Conditions for Effective Use of Interactive On-line Learning Objects: The case of a fractions computer-based learning sequence

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Abstract

Students are challenged when learning fractions and problems often persist into adulthood. Teachers may find it difficult to remediate student misconceptions in the busy classroom, particularly when the concept is as challenging as fractions has proven to be. We theorized that a technology-based learning resource could provide the sequencing and scaffolding teachers might have difficulty providing. A development team of teachers, researchers and educational software programmers designed five sets of fractions activities in the form of learning objects, called CLIPS. As part of a larger mixed-methods study, 36 observations as well as interviews were conducted in four classrooms, grades 7-10. Four students were selected by their teachers for CLIPS use from each of these four classrooms because the students were experiencing difficulty with fractions concepts. CLIPS use contributed to student achievement, provided the conditions enabled an effective learning environment and students experienced the full sequence of tasks in the CLIPS. In this article we describe the conditions that enabled student success. Three interacting contexts affected successful use of CLIPS: technological contexts (such as access to computers with audio), teaching contexts (such as introductory activities that prepared students for the CLIPS activities) and student contexts (such as the level of student confidence and opportunities to communicate to a peer). The study illustrates how a research-based set of learning objects can be effective and provides guidelines to consider when using learning objects to enhance mathematics programs.

1. Introduction

Teachers and researchers have typically described fractions learning as a challenging area of the mathematics curriculum (e.g., Gould, Outhred, & Mitchelmore, 2006; Hiebert 1988; NAEP, 2005). The understanding of part/whole relationships, procedural complexity, and challenging notation, have all been connected to why fractions are considered an area of such difficulty. Teachers and researchers have struggled to find ways to make fractions more meaningful, relevant and understandable to students.

In this article, we will identify conditions that influenced Grades 7-10 students' ability to benefit from fractions-focused learning objects. The claims are based on 36 classroom observations and 16 student cases. The study is part of a multi-year mixed methods project focused on designing, implementing and assessing learning objects that address core objectives in mathematics curricula. (To see the fractions CLIPS go to: http://oame.on.ca/CLIPS/index.html)

2. Theoretical framing

1. Challenges understanding fractions
The NCTM Standards for Mathematics (2000), educational researchers, and the majority of classroom texts concur that fractions understanding is an important element of mathematics learning. For example, the Curriculum Focus Points published by NCTM in 2006 state that in Grade 3, students should: develop an understanding of the meanings and uses of fractions to represent parts of a whole, parts of a set, or points or distances on a number line; understand that the size of a fractional part is relative to the size of the whole; use fractions to represent numbers that are equal to, less than, or greater than; solve problems that involve comparing and ordering fractions by using models, benchmark fractions, or common numerators or denominators; understand and use models, including the number line, to identify equivalent fractions.

However clear the objectives for learning fractions, the mathematics education literature is resounding in its findings that understanding fractions is a challenging area of mathematics for North American students to grasp (National Assessment of Educational Progress, 2005). Students also seem to have difficulty *retaining* fractions concepts (Groff, 1996). Adults continue to struggle with fractions concepts (Lipkus, Samsa, & Rimer, 2001; Reyna & Brainerd, 2007) even when fractions are important to daily work related tasks. For example, "pediatricians, nurses, and pharmacists…were tested for errors resulting from the calculation of drug doses for neonatal intensive care infants… Of the calculation errors identified, 38.5% of pediatricians' errors, 56% of nurses' errors, and 1% of pharmacists' errors would have resulted in administration of 10 times the prescribed dose." (Grillo, Latif, & Stolte, 2001, p.168).

To better understand student reasoning and misconceptions related to fractions, Australian researchers Gould, Outhred, and Mitchelmore (2006), had students illustrate one half, one third and one sixth on circle diagrams. The research team was concerned that students were perceiving fractions to be 'parts of a set', but not 'parts of a whole'. In the parts of a set conception of fractions 1/4 can be interpreted as meaning one object of four (a simple counting activity which assumes that the 1 represents a whole number as does the 4). Hart (1988) found that 12 and 13 year olds were able to correctly shade in two-thirds of a regional model but that this question was almost always solved by counting the number of squares in the entire figure (a figure with 3 sections) and then counting the squares that required shading (2 sections), rather than interpreting the fraction as part of a whole region. Gould, et.al. (2006) found that most students were very accurate when shading in one half of the circle. They argue that ½ is not a typical fraction, but rather a benchmark that holds special value for most children. Interestingly, one third and one sixth received a wide range of responses from students. The students overwhelmingly demonstrated a "number of pieces" approach to illustrating fractions. Most of the errors illustrated that students were using counting strategies to do their shading (for example, one student partitioned a circle into 8 sections and then shaded in 6 of these sections – counting and inserting the numerals one through 6 in the shaded pieces - to represent 1/6).

