourse:** Statements indicate the group's ability to apply concepts to a range of situations using learned operations. There is a sense of originality emerging and confidence to experiment with concepts in diverse contexts. Analogies are being drawn, abstract inferences made, as well as personal theories, all of which are highly plausible and sophisticated. As a result of these newly formed appreciations, changes are apparent in the way the group perceives concepts
	Changing as a person: As a result of learning experiences, students grow and change within themselves. These experiences lead to new understandings and appreciations.	**Ampliative Skills**: Students can use rules of logic and imagination to draw conclusions, explain implications and imagine a range of plausible possibilities.	

			about certain phenomenon.
		Self-knowledge: Students use reflection and self-knowledge to identify cognitive and affective strengths and weaknesses.	**Metacognitive discourse:** Statements reflect knowledge about the group's ability as learning entity - its strengths and shortcomings. There is an awareness of the learning context - what the task requirements are, what resources are available, how these resources can be used effectively, and what skills and processes will facilitate successful completion of the task. This incorporates knowledge and application of appropriate learning strategies (cognitive, metacognitive and resource management). Groups are able to articulate, monitor and regulate their effort, persistence, willingness to learn. Choices are made that indicate a healthy attitude towards learning in general.
		Executive control: Students demonstrate their ability to control internal and external learning problem solving processes.	
		Motivation: Students demonstrate the willful manipulation of task attention, effort, and enthusiasm. They consistently display willingness, persistence and effort.	
		Attitude: Students demonstrate a healthy attitude towards tasks. They make choices in keeping with appropriate behaviour.	

Data analysis

The unit of analysis was concerned with the cognitive processes to emerge from *groups* of students as they interacted with each other and their environment. Therefore, group dialogue was the focus of analysis although not all dialogue within the transcripts could be classified according to the five types of discourse. In keeping with Herrington's (1997) experiences of student collaborations around interactive multimedia, statements that were extraneous to the task at hand were classified as either *social (on-task or off-task)* or *procedural (equipment, software or task)* discourse. The fundamental principles of Miles and Huberman's (1994) three-step process of data reduction, data display and conclusion drawing as well as Glaser and Strauss' (cited in Lincoln & Guba, 1985) constant comparative method were used to guide the analysis process. The Non-numerical Unstructured Data Indexing Searching and Theorising (NUD·IST) program was used as a tool to organise and code the data.

Findings

One would expect that for the computer to have contributed to quality learning within the distributed learning environment, the students' dialogue would be consistent with the latter, more sophisticated discourse categories. In reality, all categories were represented in the students' dialogue - some to a greater or lesser extent. A summary of the nature and extent of this dialogue is presented in Table 2. Accompanying this summary is a short definition of the category and an example of dialogue taken from the transcripts.

Table 2. Summary of findings

Category	Summary of findings	Example from transcripts
Social discourse (on-task)	Evident (intermittently) in all transcripts. Mostly occurred when students were explaining a concept and would go off on a tangent to a related but not very relevant issue.	S1: That's like with my daughter who was told … she needed to vary her reading by the librarian … she hardly reads anything anymore and

