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Evaluating the Use of Learning Objects for Improving Calculus Readiness

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Pre-calculus concepts such as working with functions and solving equations are essential for students to explore limits, rates of change, and integrals. Yet many students have a weak understanding of these key concepts which impedes performance in their first year university Calculus course. A series of online learning objects was developed to provide students with appropriate resources for self-study in pre-calculus concepts. Each learning object consisted of text-based summary sheets, interactive video-clips demonstrating sample solutions to typical problems, and a set of online mastery practice questions. The results indicated that a majority of students used the learning objects frequently, rated them as useful or very useful, and reported significant knowledge gains in pre-calculus concepts.

To effectively tackle university level mathematics, a strong pre-calculus background is essential. Yet many international studies over the past few decades have found a decline in the algebraic ability of first year university students and have raised concerns about numeracy (Barbeau et al., 1977; Engineering Council, 2000; Jourdan, Cretchley, & Passmore, 2007; London Mathematical Society, 1995; Mustoe & Lawson, 2002).

Learning objects, defined in this paper as "interactive web-based tools that support learning by enhancing, amplifying, and guiding the cognitive processes of learners" (Agostinho, Bennett, Lockyer & Harper, 2004; Butson, 2003; McGreal , 2004; Parrish, 2004; Polsani, 2003; Wiley, et al. 2004) present a viable solution for addressing weakness in student pre-calculus knowledge. Key advantages for using learning objects include accessibility (Wiley, 2000), ease of use (e.g., Gadanidis, Gadanidis, & Schindler, 2003; Sedig & Liang, 2006), reusability (e.g., Agostinho et al., 2004; Duval, Hodgins, Rehak & Robson, 2004; Rehak & Mason, 2003), interactivity (e.g., Gadanidis, Gadanidis, & Schindler, 2003; Sedig & Liang, 2006) and visual supports (e.g., Gadanidis, Gadanidis, & Schindler, 2003; Sedig & Liang, 2006).

The purpose of this paper was to evaluate a set of learning objects designed to improve Calculus readiness for first year university students.

LITERATURE REVIEW

Addressing Gaps in Student Understanding

In order to begin their study of Calculus, students must possess a strong foundation in working with functions and the ability to perform algebraic manipulations with ease. This ability, however, is often lacking in first year and impedes students' efforts in university mathematics. Over a decade ago, a report by the London Mathematical Society (1995) found that post-secondary mathematics, science, and engineering departments appeared unanimous in perceiving a qualitative change in the mathematical preparedness of first year students, even among some high-attaining students. One of the key problems noted was that students in mathematics courses were hampered by a serious lack of essential skills in being able to do algebraic calculations and manipulations fluently and accurately.

Several international studies have noted that students have substantial difficulty with the kinds of concepts necessary to be successful in university mathematics. Jourdan, Cretchley, & Passmore (2007) reported that students experienced significant challenges in algebra, functions, and trigonometry. Lawson (2003) compared diagnostic scores from 1991 to 2001 and found a significant drop in competency in most areas of pre-calculus mathematics tested. A recent Canadian report claimed that today's students have less facility with basic algebra, trigonometry, and exponentials and logarithms and that universities have observed significant declines in student performance (Ontario Ministry of Education, 2006).

The Role of Learning Objects

Learning objects offer a number of key advantages that can benefit both instructors and students including accessibility, ease of use, reusability, graphical supports, and adaptivity. Learning objects are *readily accessible* over the Internet and users need not worry about excessive costs or not having the latest version (Wiley, 2000). With almost all universities having access to high-speed broadband connections, access to learning objects is not an obstacle. In addition, because of their limited size and focus, learning objects are relatively *easy to learn and use*, making them much more attractive to busy educators who have little time to learn more complex, advanced software packages (Gadanidis et al., 2003). *Reusability* allows learning objects to be useful for a large audience, particularly when the objects are placed in well organized, searchable databases (e.g., Agostinho et al., 2004; Duval, Hodgins, Rehak & Robson, 2004; Rehak & Mason, 2003).