It is important to note that in a study of students in Singapore (2001), more than 78% of Primary Two students were reported to have no difficulty understanding part/whole relationships when asked to shade in 1/3 of the total number of squares in a 3x4 grid. It should be noted however that the report indicates some students may have used an incorrect strategy, such as considering the denominator of 3 as the total number of squares to be coloured (and therefore coloured 3 squares).

2. Possible explanations

Educators and researchers agree that most students encounter significant problems and misconceptions when learning fractions (Behr, Lesh, Post & Silver, 1983; Carraher & Schliemann, 1991; Hiebert 1988 to name just a few). Hasemann (1981) provided four possible explanations about why children find fractions so challenging: 1) fractions are not used in daily life regularly; 2) the written notation of fractions is relatively complicated; 3) ordering fractions on a number line is exceedingly difficult; and, 4) there are many rules associated with the procedures of fractions, and these rules are more complex than those of natural numbers. Other researchers have taken up further study of some of these explanations. Moss and Case (1999) agreed that notation is one factor that could be linked to children's difficulties with fractions but they also pointed to several other complications: 1) Too much time is devoted to teaching the procedures of manipulating rational numbers and too little time is spent teaching their conceptual meaning; 2) Teachers do not acknowledge or encourage spontaneous or invented strategies, thereby discouraging children from attempting to understand these numbers on their own (Confrey, 1994; Kieren, 1992; Mack, 1993; Sophian & Wood, 1997) and, 3) When introduced, rational numbers are not sufficiently differentiated from whole numbers (e.g., the use of pie charts as models for introducing children to fractions (Kieren, 1995).

3. Strategies for tackling fractions

Researchers have developed some effective strategies of teaching toward the understanding of fractions. Recent research on interventions to support students at-risk and/or those with learning disabilities, report success with: a) the use of mnemonic devices for teaching addition and subtraction of fractions (Joseph & Hunter, 2001; Test & Ellis, 2005); b) the use of manipulatives with pictures to solve word problems involving fractions (Bulter, Miller, Crehan, Babbitt, & Pierce, 2003); and, c) the use of a Direct Instruction model (Flores & Kaylor, 2007; Scarlato & Burr, 2002). Other researchers have reported success with similar strategies for use with a broader range of student abilities. These techniques include direct instruction using a lesson schema consisting of teacher modeling, guided practice, and focused feedback (Flores & Kaylor, 2007), cue cards prompting steps in a procedure.

To add further refinements to our understanding of learning fractions, some researchers have examined gender-related issues (see Fennema & Tartre, 1985 for example). In a three year study, 36 girls and 33 boys were interviewed annually about word problems and fractions problems. They concluded that girls tended to use pictures when solving problems more so than boys and that the girls with low spatial visualization skills had greater difficulty arriving at correct solutions, even when they were able to verbalize their understanding in more detail than the boys.

Naiser, Wright & Capraro (2004) found that teachers used several strategies to engage students: review of problems, real-world applications, use of manipulatives and building on prior knowledge. The teachers used techniques such as direct instruction techniques and less commonly, student discovery, whole class discussion, and cooperative learning. Naiser et.al., reported that the area of student engagement was weak because a significant portion of student time was spent using pencil-paper techniques and rote learning. Thus they concluded that the design of instruction was crucial to improving student understanding.

Although these strategies are effective in enhancing student mastery of fraction algorithms, they are not directly focused on students' conceptual understanding. In a seminal study on lesson design in proportional reasoning, Moss & Cass (1999) investigated learning fractions from a psychological perspective. This involves an understanding of developmental and psychological units that define rational numbers within two general units: a) a global structure for proportional evaluation and b) a numeric structure for splitting or doubling. These appear at approximately ages 9 and 10. Coordination of the two units occurs at approximately ages 11 and 12 leading the child to be able to understand semi-abstract concepts of relative proportion and simple fractions such as ½ and ¼. Based on this construct, Moss & Case developed an innovative instructional lesson sequence, beginning with a beaker of water. (The students could begin by describing the beaker as nearly full, nearly empty, etc.). The lessons introduced percents such as '100% full', linking to children's pre-existing knowledge and schema, as well as their familiarity with real contexts using "number ribbons" and other familiar representations. Then, the lesson sequence introduced decimals, and finally connected these forms of describing amounts with fractions. The study used a pre-post control and treatment group design. Both groups showed improvement from pre to post however, the treatment group showed statistically greater gains. The children in the control group were able to perform standard procedures with simple numbers, however when confronted with novel problems, these students were much less successful. The treatment group children demonstrated considerable flexibility in their thinking and approaches to the problems at hand, and were more accurate with their solutions. The results of this study were promising and lead to reconceptualizing ways to teach fractions by building on students' existing knowledge and understanding as well as valuing innovative lesson design to tackle a significant problem which had not been resolved through traditional methods.