		…(CA2/2G1)
Social discourse (off-task)	Evident (intermittently) in all transcripts. Usually in the form of one-sentence remarks that generally would not affect task progress. Comments often related to students being tired.	S1: What're we doing? S2: Can we have a break? S1: I'm going to the Royal Show Saturday. S2: Are you? (CA2/2G1)
Procedural discourse (equipment)	Evident mostly in transcripts taken from the first data recording session where groups delegated control of the mouse and keyboard. Other comments were in relation to hardware and system problems.	S1: … our computer has just crashed again. S2: Quick start it up. We're not going to get anything done. (CA3/2G3)
Procedural discourse (software)	Prevalent throughout all transcripts, but most significant in the first data recording session. Many comments, questions and exclamations made about how to use the software, and its various functions. As groups became more proficient users, these comments transformed into statements in relation to their desire to perform more complex and creative functions.	S1: Oh don't forget we have to ask [the teacher] about that little square we hit last week. (CA1/2G1) S1: I'm going to flick through the pictures here to make this look a bit better. (CA3/2G1)
Procedural discourse (task)	Prevalent throughout all transcripts, albeit to a greater or lesser extent between groups. Those groups, who didn't understand task requirements at the beginning of lesson, spent much time trying to grasp the objectives throughout the rest of the class.	S1: So what are we doing here? S2: We're just doing implications of this – how we're going to organise our classroom to use this best. S1: I see. S2: So [typing] 're-cap what was learnt in the previous lesson'. (CA1/2G3)
Prestructural discourse	Mostly apparent at the introduction of topic modules where groups encountered concepts for the first time (drawing on prior knowledge). Some comments made would be based on misconceptions previously held or simply stating facts that lacked meaning.	S1: Actually you know constructivism seems to work really well in my art classes because … it's outcomes based. You've got to think of the outcome first before you can write the program. (CA1/2G1)
Foundational discourse	The most prevalent type of talk throughout the semester and across all groups. Evident when groups were trying to come to terms with concepts and their interrelationships. Questions were frequently posed to one another and to the teacher. In most cases, these uncertainties were resolved with assistance from the teacher. Discussions occurred in conjunction with the concept-map, where its image was used as a visual prompt to activate conversations. The concept-map was used frequently as a basis for groups attempting to expand the relationships between concepts.	S1: Yes I know that but how do you actually control that?... S2: … I've had enough. S3: But hang on, we've already got it here [referring to map]. That's part of what we were talking about before with elaboration and … rehearsal and those things that you do to learn something. S2: No that was levels of processing. S3: Yeah I know but … S1: So if you are really thinking about how you're going to learn it and trying to be in control you would try to elaborate like in a deep level way and not rote learn … (CAG1)
Relational discourse	Prevalent in all transcripts but a diversity between groups in terms of who exhibited this type of talk the most - some groups were more consistent than others. In attempting to explain or justify links made on concept-map, there was a sense of ease and automaticity that always consisted of integrated and relevant ideas. Authentic contexts were often drawn on for explanations.	S1: Well the concept of constructivism to me is that it's a form of learning and teaching where teachers, instead of being the expository type … who stands out the front and says "blah, blah" … the constructivist teacher designs experiences where they capitalise on what the students already know, and goes from there. So on the video … the first thing [the teacher] did was to get the kids to discuss the kinds of energy they already knew about … (CA1/2G2)
Extended abstract discourse	A few, but not many instances of this talk and only in two groups. Comments made in these instances were rich, on a par with an expert's definition and creative. Attempts made to construct own theories about aspects of concept-maps.	S1: … so like for the qualitative conception for reading you'd look for personal interpretations ... So like the person plus the text would give you the interpretation … what I do with my students. Like I'll give them this little diagram of a stick person, a book and a light globe and this means that the person plus the text gives you your own meaning of the story. S2: … you're letting them form their own opinions. (CA1/2G3)

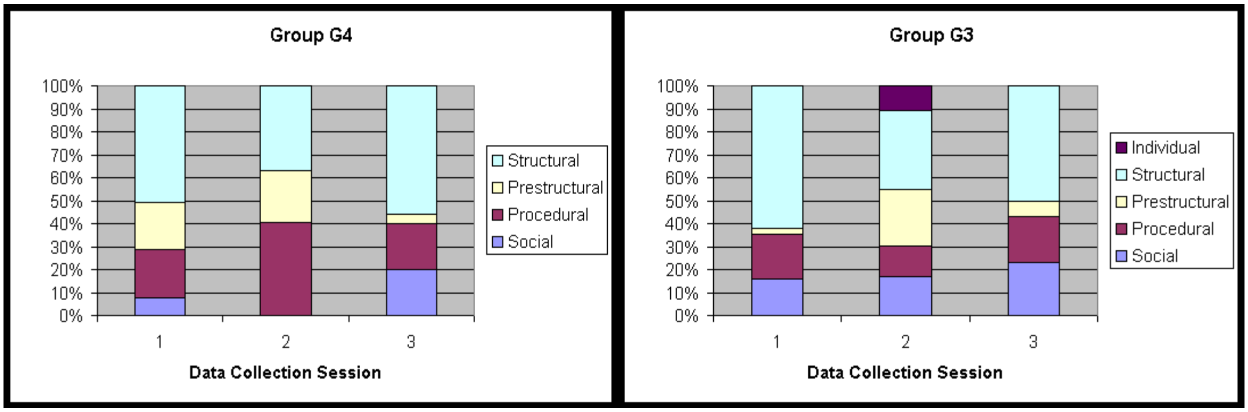
Metacognitive discourse	Evident throughout all transcripts. In many instances, the concept-map was used as a metacognitive prompt. Based on the formation of the map, groups would identify areas that needed clarification. Maps were used to indicate the progress being made by the group. Evidence that groups would monitor each student's effort and give encouragement to keep on task.	S1: Guys, I'd really like to know a bit more about levels of processing. Where's the note card for it? (CA1/2G4) S1: Why haven't we got anything about prior knowledge here? S2: We do it's in the note card for … no its not. S3: What should we put it with? What about … (CA1/2G3)

