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COGNITiVE LOAD, SCAFFOLDING AND AN ils ALGEBRA TUTOR

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The support for the use of computers in teaching and learning is widespread. Some educationalist say that the most powerful use of computing technology is as a tool for cognitive amplification or to enable students to explore mathematical concepts, and through this exploration construct mathematical understandings. Others note that the increasing power of computers enables them to exhibit artificial intelligence that can be used as surrogate tutors of mathematics. The most recent of such programs are Integrated Learning Systems (ILS) that present lessons, assess student responses and provide remedial feedback as well as monitor student progress. This study examines how a student used the feedback and cognitive scaffolding potential of a new generation ILS algebra tutor, The Learning Equation, in her learning. It was found that the student did not follow the carefully constructed intended sequence of learning provided by the ILS. However, she used a just-in-time approach to accessing feedback and a reliance on syntactic structure that enabled her to use the software in a way that accounted for most of her cognitive support needs.

introducton

This study uses cognitive load theory, dual coding theory and constructivist learning theory to explain the success a student experienced when she learnt algebra from a new generation computer based multimedia-learning environment called *The Learning Equation* (TLE; IPT Nelson, 1998). The major assumption in cognitive load theory is that a human's working memory has only a limited capacity (Bannert, 2002) and that instructional messages should be designed to minimise the chances of overloading the learner's cognitive system (Mayer & Moreno, 2002). From dual coding theory we have taken the idea that multiple representations of ideas enable students to process the information through multiple channels (Roblyer, 1999) and in particular that visual and verbal materials are processed in different systems (Paivio, 1986, cited in Mayer & Moreno, 2002). From constructivist learning theory we have taken the idea that meaningful learning occurs when learners actively select relevant information, organize it into coherent representations and integrate it with other knowledge.

Pollock, Chandler, and Sweller (2002, p. 62) have cited two sources of cognitive load:

1. Extraneous cognitive load is generated by the manner in which information is presented to learners and is under the control of instructional designers.
2. In contrast, intrinsic cognitive load is imposed by the intellectual complexity of the information.

   Further Pollock et al. (2002) noted "high-element interactivity material consists of elements that can not be understood in isolation because they interact." The study of algebra by nature requires a high-element interactivity since students need to keep in mind a multitude of conventions (e.g., number facts, equality concept, order convention, fractions, associative properties and distributive properties). The study of algebra imposes high intrinsic cognitive load because many elements must be processed in working memory simultaneously. Our cognitive architecture handles the problem of an excessively high working memory load by constructing schemas. A schema is a cognitive construction that organises elements of information categorically and stores them in long-term memory. The successful construction of schema is essential for successful algebra study. A person competent in algebra can readily transform *a/b = c* into *a = cb* in working memory despite the large number of elements involved while those with isolated understandings of the equal concept, symbolic representation of variables as letters and order convention will struggle with such transformations.

It has been noted that students have considerable difficulty in solving word problems, in part because of the difficulty that they experience in specifying relations among variables that require and understanding of algebraic structure (Sfard & Linchevski, 1994). In terms of cognitive load, word problems tend to be high in intrinsic cognitive load or that load connected with the nature of the material to be learnt (Bannert, 2002). Students who are able to solve novel word problems are thought to have some ability to work with the structural aspects of algebra, that is they have constructed appropriate schemas, a capacity that has been reported to be quite limited among middle secondary school students (Kieran, 1992). This study does not accept the notion of dichotomy in terms of *structural* and *operational* senses (as described by Sfard, 1991). Rather, this dichotomy is rejected and a duality is accepted. That is, there is acceptance that "the processes of learning and of problem-solving consist in an intricate interplay between operational and structural conceptions of the same notions" (Sfard, 1991, p. 36).

To overcome the difficulties in teaching mathematics there has been a tradition of attempting to reduce the cognitive load using the worked example technique that essentially consists of three steps (Cooper, 1998, p. 17):

1. Introduce the new topic. Present the background knowledge, principles and rules.
2. Demonstrate, using a few worked examples, how to apply the principles and rules.
3. Have the students "practice" how to apply the principles and rules.

This method of teaching imposes relatively low levels of cognitive load because attention need only be given to a limited element of the total problem at any one time. However, in implementing such an approach Norton, McRobbie, and Cooper (in press) found that only experienced teachers with very good mathematics backgrounds were effective in unpacking the underlying principles and the logic behind the rules, and placing these understandings within a coherent teaching sequence. Teachers without such backgrounds emphasised the rules as sequences of procedures but often the understanding of principles remained implicit. Such teaching has been reported to be wide spread and termed "the school mathematics tradition" (Gregg, 1995) and result in instrumental learning (Skemp, 1978).

