STUDENTS' RESPONSES TO A NEW GENERATION ILS ALGEBRA TUTOR

Stephen Norton and Tom J. Cooper
Centre for Mathematics and Science Education
Queensland University of Technology, Brisbane, Australia, 4059

This study reports on the quality of discourse between pairs of students and a new generation ILS and uses this discourse to explain some of the successes of such programs. Split image video recordings were analysed to provide a rich set of data. The quality of cognitive scaffolding provided by the ILS and the social discourse that developed between pairs appeared to foster the learning of algebra by some students. The nature of the discourse between the students and the technology and among students differed. For some students the cognitive and social scaffolding was inadequate and resulted in limited time on task. The study has impactions for the role of teachers in classrooms where such technology is the primary stimulus material.

Integrated Learning Systems (ILS) have used computing technology to harness a student model that records and updates histories of individual students, an expert system that models ideal student actions, a pedagogical model that makes teaching decisions, and a graphical interface with input and output devices for interaction to implement traditional methods of teaching and learning, in particular drill and practice and similar behaviourist approaches to teaching and learning (McArthur, Lewis & Bishay, 2000). Such programs generally have well defined goals, such as factual knowledge and/or procedural skills that can be measured on standard tests. The computer-student interactions are usually controlled by the computer: it provides a stimulus, the student responds, it analyses the response and then provides appropriate feedback and further stimuli. Usually the software breaks down the content to be taught into small units, assesses progress, and then moves on to the next unit or provides remedial instruction (Maddux, Johnson, &Willis, 1997).

ILS programs tend to be *clean* software (Papert, 1993) in that they try to mimic quality instruction by reducing mathematics to formulas describing procedures to manipulate symbols. Because of this, the quality of scaffolding or temporary support provided to students until they can perform the intellectual tasks on their own (Ertmer & Cennamo, 1995) is very important. The software may be ineffective if it does not provide cognitive support for students as they move through their *zone of proximal development* (Vygotsky, 1987). As well, Salampasis (2000) noted that the additional cognitive load of studying within an electronic medium while learning new work might be beyond some students. He argued that the task of both learning the content and learning how to navigate and learn within a new medium may exceed the working memory capacity of these students and result in disorientation, the inability to cognitively process the material being learnt, and impeded learning (Cooper, 1998).

The ILS. *The Learning Equation* (ITP Nelson, 1998) is an ILS designed to be the major mathematics teaching resource for the first four years of high school. It is a complete course that extended from Years 7 to 10. It is a multimedia environment composed of voice and textual explanations, practice questions (where text cues guided students who make mistakes), summary activities, and self-tests. The software uses a cyclic approach with each of its topic units covered in each of the year levels. Generally, each unit comprises four phases. The first is an application or mathematical modelling situation where the key concept was related to an applied problem. The second is a guided explanation of the concepts and procedures with reference to a problem. That is, the students are lead through the logic behind the concepts and procedures by a series of prompts and explanations. The third phase provides practice questions, word problems and terminology activities to consolidate and extend the knowledge introduced in the initial phases. In this phase, the students can select to see the answer, see a model solution or try a problem of similar structure. The final phase provides a self-test where students are given a selection of the types of questions studied in the lesson unit. The students can see their own responses and view correct solutions with detailed working shown.

Previous studies on *The Learning Equation* indicated improved student performance on standard tests (Bracewell, Breuleux, Laferriere, Benoit & Abdous, 1998; Norton, Cooper, & McRobbie, 2000; Pfaus, 1998). This occurred for both able and less able students (Pfaus, 1998). Students were found to be more actively engaged in activities (Pfaus, 1998) and more involved in discussion (Norton et al., 2000) than in traditional classes. The importance of peer interactions in facilitating student learning when working with technology has been noted previously (Tao, 2000). The students indicated they liked being able to work at their own pace (Pfaus, 1998). Thus, it is apparent that most of the research carried out on the effectiveness of *The Learning Equation* package has endorsed its potential to enhance mathematics teaching and learning and affect.

Norton et al., (2000) put forward two explanations for the improved student cognitive outcomes from use of *The Learning Equation*. The first was that the quality of instruction and scaffolding provided by the ILS's virtual environment might have effectively mimicked quality instruction. The second was that the classroom discourse was such that socially constructed understanding in the constructivist tradition may have been facilitated.

The aim of the study reported in this paper was to follow up Norton et al., (2000), to examine the interactions of students with the technology and with each other as they worked on the software. The focus was to determine how different students responded to the cognitive scaffolding and the social environment of *The Learning Equation.* It was hoped that examination of these variables might shed light on the apparent success of the software.