Discussion

Each category above represented a type of conceptual discourse that contributed in its own way to the groups' learning outcomes. Social discourse allowed group members to gauge each others' commitment to and perceptions of the learning situation while procedural discourse operationalised the task and computer demands. Prestructural discourse enabled the students to pool their knowledge resources and articulate misconceptions, and foundational discourse provided the basic infrastructure upon which relational discourse could take place. With sound understandings of the intricate relationships between concepts in place, extended abstract discourse allowed some individuals to attain higher levels of thought while metacognitive discourse mediated the entire collaborative experience.

However, even though each type of discourse was essential to the overall learning process, the socio-cognitive processes behind each one varied in complexity. For example, social, procedural and prestructural discourse was generally representative of lower-order socio-cognitive processes whereas foundational, relational, extended abstract and metacognitive discourse was representative of higher-order socio-cognitive processes. Therefore, for the computer to have enhanced learning, it was hypothesized that these more structural-oriented socio-cognitive processes would prevail within group collaborations.

The graphs in Figure 2 provide an overview of the extent to which foundational, relational, extended abstract and metacognitive socio-cognitive processes were evident in comparison to the other categories during the three recording sessions and for each group. Although their individual presence has been examined as part of the greater PhD project, they have been grouped together under the heading of 'structural discourse' for the purpose of this paper.



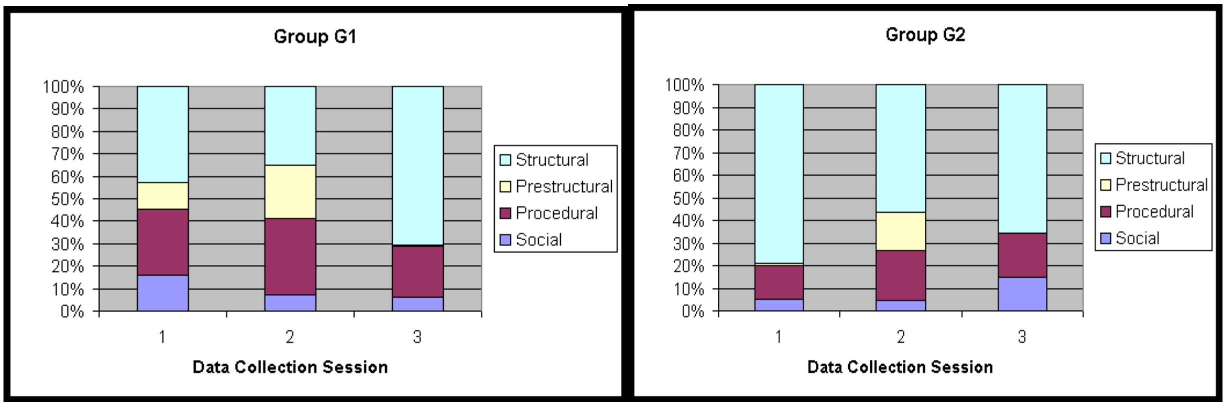


Figure 2. Comparison of discourse within groups across the three recording sessions

Given that the nature of conceptual change involves the gradual adjustment and reorganization of central concepts (Tyson, Venville, Harrison & Treagust, 1997), a considerable degree of prestructural discourse was expected to prevail in the first recording session as the groups grappled with largely unfamiliar subject matter. Similarly, it was expected that procedural discourse would dominate initially given the groups' inexperience with *Inspiration 5.0* and computers as learning tools. These types of discourse were then expected to subside as a stronger focus on structural discourse emerged alongside the groups' growing proficiency with the concepts and the computer software and hardware.

This scenario was partially evident in that substantial structural discourse was apparent in the final recording sessions for each group. During this class, between 50 and 70 percent of all four groups' discussions featured discourse which was indicative of either foundational, relational, extended abstract or metacognitive knowledge. There was a definite sense of group solidarity where collaborations between the computer and the students facilitated the development and consolidation of conceptual relationships. However, this relationship with the computer was not automatic. At the beginning of the semester, discussions were held *at* the computer, where thoughts and ideas were developed first, then recorded in the concept-map. Eventually, students began to incorporate the computer more into their groups and as such discussions were held *around* and *with* the concept-map (Crook, 1994).