4. Technology-assisted learning

In the last decade, technology-assisted learning is exploring additional ways of enhancing student understanding with challenging math concepts such as fractions. In many developed countries, computer assisted learning is becoming increasingly used as a strategy for supporting student learning (Sinko & Lehtinen, 1999; Smeets et al., 1999) particularly to provide for learners who vary in their learning pace or kind. In this time, researchers and educators have managed to document a daunting list of challenges to successful technology use. These include problems such as a lack of time to learn and use the technology (Wepner, Ziomek & Tao, 2003), pervasive problems of teacher and student access to technology - which is expensive relative to most other learning tools, or conversely, under-use of technology due to pedagogical concerns of not knowing how to successfully incorporate the technology to compliment or enhance other teaching methods (see Cuban, 2001).

Most recently, several researchers have begun to identify enabling conditions for technology implementation, specifically related to learning objects. In a study of 111 secondary students using learning objects designed by a teacher team, Kay and Knaack (2007) reported that there were certain conditions that enable learners when using the learning objects. They found that:

> Students benefited more if they were comfortable with computers, the content was perceived as being useful, instructions were clear, and the theme was fun or motivating. Students appreciated the motivating, hands-on, and visual qualities of the learning objects most. Computer comfort and learning object type, but not gender, were significantly related to learning object quality and benefit. (p 261)

The findings of Lim, Lee and Richards (2006) compliment those of Kay and Knaack. Lim et.al. conducted extensive interviews with secondary school users of online learning objects and found that careful chunking of the material within the learning sequence and clear instructions were important, and that student ability to navigate the site while controlling the pace of their learning led to most effective student learning. Further, their study pointed to the importance of teacher planning that incorporated the online learning objects with his/her other program components (described as 'wrappers') in a blended format to make the learning objects tasks more meaningful to students. Finally their study suggested that teachers should ensure that students are cognitively ready for the online learning tasks.

One perceived advantage of using computer-based learning objects is that it might provide support to teachers who are having difficulty teaching challenging concepts such as fractions, which require extensive and detailed exploration and instruction. Further, with learning objects, students who are struggling with fractions concepts may have the opportunity to receive targeted and varied learning opportunities beyond those provided in the regular classroom setting. In contrast to Lim et.al., in the case of this study, the *lack* of 'cognitive readiness' for more complex fractions learning was viewed as a signal that CLIPS would help the student gain fundamental fractions concepts, thereby developing readiness for more advanced (and grade appropriate) fractions learning. It is difficult for teachers to sufficiently differentiate instruction in the busy classroom and we theorized that a highly field-tested and researched computer-based set of learning objects was one viable strategy to provide the sequencing and scaffolding required to support student learning in fractions.

3. Research design

1. CLIPS development

Over a period of two years, researchers, teachers, math consultants and the Ontario Ministry of Education in Canada partnered to develop a specific series of online learning activities in fractions – to support struggling Grade 7-10 learners in this well documented area of challenging mathematics. The computer-based learning package is named CLIPS. CLIPS (Critical Learning Instructional Paths Supports) is comparable to a learning object (i.e., an activity, frequently involving multi-media, which presents a learning activity for students to address specific course expectations). The development team took the above literature about fractions into consideration and subsequently identified the following characteristics that needed to be embedded in the CLIPS for greatest success:

1. The CLIPS should make real-life meaningful connections to student experiences in order to explore fractions concepts.
2. The CLIPS should begin with very basic concepts of fractions to ensure that students understand part/whole relationships as well as part/set relationships.
3. The CLIPS tasks and instruction should be sequenced to carefully build from one key idea to the next, so that they make cumulative sense to students.