Method

Subjects and Contexts. The subjects of this study were 28 Year 9 students (about 14 years of age) in a secondary school of 650 students located in a middle class suburb in the metropolitan area of Brisbane, the capital of Queensland. Of these, a pair of capable boys, a mixed ability pair of girls and a pair of girls who were regarded as average students were purposefully selected using pre-test results for detailed study to illustrate a range of student responses to the software. The class was taught by an experienced mathematics teachers who was regarded as a quality teacher by his peers but whose normal teaching conformed to that described as the "school mathematics tradition" (Gregg, 1995, p. 443).

Data collection methods. The methods used were observation, collection of artefacts, interviews and tests. The student pairs were observed over six lessons and split-screen videotape data (combining feed from the computer with a video) was recorded for two lessons. This enabled the face reactions of the students and their discussions to be superimposed alongside *The Learning Equation* software screen, showing interactions between the students and the technology. The student pairs were interviewed following the observations. All students were administered pre- and post-tests with respect to algebra achievement. The results of these were reported in Norton et al., (2000). As the focus of this study was to examine students' response to the *The Learning Equation* software, the data from these tests are not provided in this paper.

Analysis. A hermeneutic interpretive and naturalistic approach to data analyses was adopted (Denzin & Lincoln, 1994). Information was analysed for commonalities cumulatively across the life of the study.

Results and Analysis

In *The Learning Equation* class, students sat and worked in pairs at small desks upon which the networked computers were located. Typically, the lessons started with an overview of the tasks to be undertaken that day. On most occasions, the early part of the lesson was also used to model key procedures that students had been required to complete for homework. Interactions between the three pairs and the teacher were very limited. For most of each lesson, students worked almost exclusively on the computers. The classroom was quite noisy.

The three pairs of students recorded divergent responses to *The Learning Equation*. The capable pair (Malcolm and Brendan) and the mixed ability pair of girls (Michelle and Sarah) achieved good marks in both the *operational* and *structural* components (Sfard, 1991) of the post-test after working on the ILS. The performance of Malcolm, Brendan and Sarah was consistent with their previous grades in mathematics, while Michelle's performance was an improvement upon her previous grades. The third pair (Candice and Lota) performed poorly after working on *The Learning Equation*. Their results in mathematics in previous tests had been average.

When working on *The learning Equation,* Malcolm and Brendan took turns with the mouse and keyboard to input responses. They initially kept a record of procedures "so you know where you are if you make a mistake, you can go back and do that bit"; however, as the study progressed they ceased this behaviour. They increasingly used mental arithmetic; that is, most "minor" computations, which might involve two or three steps, were carried out without resorting to pencil and paper algorithms. When working with larger numbers the pair resorted to using a hand held scientific calculator, often reading the problem aloud to each other.

If, they made an error, the pair would read and re-read the given information (as evidenced by the movement of the mouse indicator over the screen) and then discuss the possible options. Most often these discussions were very brief and justification was not attempted; it was rare for a discussion to last more than 10 seconds. They would then try an option and see if the input resulted in affirmation from *The Learning Equation* that they were correct. They appeared to operate in small bites of information before trying it out and moving to the next trial. Their comments were typically of the form, "well why don't we try dividing both sides?" After several failed attempts, the pair would cease study and randomly input until the software provided hints and finally the correct answer. Sometimes, they were systematic in using a process of elimination in order to get the correct answer. They systematically tried all probable solutions without an apparent preferred sequence until the software accepted their response. Sometimes the pair discussed why the answer was correct but this was rare. They engaged in reflection only occasionally.

Malcolm and Brendan exhibited clear enjoyment when their work was rewarded with a tick. The immediate feedback seemed to motivate them. Their cognitive time on task was very high, with little off task chat noted on the videotapes. What snippets of off task chat there were seemed to act as mental breaks and did not usually last more than a few seconds. They repeated the self-checks up to three times, trying to improve upon their score. The boys explained, "We want to get that one question we always get wrong right, we kept doing it to get a past." They rarely asked for the assistance of the teacher explaining "he takes too long to get here." Instead they either worked it out themselves, used the cognitive scaffolding provided by the software, or used the feedback facility to cheat the system; they became autonomous learners. They often did not follow the prescribed sequence of activities recommended by the software, but moved about according to their own preferences.

The following is a synthesis of their comments on *The Learning Equation* environment. The paragraph is a joint construct since the boys shared their evaluation of the program.