TLE is essentially an ILS. Typically the operation of these systems has been described as consistent with an "instructivist pedagogical culture" (Reeves, 2000, p. 6). Quality ILS software is by its nature very "clean" (Papert, 1993) in the sense that mathematics learning is reduced to "formulas describing procedures to manipulate symbols" (p. 135). A number of authors have criticised this "clean" use of technology. For example, Bracewell, Breuleaux, Laferriere, Benoit, and Abdous (1998) described this form of software as "canned content" and argued that the paradigm it uses is essentially behaviourist. However a meta-analysis of ILS software studies indicates that students using such programs have consistently demonstrated significantly higher scores on tests and slightly improved attitudes towards the subject being taught than comparison students who did not study with the software (Kirkpatrick & Cuban, 1998). Others (e.g., Bennett, 1999) have provided support for this finding by arguing that, as ILS software can provide every student with "a private tutor in the computer that teaches him or her" it "will give more individual attention to students than teachers can hope to do in today's schools" (p. 7). Some of these authors, notably Bennett (1999), even argued that the advent of ILS software "will solve the educational crisis" (p. 1).

Typically, an ILS provides a stimulus, learners respond, the software analyses the response and provides appropriate feedback, and then the software or learner selects the next interaction. The software mimics a patient instructor who provides examples, asks questions and corrects errors via feedback. Feedback is considered critical (Roblyer, 1999) and is "most helpful when it emphasises relevance to the concept under study rather than whether the answers are right or wrong" (p. 35). Clearly, the finer the grain of instruction at which an ILS can respond the less load it places on working memory and the greater chance of success it is likely to have. Other factors that are interrelated to the quantity and quality of information, which learners can process, are the degree of student control of direction and pace of learning (Bagui, 1998, cited in Roblyer, 1999) and the extent to which the multimedia representations enable students to process information through multiple channels (Roblyer, 1999). The ILS aims to provide scaffolding to temporarily support students until they can perform the tasks on their own, which is to move through their Zone of Proximal Development (Luckin, 1999).

The particular ILS studied in this paper, TLE, used a cyclic approach with each of its topics covered in each of the year levels, and with each topic comprising a number of lesson units. The producers employed a large team of experts from both mathematics teaching and mathematics backgrounds. The thoroughness of their responses in using detailed sequences of carefully constructed learning activities is seen in the *Variables and Equations* unit from the *Patterns and Relations* topic, on which this study is based. There were thirteen lessons through which students had to progress. Generally, each lesson comprised four phases. The first phase was an application or mathematical modelling situation where the key concept was related to an applied problem. The second phase consisted of problems and guided explanations both in text form and through audio explanation. These explanations used multiple channels (i.e., dual coding Roblyer, 1999) were detailed and focused on both the*operational* and *structural* (Sfard, 1991) aspects of the algebra. That is, the students were led through the logic behind the concepts and procedures by a series of prompts and explanations. The third phase consisted of tasks providing practice questions, word problems, and terminology activities to consolidate and extend the knowledge introduced in the initial phases. If students made an error they were told that this entry was not correct and to try again. A subsequent error elicited more relevant cognitive scaffolding such as that depicted in Figure 1. For example, when asked to solve 2x = 9 , a student who selected "multiply by -1" from the provided options received the following scaffolding.

This would change the equation to –2x = –9. To solve the equation, you need to isolate x.

Try again.

Figure1: Error induced cognitive scaffolding.

The fourth and final phase provided a self-test or a test the student completed to assess their progress. In this phase students were given a selection of the types of questions studied in the lesson unit. Students could see their own responses and could view correct solutions with detailed working-out steps. Figure 2 shows a self-check question where the student had opted to *See sample solution*.