There was no prestructural discourse evident in the third recording session for groups one and two, and only a small amount for groups three and four, which perhaps is suggestive of the groups' attainment of higher levels of understanding of concepts, or at the very least, their efforts to reach higher levels of understanding. The presence of approximately 20 percent of procedural discourse in all groups was largely in relation to technical problems with the computer hardware which occurred that day. While still relatively low, social discourse was at its highest for most groups during the third recording session. Interestingly, this social discourse was largely in relation to on-task discussions that were so in-depth that the groups often lost focus and direction.

There is no consistent pattern, however, across the first two recording sessions, nor across all four groups. For example, in the first recording session, group two participated in structural discourse almost 80 percent of the time. Their explanations and challenges were firmly grounded in existing knowledge which facilitated discussions that were comprehensive and typically situated in authentic situations. This finding is believed to be an outcome of both the group's previous knowledge of the topic being studied, and the distributed learning environment within which this collective memory was nurtured into well-connected knowledge structures.

Although still relatively high (approx 55%), structural discourse for the same group decreased in the following recording session. Prestructural discourse, on the other hand, was higher indicating the group's efforts to come to terms with new concepts. This was the case for all groups during the second recording session within which the topic of Learning Strategies was being tackled for the second consecutive week. It can be inferred from the data, therefore, that this topic was perhaps a little more complex than the others. Consequently, each group devoted between 15 and 30 percent of their time trying to understand individual facts before integrating them into meaningful, interconnected conceptions.

Procedural discourse was also prevalent in the second recording session, particularly for groups one and four. In looking at the specific breakdown for these two groups, most of the procedural-oriented discussion was in relation to the task. In both instances, these groups misinterpreted the task requirements and consequently spent up to 40 percent of their time trying to rectify the situation.

Group three also experienced some degree of difficulty in their efforts to collaborate during the second recording session. The outcome was a patchwork of various types of discourse that did not really dominate in any one area. Although there was more structural discourse in comparison to the other categories, the data suggests that it was largely in relation to their recognition that the concepts could be integrated but no definite relationships were made. Furthermore, there were brief instances where this group entered into dialogue that was more individually oriented than distributive and collaborative. Given that the unit of analysis was the socio-cognitive processes to emerge from group discussions, these instances were simply classified as 'individual discourse'.

On the whole, however, it can be said that structural discourse had a strong presence in each recording session. When presented with a task or concept, there was consistent evidence in the data that groups reflected on their combined prior knowledge, made inferences about it, challenged each other, determined the implications of interrelationships and made attempts to fit ideas it into a coherent explanations. As was indicated in Table 2, this process typically occurred in the presence of the concept-mapping tool, which clearly provided the group with visual representations of their developing understandings. Given that the socio-cognitive processes needed to construct these understandings required a higher level of thinking, it can be inferred that the learning context was conducive to this type of learning. In other words, the cognitive tool, within the distributed learning environment contributed to effective learning.

Conclusion

It can be concluded from these findings that the characteristics that presuppose the development of foundational knowledge, relational knowledge, metacognitive knowledge and (possibly) extended abstract knowledge are present due to a form of socially organized intervention with the computer. Collaborative group work with and around the computer has fostered the conditions that lead to quality learning outcomes in a distributed learning environment. Interaction with the computer appears to have mediated the groups' attempts to place structure and coherency in their dialogue, identify gaps in their understandings and take the appropriate steps towards integrating knowledge.

References

Biggs, J.B., & Collis, K.E. (1989). Towards a model of school-based curriculum development and assessment: Using the SOLO Taxonomy. *Australian Journal of Education*, 33, 149-161.

Brown, A., Ash, D., Rutherford, M., Nakagawa,, K., Gordon, A., & Campione, J. (1993). Distributed expertise in the classroom. In G. Salomon (Ed.). *Distributed cognitions: Psychological and educational considerations* (pp. 188-228). Cambridge: Cambridge University Press

Lincoln, Y., & Guba, E. G. (1985). *Naturalistic Inquiry*. Beverley Hills: Sage.

Marton, F., Dall'Alba, G., & Beaty, E. (1993). Conceptions of learning. *International Journal of Educational Research*, *19*, 277-300.

Tyson, L.M., Venville, G.J., Harrison, A.G., & Treagust, D.F. (1997). A multidimensional framework for interpreting conceptional change events in the classroom. *Science Education, 81*: 387-404.

Underwood, J.D.M., & Underwood, G, (1990). *Computers and learning*. Oxford: Blackwell.

Vygotsky, L.S. (1978). *Mind in society*. Cambridge: Harvard University Press.