4. The CLIPS should provide helpful structures to support students in acclimatizing themselves to fraction notation.
5. The CLIPS should appeal to multiple learning styles (such as providing varied visual representations).
6. The CLIPS should provide immediate and helpful feedback to students in order to address misconceptions quickly and clearly.

With these guidelines in mind, the following sequence of CLIPS fractions tasks was designed:
A. Representing simple fractions
B. Forming and naming equivalent fractions
C. Comparing simple fractions
D. Forming equivalent fractions by splitting or merging parts
E. Representing improper fractions as mixed numbers
Within each set of activities there are introductory instructions, interactive tasks, consolidation activities and quizzes, as well as extension activities. For example, *CLIPS A* has an introductory activity on representing simple fractions. There is a voice-over with visual representations of a nutrition bar, a pizza and a hexagonal block which are then connected to area models that appear next to the real-life objects. The emphasis of the introduction is on part-whole relationships. The introduction of fraction notation is also introduced with a dissection of the component parts (numerator and denominator) in the context of real life objects (in regions such as a rectangular snack bar to be shared by three people *and* in sets such as a collection of balls). In the second activity students are asked to create area models with partitioning and to describe the fractions by entering the numerator and denominator. There are three additional mini-sets of activities. Users can take a quiz on representing simple fractions: Students drag their answers to a box and receive immediate feedback. If incorrect, they are given an explanation to help them try again with additional information. The final component of *CLIPS A* is a “show what you know” screen which suggests five different activities (e.g., a fractions card game or designing an information poster) students could do to consolidate their learning. The same structure is repeated for each of the five CLIPS. (go to http://oame.on.ca/CLIPS/index.html)

2. Testing and revising the CLIPS
The design for testing the fractions CLIPS included six research stages (see table 1) over two years in an extended-term mixed-method design (Chatterji, 2004). This article briefly reports the results of Stage 5 and then discusses results of Stage 6 in more detail. The purpose was to identify the conditions which made the CLIPS accessible and helpful to students. In earlier stages, we found that the full sequence of five CLIPS contributed to student understanding of fractions concepts.

Table 1: *Stages in CLIPS research and development*

Stage	Purpose	Research Approach
1	Identify specific learning expectations (in order of	We conducted a systematic needs assessment (Ross, Ford & Bruce, 2007) combining student

	importance) to be addressed by the CLIPS	performance data, student beliefs about their mathematical competencies, and teacher perceptions about the difficulty and importance of learning particular fractions objectives. The results was a rank ordered list of student learning needs.
2	Development of CLIPS	The needs list was transformed into an integrated learning agenda that prescribed an instructional sequence designed to overcome student deficits. A design team drew upon research on teaching fractions (particularly Gould, Outhred, & Mitchelmore, 2006; Moss & Case, 1999; Streefland, 1993) to develop interactive activities addressing each learning need.
3	Formative assessment using a few classrooms	Qualitative observation of the CLIPS being pilot tested in two classrooms assessed the functioning of the CLIPS, and generated detailed recommendations for their revision (Ross, Bruce, Scoffin & Sibald, 2007). This included re-sequencing tasks to better match student need based on close observations.
4	Revision of CLIPS	The CLIPS were revised on the basis of qualitative data collected in the pilot test and re field-tested.
5	Assessment of CLIPS effect on student outcomes in varied instructional contexts	Randomized field trials of larger scale implementation in a variety of school districts and classrooms (see Ross & Bruce, in review)
6	Identification of conditions that enable students to learn most effectively with CLIPS	Qualitative study and analysis of cases within the randomized field trials (reported in this paper).

3. Results of stage 5

In stage 5, we conducted two comparative group studies to determine the effects of CLIPS on student understanding of fractions. Results on student achievement measures pre and post CLIPS implementation with treatment and control groups using the same curriculum indicated that the CLIPS learning objects completed by students, with relatively little teacher direction, improved student understanding of challenging fractions concepts. The key finding of the field trials was that students needed to complete all five CLIPS in order to make significant gains in their understanding of fractions. Those students who missed some, or even one, component(s) of the learning sequence had minimal success. Students who did not complete all five components of the learning sequence were deprived of instruction in one or more constructs linked carefully to other key ideas in the conceptual sequence. Further, it is probable from our observations that incomplete sequences provided insufficient practice to remediate student misconceptions. (see Ross & Bruce, in review for details of the quantitative findings)

4. Research design for stage 6: multiple case studies

During the field trials, a qualitative research question was being investigated in four case study classrooms: *Under what conditions did CLIPS contribute to students' understanding of fractions?*

We recognized that the task of identifying the conditions of implementation was complex because of the reality of mathematics classrooms, school timetables, attitudes of struggling students toward learning mathematics, and student access to computers. We observed student learning closely, not only during math lessons that involved CLIPS use, but also during lessons on fractions topics that did not involve using CLIPS (to see how the learning was different and the same in the two contexts). We conducted 36 observations across 16 student cases to increase transferability of our claims.