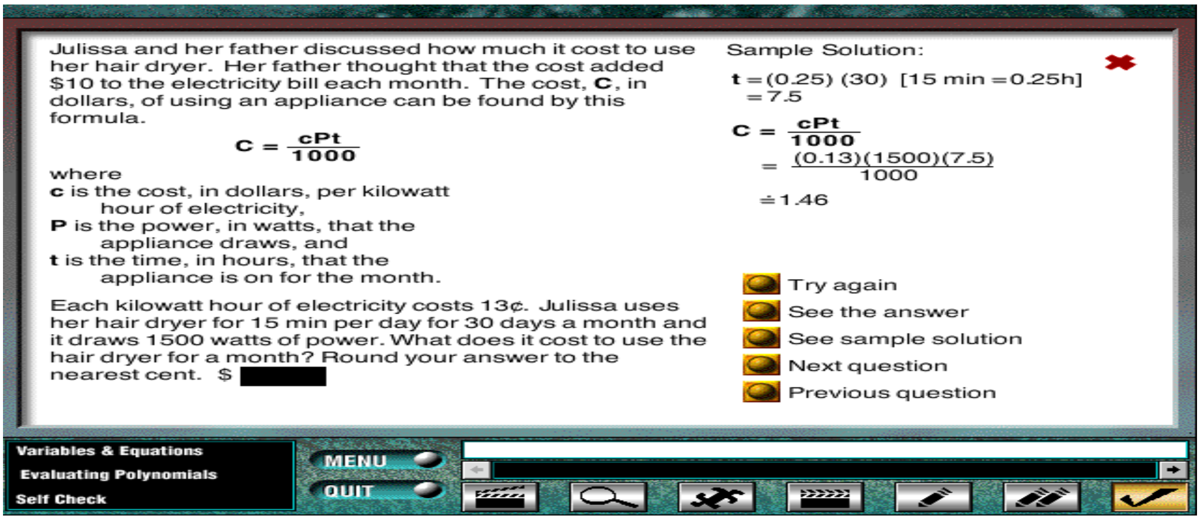

Figure 2: Modelled solution where a student had selected "See sample solution. "

Overall the TLE program appeared to conform to the principles of cognitive load theory (Bannert, 2002; Cooper, 1998) with careful task analysis, well-defined content, worked examples with careful control over presentation, pace and practice. Previous studies that have reviewed TLE indicated improved student performance on standard tests (Bracewell et al., 1998; Norton, Cooper, & McRobbie., 2000). This occurred for both able and less able students. The authors sought to explain the better performance of the students who worked with TLE by examining their level of engagement and the social discourse that occurred between pairs of students who worked with TLE (Norton & Cooper, 2001) and also the changed role of the teacher from a transmitter of information to a participant in a problem solving partnership with students (Norton, Cooper, & Baturo, 2001). There has, however, been limited research carried out on the nature of discourse between the students and TLE and, in particular, how students use the ILS's cognitive scaffolding potential and inherent navigational flexibility to control the level of cognitive load that they experience. This study has taken that focus.

METHOD

The study was a randomised control group pre-test-post-test design with one class using the multimedia environment of TLE as a treatment and two control classes being taught using traditional methods. This design was elaborated on by observing a sample of students in detail to provide case study data, which provided rich descriptions of how the students worked with the software. One such case study is reported below, that of Lisa. Lisa was selected because she was a capable students who progressed her learning of algebra. There were many aspects about the way she used the software that was typical of the way many students interacted with TLE. A hermeneutic, interpretive, and naturalistic approach to data analyses was adopted (Denzin & Lincoln, 1994). Information was continually analysed for commonalities cumulatively across the life of the study.

Subjects and contexts. There were 54 Year 9 students in a secondary school of 650 students located in a middle class suburb in the Brisbane metropolitan area. The students were randomly allocated to one computer class (28 students) and two control classes (13 students in each class). The test and control students studied the same content. The primary resource for the control students was a traditional textbook (*Mathematics 9*; Priddle, Davies, & Pitman, 1991). The teachers were assigned to teach the unit prior to the study commencing; (Max (all names are pseudonyms) taught one of the control classes and the treatment (TLE) class, Anna taught the other control class until the last fortnight when she took sick leave and Jack taught her class. All three teachers were considered by their colleagues as competent senior secondary mathematics teachers and each had over 10 years of mathematics teaching experience.

The mathematics content of a chapter in *Mathematics 9* was matched to TLE *Variables and Equations*, where the content ranged from processing first-degree single variable equations using the tiles environment to dividing polynomials by monomials. The exercises included manipulating algebraic equations and solving word problems.