With respect to learning, a number of learning objects are interactive tools that support exploration, investigation, constructing solutions, and manipulating parameters instead of memorizing and retaining a series of facts. In addition, a number of learning objects have a *graphical component* that helps present abstract concepts in a more concrete manner (Gadanidis et al., 2003). Furthermore, some learning objects permit students to explore higher level concepts by reducing_*cognitive load*. They provide perceptual and cognitive supports, permitting students to examine more complex and interesting relationships (Sedig & Liang, 2006). Finally, learning objects are *adaptive*, allowing users to have a certain degree of control over their learning environments, particularly when they are learning and for how long.

Student perspective. In a review of 10 studies examining the use of learning objects in higher education, undergraduate or graduate students had positive attitudes about learning objects in eight studies (Bradley & Boyle, 2004; de Salas & Ellis, 2006; Docherty, Hoy, Topp & Trinder, 2005; Kenny, Andrews, Vignola, Schilz, & Covert, 1999; Lim, Lee, & Richards, 2006; MacDonald et al., 2005; Mason, Pegler, &Weller, 2005; Schoner, Buzza, Harrigan, & Strampel 2005), neutral attitudes in one study (Concannon, Flynn, & Campbell, 2005) and negative attitudes in only one study (Van Zele, Vandaele, Botteldooren, & Lenaerts, 2003). Most papers presented informal or qualitative evidence, although three studies quantified their results by noting that 50% to 60% of higher education students liked using learning objects (Bradley & Boyle, 2004; de Salas & Ellis, 2006; Howard-Rose & Harrigan, 2003).

Students made positive comments about a wide range of features including animations (Bradley & Boyle, 2004), self-assessment (Lim et al., 2006), attractiveness (Bradley & Boyle, 2004), control over learning (Lim et al., 2006), ease of use (Kenny et al., 1999; Schoner et al., 2005), feedback (Concannon et al., 2005; Lim et al., 2006), scaffolding or support (Lim et al., 2006), interactivity (Concannon et al., 2005; Lim et al., 2006), navigation (Concannon et al., 2005) and self-efficacy (Docherty et al., 2005). Negative comments targeted problems with navigation (Concannon et al., 2005), technology (Concannon et al., 2005) and workload (Van Zele et al., 2003).

Student performance. Regarding student performance, three studies reported qualitative data suggesting that student learning performance improved when learning objects were used (Kenny et al., 1999; Lim et al., 2006; Windschitl & Andre, 1998). Two studies provided descriptive evidence suggesting that learning objects enhanced student learning (Bradley & Boyle, 2004; MacDonald et al., 2005). Bradley & Boyle (2004) noted pass rates increased by 12 to 23%. Docherty et al. (2005) observed that nursing students were significantly more positive about learning objects than control groups, but the marks on the final course were not significantly different. Rieber, Tzeng and Tribble (2004) cited that students, provided with embedded explanations and graphical representations, performed significantly better than those students who did not receive this scaffolding. Finally, Windschitl & Andre (1998) noted that simulation-based learning objects resulted in significant gains in two out of six concepts taught. The remaining four concepts showed no significant difference.

The purpose of this study was to develop and evaluate learning objects designed to improve student understanding of pre-calculus concepts.

METHOD

Sample

Students. The student sample consisted of 289 engineering or science students (189 males, 100 females) enrolled in a first year Calculus course. This sample size represents a survey response rate of about 60%. Students reported high school calculus grades of 60-69 (12%, n=35), 70-79 (37%, n=107), 80-89 (34%, n=98) and 90+ (13.5%, n=39).

Learning Object Design

As stated earlier, each learning object in this study consisted of three components: a text-based summary of a topic, a set of 2-8 minute video clips focusing on representative problems, and a set of online questions assessing student understanding of the topic. Five key topics were covered including operations with functions, solving equations, linear functions, exponential and logarithmic functions, and trigonometric functions. A detailed description of each component of the learning objects is provided below.