Data sources for the case studies included: a) classroom observations during regular mathematics instruction (approximately 60 minutes per observation); b) field notes of student interaction with CLIPS on computers; c) recorded responses of students to researcher questions during CLIPS use (the researchers probed students with questions such as: What are you doing? What is the activity trying to explain? How difficult or easy is this task?); and, d) verbatim transcripts of student interviews following CLIPS use. Typically, observations documented teachers beginning the lesson with all students in the class participating in an introductory activity (such as reviewing key concepts and procedures from previous lessons, mentally preparing students for new learning, providing instructions on manipulative use or problems to be explored). This was often followed by group work or independent activities while assigning some students to work with CLIPS at the computers (in the classroom or in a lab setting) - during the CLIPS implementation phase. In some cases, teachers would finish the lesson with a whole class consolidation discussion. In each classroom, two observations occurred prior to any CLIPS implementation, five observations were completed during CLIPS implementation and two occurred upon completion of CLIPS use. In each of the four classrooms, there were four students who were then in focus for CLIPS observations and interviews.

Once all data were compiled electronically, researchers followed five sequential steps of coding the qualitative data: 1) Initial reading of text data; 2) division of text into segments of information (based on utterances); 3) labeling of each utterance with codes; 4) reduction of overlap and redundancy of codes; and, 5) collapsing codes into themes (Creswell, 2005).

4. Findings

In our observations, there were three principal interacting contexts that determined success of CLIPS implementation: Technical contexts; Teaching contexts; and Student contexts.

1. Technical contexts

Technical contexts refers to access to, availability of, and quality of computers used for CLIPS. The researchers underestimated the influence of hardware and software on CLIPS implementation. If the technology was working well (i.e., students were able to quickly and easily access the CLIPS and proceed smoothly from task to task with full sound) they were motivated to engage in the CLIPS activities. Unfortunately, hardware problems included: sound ("lost audio"), inability to launch the program ("CD ROMs on computers didn't work") and sporadic problems running the program ("screen freeze"). Software issues were related to the use of the CD version of CLIPS rather than the web version of the program. For example, students were unable to open the disk, the program did not run or run-time was discouragingly slow. A third problem was lack of access to computers in the classroom setting. Often students were required to work on computers in locations other than the classroom (e.g., in a library or computer lab). In these non-classroom locations students had no access to teacher support or guidance. Students were monitored for behaviour only (i.e., if students appeared to be working on the program, regardless of how, the supervisor of the computers did not intervene).

A final technology context had to do with the operation of the CLIPS: Students were more confident and developed a sense of agency when the program offered them forward and backward navigation buttons. This gave the students the opportunity to move ahead quickly or slowly, and to return to previous explanations for review as they wished. Based on this finding, the development team added additional simple navigation buttons throughout the CLIPS for student control of the pace of the learning activities and instructions.

2. Teaching contexts

Teaching contexts refers to the whole class teaching situations which directly preceded student use of CLIPS. Observations of classroom activity revealed that the introductory activities (or mental set) had a significant influence on preparing students for their work with fractions in the CLIPS tasks. For example, if the teacher was not focusing on fractions in the introductory activities, the students had to adjust their thinking to fractions in order to work with the CLIPS. Of particular interest, researchers noted the positive effects of teacher lessons where the introductory activity (the mental set) matched directly to student learning using the CLIPS. These opportunities led to greater success for students who immediately thereafter used the CLIPS to further their learning. For example, in one classroom, the teacher used the Interactive Whiteboard to illustrate how to use simple regional models to explore improper fractions. The teacher gave the students a fraction (such as 5/3) and the students illustrated 5/3 using circle pieces (3 1/3rds to make one whole plus 2 additional thirds). In the CLIPS following this introductory activity, the selected students were working with improper fractions using pizza slices. The CLIPS task was slightly more challenging than the introductory tasks in the mental set that students had done in class. There was clear evidence in the field notes of observations that all four CLIPS students were more engaged with the CLIPS activities immediately following this lesson than in other sessions. What was surprising to the researchers was that the introductory tasks proceeding CLIPS use did not often match the learning in the CLIPS tasks. This speaks to the need for educators to see the importance of focusing on the direct relationship between online learning tasks and in-class learning tasks whenever possible rather than treating computer-based learning activities as an isolated event.