Instruments All students were administered pre-test and post-tests with respect to algebra achievement. These tests evaluated student's abilities in four domains: operational algebra, the variable concept, and structural algebra and word problems. For the purposes of reporting to parents the post-test was divided two sections, the first three domains that totalled 15 questions each worth two marks and the four word problems each worth three marks. One of the word problems was relatively easily solved using a table of ordered pairs while the others were modelled on problem structures that Kieran (1992, p. 393) described as "with problems of this type, students can no longer rely on the approaches they used in arithmetic." In particular students had to use solving procedures that operated on both sides of the equation, which is a process that operates on an algebraic object.

Data collection methods. Data collecting techniques were observation, collection of artefacts, interviews, tests and split-screen videotape data (combining feed from the computer with a video). In this latter technique is enabled the face reactions of the students and their discussions were superimposed alongside the TLE software screen to show interactions between the students and the technology. This enabled the subjects' actions and interactions with objects (TLE) to be part of the analysis rather than relying heavily upon what students said. Roth (2001, p. 777) in explaining the importance of taking into account gestures and actions noted "the enormous amount of mental effort involved when people have to construct complex sentences and verbal arguments in domains which with they are not familiar and therefore lacked vocabulary and verbal fluency." By considering gesture as well as speech more complete analysis of interaction occurred. This method assumed that external actions were a manifestation of mental processes. Such an assumption is consistent with activity theory interpretations of actions (e.g., Rodriguez, 2001). Pairs of students were interviewed following the observations and videotaping with respect to their beliefs about the virtue of learning with the software. Six lessons of split screen video recording were recorded and examined. As the focus of this study was on how students interacted with *The Learning Equation* software, data concerning the tests, the discourse between students and the role of the teacher are not provided in this paper. They are reported in Norton, Cooper and McRobbie (2000)

RESULTS AND DISCUSSION

The pre-test and post-test achievement data showed that students who worked with TLE outperformed their peers in all domains tested indicating that they were better prepared to advance to the next level of algebra learning and problem solving (Norton, Cooper & McRobbie, 2000).

An overview of pre-test results are summarised in Table 1. The arithmetic component of the pre-test was 30 marks while the algebra component was 48 marks. The post-test results have been summarised in Table 2. Although there were 28 students in TLE class, only the results of 24 are reported because of student absences.

Table 1 Summary of Overall Results of the Pre-test

Test	N	Mean	SD	t
Control group (arithmetic)	25	22.50	3.89	1.38 (p=.98)
TLE group (arithmetic)	24	23.27	2.32	
Control group (algebra)	25	4.18	2.61	0 .01 (p= .38)
TLE group (algebra)	24	4.18	2.18	

The pre-test results indicated that no statistically significant differences existed between the classes in either algebra or arithmetic performance. Both groups performed poorly on the algebra questions.

Table 2 shows the mean subtotal score for each problem type of the post-test. Independent 2 tailed t-test significance has been calculated for the total scores on for each of the problem types (operational algebra, variable concept, structural algebra and word problems).

Table 2 Post-test Comparisons.

	Control	TLE	
Subset	Mean SD	Mean SD	t
Operational algebra	5.08 2.26	6.34 1.79	2.09 *
Variable concept	4.16 1.40	5.36 1.30	3.03 **
Structural algebra	2.88 2.72	4.41 2.55	1.98
Word problems	3.62 2.89	5.84 3.31	2.46*

**p*< .05. ***p*< .01

Clearly both classes improved in their abilities on these types of algebra questions in the tests. However, the students who studied using the TLE software outperformed the control class on all classes of questions and this was statistically significant on all except the structural algebra subset.

A rich description of how Lisa interacted with TLE is presented to provide information on how a capable student used the ILS as a source of cognitive scaffolding for the basis of their algebra learning. Lisa's previous mathematics performance as measured in the pre-test and also through examination of her academic records indicated she was a little above average in mathematical test performance and showed she was stronger than most of her peers in terms of her capacity to work with algebraic symbols. Her final results indicated that she had made substantial gains in algebra learning as measured by pencil and paper tests through the course of the study. For example Lisa achieved 8/8 for operational algebra questions; 6/6 for the three questions testing knowledge of the variable concept and 6.5/8 for the structural algebra questions since she made errors in collecting like terms and did not attempt to factorise 2yz-2y. Lisa achieved 7/12 on the word problem section. For this mark Lisa provided two complete and correct solutions to the four word problems, one partially correct solution and attempted to use algebraic techniques in all questions (one simultaneous solution question was solved by some students using a table of ordered pairs). Analysis of her solutions showed that she was limited to some degree by misconceptions related to arithmetic laws; particularly the distributive and associative laws.