> *We would have done better by working with the computers because if your get an error you can go back and re do it. In a normal class, you can not really do that because of the limited number of questions of a particular type. But we work harder in a normal class because a teacher can supervise you all the time. When you work in a pair, it is good because you*

can sometimes help each other work it out. The problem questions lets you see how the maths is related to the real world better than a textbook. We liked the pictures and how each question is explained. And you get sample solutions and not just the answer like you do with a textbook. We would like to work with the computers again. There is no mathematics teacher we have had that we would prefer over the computer. The teacher should just tell us what units have to be done and then let us do it.

In summary, the boys appreciated: (a) the cooperative working in pairs; (b) the practice examples, the variety of activities and the cognitive scaffolding provided by the ILS; and the medium of delivery (the computer).

Like the boys, Michelle and Sarah shared turns, reduced their quantity of note taking, enjoyed success, and gradually became largely independent of teacher assistance. However, they discussed and argued more than the boys before submitting a response. They also rationalised to each other more frequently. Comments such as the following were frequent while they worked, "How did you get that? … Well, I just divided both sides by *x* squared … Why does that make sense to you?" When one did not understand, they would try to explain it to each other and, unlike the boys, did not quickly resort to a form of guessing strategy. Comments like, "no you don't divide you take because the other way is add," were common when they made an error. This seemed to represent a genuine attempt to understand the underlying structures. In summary, their discussions were overtly focused on algebra structure and procedures; they particularly provided a rich discourse in algebra procedures.

Unlike the boys, Michelle and Sarah generally followed the suggested sequence of the program, including most of the examples. The time discussing each question they did not understand meant that they completed fewer questions than the boys had. When the girls had the option of selecting from "try again", "see the answer" or "see a complete solution", they most often selected "see the answer" as a first option and tried to explain the result to each other. After several attempts without understanding, they would select "see a complete solution". When competing the self-checks, the girls operated as a pair and shared the workload so that it was really a learning activity rather than a testing activity.

The following comments represent a summary of their assessment of *The Learning Equation.*

The program is good, as we went along we got better and worked better together. With the computer you don't get as bored because you can read the instructions rather than just listening. But when you have a teacher, they can show you to do this step and then this step and I like that kind of teaching and help. We work harder on the computer because we do it together and that helps us to work hard. We also talk a lot more, helping each other, in a normal class we focus more on our individual work. The teacher tells us to "shut up" if we talk. But sometimes on this thing, I get *really frustrated because I don't do well on the self-check. I work so hard and just die when I get poor result on the self-check (Michelle). However, if the teacher is really good at explaining then I would prefer to work in a normal class.*

Overall the impression was that, like the pair of boys, the girls had formed an efficient symbiotic relationship helping each other with their learning. They placed greater emphasis on the importance of cooperative work and discussing than the boys, and they had some complaints about the cognitive scaffolding provided by the software. They felt that there was not enough information to enable them to understand the procedures. Like the boys, they appreciated the variety of work and stimulus media; but, unlike the boys, they felt that the program encouraged them to work harder than in a traditional class.

The third pair, Candice and Lota, had a poor attitude towards *The Learning Equation*. Initially, they were non-committed, but they gradually grew hostile toward the software and trying to learn from it. This process started in the first lesson when they had trouble logging on. Three lessons later they were still having problems. It seemed a case of "Murphy's law"; technical "hitches" seemed to plague them. The girls quickly developed anger toward the technology and resented using it. They complained that the structure supplied "was not detailed enough and did not make it clear what had to be done". This was particularly so when procedures required more than one step, a frequent occurrence for the ILS. They resisted using pencil and paper even when encouraged to do so.

Candice and Lota appeared to require higher teacher input and supervision than the other two pairs, both in terms of behaviour and mathematics, in order to work with the ILS. The teacher continually exhorted them to "work". They would not use their calculators unless told to get them out, they would not begin work until told which activities to work on, and they would continue repeating old work unless told to move on to new section. In order to progress through the mathematics activities, these girls frequently typed in random letters and the answer was provided by the technology, sometimes as a first option. Often the girls did not process the data nor did they read the explanations provided, but simply progressed to the next task. The girls constantly complained that *The Learning Equation* was "too complicated". Arithmetic problems, particularly dividing and multiplying by fractions, constantly thwarted the girls and made it difficult for them to complete the algebra. The girls' response to frustration was to put their hand up for teacher help. Often this was not forth coming, so the girls went off task, discussed social issues, and distracted other pairs of students. Their attitude was summed up simply, "we hate it, it does not explain like a teacher … it is too much for our brains and it aggravates us!". Both girls wanted to return to a classroom where a teacher taught the mathematics. They believed they would get more encouragement and better explanations from a teacher that from *The Learning Equation*.