Conversely, during a different whole group introductory activity, the students used manipulatives to explore the multiplication of fractions. Andrea, a selected CLIPS user, demonstrated inconsistent understanding during this lesson. Her prior comfort with regional models did not seem to help. For example, when initially making slices of pizza, Andrea decided to cut it into uneven strips rather than equal sized wedges. After two instructional interventions focusing Andrea on equal sized pieces and review of the steps to take, Andrea had success finding 1/4x1/2=1/8. In the second class example, Andrea had an independent mastery experience with a rectangular visual representation. The teacher recognized that Andrea was successful and called on her to give the answer to the class. Subsequently, Andrea began working with CLIPS deciding that she should use her newly learned multiplication strategy to a fractions task that asked the student to compare two fractions (not multiply them). Her multiplication strategy did not translate smoothly because the task was asking her to compare the values two fractions and determine which was greater. Andrea had difficulty shifting from the whole group task of multiplying fractions to the CLIP of comparing fractions. Andrea indicated that she found the instructions hard to follow. “They were confusing. Yesterday was easier”.

Similarly, if the classroom-based introductory activity was too far beyond the student’s zone of proximal development (or readiness), the student became frustrated and then subsequently disengaged with the CLIPS activities. For example, in one classroom, the teacher was visually representing the division of fractions. This lesson was well beyond Mandy’s zone of proximal development. She was not able to make connections between computation of equivalent fractions (which she demonstrated understanding of in previous observations) to computation with non-equivalent fractions, indicating a possible wavering stage of conceptual understanding. Immediately after the whole group lesson, selected students including Mandy, were working on CLIPS. By the time Mandy began her work with CLIPS activities she was fully disengaged and distracted, and she described the CLIPS activity of partitioning a swimming pool into lanes as “unrealistic”.

3. Student contexts

Student contexts refers to student attendance, selection of students for CLIPS, the organization of students using the CLIPS (in pairs for example), student perceptions about CLIPS use, confidence in mathematics, and student facility with technology.

Absence, not surprisingly, played a role in student success. Those students who attended class regularly were able to follow along relatively smoothly with in-class and on-line tasks. Those students who attended school sporadically found it difficult to maintain the learning momentum with CLIPS, building from prior knowledge acquired on previous days. Interestingly, some teachers treated the five sets of learning objects within CLIPS as though they were connected to days of the week. In other words, if a student was absent on the third day of school where the CLIPS were being implemented, the teacher would often have the student skip the third section of the CLIPS and move onto the fourth section when the student returned on the fourth day of school. Students who experienced the entire sequence of learning activities in CLIPS without prolonged interruption showed the greatest gains in their understanding.

Students selected to use CLIPS, were identified by their teacher because they had experienced difficulty understanding fractions in class activities and assessments. Hannah, for example, was selected because of her weak understanding of fractions in Grade 7. She was working well below grade level. Hannah was quiet in class and shy. During classroom observations, Hannah was never observed participating voluntarily in whole class discussions and only on one occasion was she called on by the teacher. In group assigned tasks Hannah was observed to consistently depend on the other members of her group to complete the tasks. At times she would be seen to be “off-task”, for example doodling on her partner’s binder. Hannah’s attendance was regular during the nine observations.

There was evidence in most of the CLIPS sessions of Hannah’s low self- confidence as a math student. Hannah was very quick to say, ‘I don’t know what to do’. When Hannah observed some other students struggling and laughing with a more challenging fractions drop ball game, she was giggling at their attempts to place an improper fraction on the line correctly. However, when asked if she would like a turn, she refused, even when told she could work with a partner of her choice.

When interviewing Hannah one-to-one to further probe a CLIPS partitioning activity in the context of dividing up a storage box, there was evidence of her ability to problem solve and to verbalize her strategy: “Hannah decided that four sections were needed. She then divided the box with three lines to get four sections and checked her answer.” Later in the learning sequence, while working on a similar task where a pool is being split into lanes, Hannah experienced clear success and increased her confidence and ease with the use of CLIPS. Overall, her gains were slow and incremental. In the final interview, Hannah indicated that she had learned a great deal about fractions by participating in the CLIPS and that she would like to participate in similar learning experiences in the future.