The description contains little information on how the teacher interacted with Lisa as the teacher did not interact directly with Lisa in most lessons. While the description focuses on Lisa, her behaviour was not unique; her partner operated in a similar way and there were elements of Lisa's behaviour observed in the behaviours of other students in the class.

Description of Lisa's Use of TLE. In her use of TLE gGenerally, Lisa did not read the explanations presented in the introduction phase but she tended to rely heavily on the ILS's error-response scaffolding. When asked when she was reading the text explanations she responded: "Well kind of, but I mostly listen [to the audio explanation]. I kind of read it but I mostly listen." When further questioned about how she used the software Lisa indicated that she got help when she needed it. Observations of her use of the scaffolding supported this statement, that is that she skim read while listening to the instructions. This is evidence that Lisa used the dual coding capacity offered by the software, particularly first and second phases of the learning cycle (application of mathematical modelling and explanation phases). Analysis of Lisa's use of the software showed that she (like the other students) spent most of her learning time doing practice problems (worked example) and the self-check phase that could also be used in a worked example fashion. When working in these phases Lisa oscillated between problems, hints and partial and full solutions. She They used a *just-in-time* approach to get cognitive scaffolding to help with the problems. That is, she happily (apparently) made errors so that she could seek help from the software. Lisa tended to rely on a memory of the syntactic structure of problem types. She became familiar with the structures by using the help facilities of the program. The two main ways she gained syntactic familiarity was by accessing the help on practice problems (such as that modelled in Figure 1), selecting the option to do a problem of similar structure and also by examining the solutions in the self-check phase (such as that modelled in Figure 2). She then used ready access to cognitive scaffolding to this to build a pattern of to related problems and solutions as illustrated by Lisa's response to the author's questioning about how she used the previously provided cognitive scaffolding to do questions. The dialogue helps to illustrate that Lisa was focusing on patterns in developing her understanding of various problem structures.

Lisa Um ... I don't know ... you automatically think back to this one [points to the previous example].

Author So there are two parts, (to this problem) you always think they are going to do the second part first?

Lisa Yeah, they do it all the time.

"They do it all the time" is a telling comment, in that it illustrates her familiarity with the model of doing the second part of the problem first that was provided by the software.

The research literature provides some explanation for Lisa's achievement. For example, Lisa's appreciation of being able to control her pace of learning supports earlier studies that identified this as an important factor in the success of an ILS (e.g., Bagui, 1998 cited by Roblyer, 1999). However,

Lisa used the software's potential to control the pace and sequencing of the learning episodes in a way not intended by the producers. Apart from not reading most of the explanations, she did not follow the carefully ordered learning sequences. The bottom of Figure 2 shows that a learning sequence menu moves from an introduction through various models and practice to a self-check indicated by a tick. In early activities in each sequence, the software provided detailed cognitive scaffolding but, as the activities progressed, the amount of support was reduced. Lisa frequently skipped ahead to try more difficult problems but, if she experienced too much difficulty, revisited activities where more scaffolding was forthcoming. That is, Lisa managed the intrinsic cognitive load she experienced by going back to examples where cognitive scaffolding was more detailed or the activity simpler and the intrinsic cognitive load reduced. As Lisa noted "you can figure it out, then when you get further along you know what to do, but if you stuff it you can go back." While the verbal vignettes support the above assertion relating to her use of the ready access of cognitive scaffolding, her actions tracked by the split screen video provide clearer evidence that she gained familiarity with the various problem structures by accessing various levels of cognitive scaffolding and also managed her cognitive loads in the same way to develop her ability to do algebra. Lisa's statement also acknowledges her appreciation of the opportunity for her to control the pace of her learning. Which is an important factor in the success of ILS programs (e.g., Bagui, 1998, cited by Roblyer, 1999).