Analysis

The cognitive time on task for the successful pairs of girls and boys was high and their knowledge of the operations and structures of algebra improved. Both pairs commented that the cognitive scaffolding provided by *The Learning Equation* was a positive factor. They liked particularly that every question was explained, and that explanations "showed you this step then this step". They also believed that the paired interaction with the program was beneficial. As was stated, "you can sometimes help each other work it out", and "we work harder because we do it together".

The boys used a form of "immersion" in order to learn to do the problems. This included guessing and doing the self-checks repeatedly until they achieved mastery. However, while the boys progressed in their structural knowledge of algebra (as tested by word problems), their discussions did not reflect a structural orientation. Michelle and Sarah differed from Malcolm and Brendan in that the social aspect of the cooperative learning process was much more important and pronounced in their behaviour. As well, their discussions showed that they tried to understand the structures of problems.

For Malcolm, Brenda, Michelle and Sarah, the cognitive and social scaffolding provided by *The Learning Equation* was sufficient to foster a quality-learning environment. However, for Candice and Lota, the combination of mastering a new instructional medium and new mathematical content provided a cognitive load that was beyond them; they had cognitive overload. They found the cognitive scaffolding of the ILS inadequate; as a pair, they could not provide each other with the support they each needed. These factors together with the limited intervention of the teacher in both the cognitive and social domain resulted in them spending limited time on task and little movement within their *zone of proximal development*. Both girls exhibited a hostile attitude towards the ILS, technology in general, and mathematics; and they learnt very little algebra from *The Learning Equation*.

Implications

The study provides evidence that when well-structured ILS programs are used with pairs, the cognitive scaffolding of the ILS can combine with the social discourse that develops between students to promote learning (in this case, learning of algebra operations and structures). However, this success is not uniform. Different pairs may adopt quite different discourses with the software and each other, and this may be gender based. Some students, particularly those with lesser mathematical background and a greater need for teacher intervention and direction, may well show limited cognitive progress and exhibit negative attitudes to the technology and mathematics. For such students, the role of the teacher remains critical.

References

Bracewell, R., Breuleaux, A., Laferriere, T.; Beboit, J., & Abdous, M. (1998). The emerging contribution of on line resources and tools to classroom learning and teaching. http://www.tact.fse.ulavla.ca/ang/html/review98.html (1/12/00).

Cooper, G. (1998). *Research into cognitive load theory and instructional design at UNSW.* http://arts.unsw.edu.au/education/CLT_NET_Aug97.HTML. (8/08/00).

Denzin, N., & Lincoln, Y. (1994). Part V the art of interpretation, evaluation, and presentation. In N. K. Denzin, & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 479-483). Thousand Oaks, CA: Sage Publications.

Ertmer, P.A., & Cennamo, K.S. (1995). Teaching instructional design: an apprenticeship model. *Performance Improvement Quarterly. 8*(4), 43-58.

Gregg, J. (1995). The tensions and contradictions of the school mathematics tradition. *Journal for Research in Mathematics Education, 26*(5), 442-466.

ITP Nelson, (1998). *The learning equation mathematics 9*. Ontario, Canada: ITP Nelson.

Maddux, C. D., Johnson, D. L., & Willis, J. W. (1997*). Education Computing: Learning with Tomorrow's Technologies*. Boston, MA: Allyn & Bacon.

McArthur, D., Lewis, M., & Bishay, M. (2000). The roles of artificial intelligence in education: Current progress and future prospects. http://www.rand.org/hot/mcarthur/papers/role.html. (22/12/2000).

Norton. S. J., Cooper, T .J., & McRobbie, C. J. (2000). Can a new-generation computer-assisted learning package compete with "the school mathematics tradition" in enhancing algebra performance. In M. O. J. Thomas (Ed.), *TIME 2000, An International Conference on Technology in Mathematics Education: Proceedings* (pp. 203-210). Auckland, NZ: The University of Auckland and Auckland University of Technology.

Papert, S. (1993). The children's machine: rethinking school in the age of the computers. New York: Basic Books.

Pfaus, B. (1998). *The Learning Equation Project TLE Mathematics 9: A Success Story.* Ottawa, Why Interactive.

Salampasis, M. (2000). Hypermedia short comings. http://osisris.sund.acuk/~osomsa/msa-home.htm (08/08/00).

Sfard, A. (1991). On the dual nature of mathematics conceptions: Reflections on processes and objects as different sides of the same coin. *Educational Studies in Mathematics, 22,* 1-36.

Tao, P-K. (2000). Computer supported collaborative physics learning: Developing understanding of image formation by lenses. Paper presented at 2000 *Annual Meeting of National Association of Research in Science Teaching.* 28th April-1st May, New Orleans, LA.

Vygotsky, L. S. (1987). *The collected works of L. S. Vygotsky Volume 1*. New York: Plenum Press.