The example of Hannah is rather typical of the students selected to engage in CLIPS and supports the claims of existing research in the area of computer-based learning. The students began feeling timid, nervous and “not able to do math”. Over the course of using CLIPS, those students, like Hannah, who worked through the tasks in sequence, developed higher confidence in their ability to understand fractions. These students found that being able to proceed at their own pace, and review tasks as frequently as they wanted (using arrow navigation features in the CLIPS), allowed them to revisit fractions concepts and skills that had been previously difficult. This is important because many previous learning strategies developed to support students learning fractions have been relatively unsuccessful, however the explictness of the fractions concepts and skills presented in the CLIPS learning sequence combined with computer-based learning holds promise. Further when students like Hannah, worked with a partner of similar ability, their willingness to take risks and ability discuss possible solutions increased. Students enjoyed working with a peer whenever possible on the CLIPS and showed increased understanding through their need to communicate understanding to one another in clear and precise language.

> Anthony watched Annie working with the fractions strips, and then she moved to the next activity, which was “forming equivalent fractions”. Annie made 100 fractional parts in the rectangle region.
> Anthony: Explain what you are doing there.
> Annie: I wanted the denominator to go to 100. It’s going up by two’s. I know the numerator is 40 because two fifths equals 40/100ths.

Those case study students who began with higher confidence in their abilities to do mathematics from the onset, also benefitted from the CLIPS in terms of further increasing their sense of efficacy and their understanding of fractions. These students were more motivated to explore the most challenging games and tasks in the lesson sequence through to mastery. Similarly, those students who were already comfortable using technology, even though their math skills were deemed lower, were more apt to seek out and try all the tasks in the CLIPS.

> Adam's computer literacy emerged in this first session as he jumped in to assist Rudy with a task. Rudy was unsure of where to enter the number of fractional parts on the screen. Anthony appeared to know intuitively where the number was to be placed. "Put the number of parts in that box. Click on the part to colour them." He went on to assist Heather and as if sensing that he was emerging as the computer expert in the group, proudly announced, ' My dad taught me about computers.'
>
> Although a struggling student, CLIPS A provided Adam with an opportunity to be exposed to new fractions concepts, culturally specific examples of where we use fractions (the video) while taking advantage of his computer skills.

The complexity of student contexts was high. Each student illustrated a unique story that was influenced by many factors such as student confidence learning mathematics and using technology. This study provides an opening for more research in the area of the factors that influence successful student use of learning objects in mathematics.

4. Conditions for successful implementation of CLIPS

After analyzing all case study data of classroom and CLIPS activity by selected students, the three contexts described above helped researchers identify the conditions for successful implementation of CLIPS. Table 2 highlights the ideal enabling conditions for CLIPS implementation and inhibiting conditions that will affect the quality of implementation.

Table 2: *Conditions affecting student learning with CLIPS*

Ideal Enabling Conditions	Inhibiting Conditions
Technical Conditions	
Easy access to computers, required software, learning objects, audio technology such as headphones	Lack of access to computers, required software, learning objects, audio technology such as headphones (lacking at all sites.)
Technical ease of the learning objects (e.g., capability of Flash) for the user	Technical problems with the learning objects (e.g., in a beta version of the Fraction Strips task, the screen froze at times so students assumed the activity was done and moved on without consolidating understanding)
Appropriate pace of CLIP learning object with click forward option for student control (e.g., navigation buttons that user controls)	Fast or slow pace of clip materials without student control (e.g., no navigation buttons)

Teaching Conditions	
Whole class instruction (introductory activity) is within zone of proximal development of the student	Introductory activity is beyond of zone of proximal development of the student
Introductory activity matches the conceptual and procedural focus of the CLIPS (i.e., related to fractions and specifically to the CLIPS concept that the student is working on)	Introductory activity is unrelated to conceptual focus of CLIPS (i.e., not related to fractions)
Teacher interventions in class are specific to the individual student and their specific need, supporting positive mastery experiences	Lack of teacher interventions for the individual student so that the student remains confused about the concept
Student Related Conditions	
Regular attendance at school and complete use of the lesson sequence	Irregular attendance at school and sporadic or punctuated use of the learning objects sequence
Targeted selection of students based on need	Selection of students without regard to learning need
Pair of students working on the CLIPS together who work collaboratively to construct their understanding	Pair of students working on the CLIPS who are incompatible, or non-communicative
Students perceive that they are selected to work with CLIPS as a reward or as a positive opportunity	Students perceive that they are selected to work with CLIPS as a punishment or as a negative opportunity (e.g., because "we are stupid")
Positive efficacy of student [having confidence to do math]	Negative efficacy of student [lacking confidence to do math]
Student facility with technology: Student has a high level of comfort using the computer and is willing to experiment with the learning objects (buttons, keying in information, etc)	Lack of student facility with technology: Student has a low level of comfort or experience using the computer and is unwilling or fearful of experimenting with the learning objects (afraid to touch buttons, lack of intuitive sense of 'what to do', etc)