Cognitive load theorists such as Cooper (1998) have supported the worked example technique for teaching mathematics, for example, "worked example techniques have been demonstrated to be highly effective at facilitating learning" (p. 18). In most traditional mathematics classes students repetitively practice problems of a similar structure by carefully writing down the steps involved in solving the problem. The problems in text books tend to go from less to more difficult in a sequential fashion. When working with TLE Lisa was able to access a huge data bank of problems and these problems were catalogued on the basis of structure and difficulty. Both the quantity and diversity of problems that Lisa was able to access was much greater than that available to the students in the control classes studying from the traditional textbook. This was particularly so in the case of word problems. Further, as noted previously Lisa could access fine grain scaffolding for these problems. In contrast, the students working with the traditional text had access to a few completed solutions and there after had to rely on the "numerical answers" only provided in the back of the text. Of course the teacher was available to provide feedback. However, as reported by Norton, Cooper and Baturo (2001) the discourse between Mr Max and the control class students was typical of what Brousseau (1984) called the "Topaze" effect and what Lesh and Kelly (1997) called bug repair, that is, guiding students step by step in a manner that avoids error. The duration of these exchanges was frequently less than a minute and rarely more than two minutes. In general, the class discourse was typical of explain-practise instruction, which has limited potential to foster mathematical achievement (Lo, Wheatly, & Smith, 1994). While TLE mimicked the patient instructor model the experience of the students was quite different. Firstly, the feedback provided by the teacher was usually verbal and some times visual with written solutions on the blackboard, while TLE feed was often verbal and always visual. Secondly the students could access the feedback from TLE at any time while student access to the teacher's explanations in the control classes was less under their control (Norton & Cooper, 2001).

When working with TLE Lisa's did limited pencil and paper manipulation of problems although she initially . Initially kept pencil and paper records of her worked examples. However, as the trial progressed this became less so. Lisa explained her mode of operation as follows.

> Well sometimes I write it down if it is too hard to do in my head, but yeah usually I kind of just figure them out and then it gives you hints down the bottom if you get it wrong, there is a little thing that comes up and tells you what you have to do to get it right ... I like it cause I am not as good as some other people and I can just work away slowly.

Lisa's statement indicates that she relied on mental strategies and the cognitive scaffolding offered by TLE as well as an appreciation of the opportunity to control her pace of learning and the quality of cognitive scaffolding she was able to access. Despite the lack of practice in writing down her solutions, Lisa presented well setout worked solutions in the final test. The good quality of Lisa's pencil and paper setting out suggests that doing worked examples need not necessarily involve lots of pencil and paper manipulation. Lisa did do some pencil and paper working out, a limited amount in class and some for homework but considerably less than her peers in the traditional classes. Writing down all the steps in a problem solution is a relatively time consuming process. It is hypothesised that the shedding of this process by Lisa enabled her to do many more worked example solutions than the students in the control classes were able to do. This hypothesis was supported by observational data which showed that Lisa seldom completed pencil and paper activities in doing the worked examples. Greater familiarity with a range of problems may also have contributed to Lisa's better than average results in that the increased familiarity with the tasks reduced her cognitive load such that she was better able to focus on specific solution steps and thus over time better able to induce generalised solutions.

The video evidence showed that both Lisa and her partner had a high level of engagement and worked consistently through out the lesson. This may have been because quality of cognitive scaffolding offered was such that it was neither too simplistic nor too difficult and thus suited to facilitating the students' movement through their Zone of Proximal Development (Vygotsky, 1978) at a pace that they could control. The central role of teachers in the process of helping students move through their Zone of Proximal Development has been well recognised (Kieran, 1992; Luckin, 1999). In the case of Lisa the computer provided most of the "helping" for Lisa to move through this zone. Thus, t There was evidence that the combination of multimedia format, cognitive engagement, seeing appropriately set out solutions and limited pencil and paper practice seemed to be sufficient for Lisa to learn the algebra and communicate it with appropriate setting out.

CONCLUSION

There is discussion in the research literature in relation to the degree of support students ought to have in order to foster mathematics learning (e.g., Sfard, Nesher, Streefland, Cobb, & Mason 1998). For example, in face-to-face teaching, the provision of fine-grained scaffolding has thought to have limited potential to foster conceptual learning since it removes the need for the student to think hard and because students execute "sequences of steps with no apparent understanding about why the various steps were taken" (Lesh & Kelly, 1997, p. 411). There has been considerable support for teachers to avoid funnelling student's thinking and encouraging them to adopt less directive behaviours that focus on questioning students' misconceptions (e.g., Lesh & Kelly, 1997; Simon, 1997). However, as Simon (1997, p. 59) noted:

> Our ability to understand student's current knowledge and thinking is (and will always will always be) limited at best. Therefore, a model of teaching that requires a teacher to provide each student with what he or she needs at each point in time cannot succeed.