5. Discussion

The findings from this study support previous studies about success conditions for learning objects:
a) Pacing matters: Learner controlled pacing of the learning object tasks led to more effective learning. When interviewed, learners indicated that they felt more in control of the learning situation when they could control the pace of the tasks using forward and backward navigation arrows, and comprehensive, intuitive menus.
b) Sequencing matters: Both the qualitative and quantitative results showed that students who did not do all the fractions CLIPS activities did not benefit significantly from engaging with some of

the CLIPS tasks. It was those students who proceeded through the learning sequence methodically, without skipping tasks or prolonged periods of no-use, who benefited the most in terms of overall student achievement measures and self-reported feelings of success. Initially researchers thought that students could select their own entry point into the learning objects tasks wherever they (and possibly their teacher) decided would be a good entry point for them. We were surprised to find out that this was not the case. The learning object fractions tasks built from one to the next in a careful sequence that was field-tested and revised repeatedly, and when students did not experience the entire sequence, they missed key concepts and ultimately did not progress in their overall understanding of fractions. In retrospect, this finding makes sense.
c) The introductory off-line tasks matter: Targeted introductory tasks that connected directly with the learning goals (key concepts) of the learning objects helped students to mentally prepare for the learning objects tasks. When the introductory offline tasks were unrelated or fractions-related but not directly connected to the skills and concepts being presented in the CLIPS tasks, students were derailed and struggled to orient themselves to the online learning activities.
d) Technological facility of the user matters: Adept technology learners were more confident using the CLIPS even when these same users began with very low understanding of fractions concepts. This leads us to thinking about how those students who struggle with math concepts but have high technology facility might benefit more from online learning objects as a method of instruction.

6. Implications

Overall, researchers found that the CLIPS fractions tasks were successful in supporting student learning. However, even with this highly researched, refined, and sequenced group of learning objects, there were important contexts that affected the success of CLIPS use by specific students. The three interacting contexts were related to technical, teaching and student factors which operated simultaneously in the learning environment of CLIPS implementation. The revealing of these contexts through the study led the researchers to developing a guide to support teacher implementation of CLIPS. The guide was based on the summary findings in Table 2. This table format attempted to clearly illustrate ways that researchers, educators and technology providers could help to generate *better* conditions for student success using learning objects that compliment classroom mathematics programs.

Teachers and technology support staff can consider how they are addressing the enabling conditions to provide maximum opportunity to learn using computer-based learning objects. Suggestions from this study include:
a) Ensure that the computers being used have working audio capabilities and are functioning well
b) Check the learning objects to see if the user can control the pace of the activities – users report that this is valuable
c) Teach introductory lessons that match the activities of the learning objects whenever possible to prepare learners for the subsequent learning objects experiences
d) Select students for learning objects use based on demonstrated student learning needs
e) Promote the use of learning objects as “another way” to learn that *compliments* classroom activity, rather than as a punishment or reward
e) Consider having students working in pairs where they are expected to discuss what they are doing on the computer with one another to increase mathematics communication
f) Ensure that students experience the entirety of the learning activities sequence if the learning objects are constructed to build understanding in a specific sequence, such as with CLIPS

g) Offer students opportunities to investigate use of the computer as a learning tool so that they increase their confidence using computers for learning support, and thus explore the learning objects to their maximum potential.

In this study, researchers evaluated the conditions under which a highly refined learning sequence in the form of CLIPS learning objects could be implemented. The case study classrooms and students formed the grounding for determining what the conditions and contexts were that influenced student success learning fractions using CLIPS. Although the learning objects were crafted within an extremely detailed research design, technology, teacher and student contexts clearly played significant roles in determining student success. These contexts help us to think about optimal conditions for student learning when incorporating learning objects as part of the teaching and learning trajectory of challenging concepts and ideas such as fractions.

7. References

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