On the other hand cognitive load theorists (e.g., Mayer & Moreno, 2002; Pollock, Chandler & Sweller, 2002) state that learning is likely to be more effective when students' mental capacities are not overloaded, as working memory is very limited. In order to understand, various elements of a problem need to be processed simultaneously and this is difficult to do unless the various interactive elements have been incorporated into schema. In the case of algebra study this theory implies that it may be necessary for students to learn the various solution steps singularly before integration is attempted since it is frequently not possible to process all of the elements in working memory simultaneously. As Pollock et al. (2002, p. 84) noted: "Instructional designs intended to encourage students to understand very complex material prior to the construction of appropriate schemas will fail." The reason for this is that working with complex material involves the interaction of a number of elements that have to be held in working memory and that this imposes excessive cognitive load on learners hindering learning. Interestingly, Lisa failed on those questions where she lacked mastery of fundamental prerequisite concepts (e.g., the distributive and associative laws) and was thus unable to integrate "elements" of the more difficult structural algebra and word problems. This finding supports Pollock et al. (2002, p. 61) who further stated "for certain groups of learners, information is better learnt through the isolated -interacting elements instructional method," a method of instruction that reduces cognitive load.

This study does not provide evidence to refute the idea that teachers ought to ask more and tell less and to focus on activities that result in students constructing powerful mathematical ideas. Rather, it provides evidence that when students are given appropriate opportunities to manage their cognitive loads, provided with appropriate models of solutions and with incremental help the learning experience can be successful in fostering algebra learning. This study presents evidence that the multimedia form in which the fine grain scaffolding was available in both visual and verbal form (dual coding) was adequate for Lisa to progress her learning. In particular this learning was demonstrated by her completion of word problems that have previously been reported to require students to have developed schema in order to complete (Sfard & Linchevski, 1994).

The multimedia environment presented information in both visual and verbal format and was in a flexible form that enabled Lisa to access explanations and scaffolding as many times as she wanted and to control the grain of cognitive scaffolding in a way that a teacher teaching from a black board would have great difficulty providing. Further, usually a teacher's explanations follow a linear sequence and students are expected to remember earlier steps and explanations. If the teacher is made aware of a failure by students to learn the teacher can reteach, but accounting for individual learning difficulties is challenging (Simson, 1997). In addition the stimulus material in the control classes (the text book) provided a much smaller number of problems of each type, this was most noticeable in the case of word problems. In the multimedia environment the student can readily return to previous scaffolding and control the degree of difficulty of problems. This enables students to control the degree the cognitive load placed upon them. There is some similarity in the way Lisa used the ILS program and the way many students use traditional texts books, that is, students model the application of provided solutions at the beginning of the exercise and check answers to those problems in the back of the book. However, the difference between this method of sourcing cognitive scaffolding and Lisa's use of the cognitive scaffolding available from TLE is that Lisa could choose the degree of cognitive scaffolding she needed at any point and more often the scaffolding provided by TLE is of a much finer grain than the few worked solutions and simple answer provided by most textbooks. Pollock et al. (2002)

noted that extraneous cognitive load was under the control of the instructional designers. However, the way Lisa used the TLE enabled her to manage the extraneous cognitive load inherent in the TLE. She did this by becoming fluent in the use of the multimedia genera, skim reading text clues, listening to instructions and learning how to navigate about the learning activities to find appropriate cognitive scaffolding. Lisa's management of the extraneous cognitive load enabled her to access cognitive scaffolding to manage the intrinsic cognitive load (that imposed by the intellectual complexity of the algebra learning). In effect TLE gave Lisa the tools to control the internal cognitive load by enabling her to regulate her learning processes. She was able to move forward, backward and laterally within the program. Lisa could select the type of problem she wished to experience and the type of cognitive scaffolding she needed. Such flexibility was much less evident in the control classes.

The study illustrates that the introduction of multimedia into teaching and learning has special discourse features. Few educational researchers support behaviourist approaches to teaching and learning mathematics, and many authors consider that the application of such approaches in the use of computing technology is not the most powerful use of computing power (e.g., Papert, 1993; Roblyer, 1999). However, this study has provided evidence that multimedia ILS where student can control cognitive scaffolding options and in particular control the amount of support that they wish and to easily navigate within the electronic medium to access a large number of problems of different structures but organised systematically in classes of problems seemed to play a central role in the success of such software. The inherent flexibility of the medium helped the learner to organise information into coherent representations linked with other knowledge and to construct schema. In summary the learner was able to mediate the intrinsic cognitive load through her control of the external cognitive load.

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