The ***text-based summaries***, typically no longer than a page, summarized the basic mathematical concepts within a specific topic. They consisted of definitions, theorems, diagrams, and simple examples. The main goal of these summaries was to present clear, text-based instructions with well thought out explanations and simple illustrative examples. These summaries were designed to help students decide whether they needed further help on specific concepts. If a student believed that more instruction was needed, he or she could choose to view the mini video clips (described below). Each topic included from 2 to 6 summary sheets. The intent was to focus on smaller chunks of information within a topic so that students would not be overwhelmed.

Within each concept covered by a text-based summary, a set of short video clips (also known as ***mini-clips***) were available that showed students how to solve specific problems in real time. In addition, students were asked to solve a similar problem of their own based on the information provided in the mini-clip. The benefits of using worked examples are well documented in research on effective teaching strategies (Atikinson, Deryy, Renkl, & Wortham, 2000; Clark & Mayer, 2008; Crippen & Earl, 2004; Renkl, 2005; Zhu & Simon, 1987). Each mini-clip had video controls enabling a student to easily pause, rewind, and fast forward a clip.

Students also had the option of testing their knowledge on a specific topic using an ***online assessment system*** called Maple T.A. The system allows for a variety of question types and supports the incorporation of algorithmic questions, graphs, and free-form responses. Furthermore, Maple T.A. provides a "scaffolded" approach to learning. The student is taken through a series of difficulty levels; if a student is struggling at a particular difficulty level, the student is directed to an easier level to build confidence and a stronger mathematical foundation before moving on. Feedback is immediate with full solutions provided, and a summary of the students' progress at each difficulty level is shown throughout the test. Students can also access their results at a later time, and can choose to retake the test as many times as they like, being presented with new questions on each attempt. Test-enhanced learning or the use of practice tests has been shown to be particularly effective (Angus & Watson, 2009; Kotcherlakota & Brooks, 2008; Roediger & Karpicke, 2006).

Procedure

The learning objects were made available to students three weeks prior to a pre-calculus diagnostic test implemented during the second week of school. After students received their results, they were asked to fill in a 10-15 minute survey asking about their use of and attitudes toward each of the three learning object components: written documentation, mini-clips, and online-testing (Maple T.A.). The learning objects used by students are located at http://faculty.uoit.ca/kay/precalc/index2.html and the survey used to evaluate the impact of the pre-calculus learning objects is available in Appendix A (Kay & Kletskin, 2009). Participation was voluntary and anonymous and in no way impacted a student's grade.

Data Sources

Background information and learning object use. Students were asked their gender, program of study, and their Calculus grade in high-school.

Use of learning objects. The number of site visits to each component of the learning object (written documentation, mini-clips, and online mastery testing) was recorded by a custom designed tracking tool. Students were also asked to estimate when and how many times they visited the pre-calculus learning object. Finally, students were asked how much time they spent using each of the three learning object components.

Written documentation. Students were first asked if they used the online written documentation and their reasons for this decision. Students who used the written documentation were asked which topics they reviewed, and to rate overall usefulness.

Mini-clips. Students were asked if they used the online video clips and their reasons for this decision. Students who used the mini-clips were asked which topics they reviewed and to rate overall usefulness. They were then asked to rate nine features about the mini-clips listed in table 1. The internal reliability of all scale items (expect for how many times a single clip was looked at) was 0.84. However, all items were also analysed individually in order to gain further insights into this new format of learning object.

Online mastery testing (Maple T.A.). Students were asked if they used online mastery testing and their reasons for this decision. Students who used the mastery tests were asked which topics they reviewed, and to rate overall usefulness. They were then asked to rate seven qualities of the online mastery testing tool (see table 1). The internal reliability of all scale items was 0.87. However, all items were also analysed indepedently in order to gather detailed information on this part of the learning object.

Table 1
Description of Pre-Calculus Learning Object Survey

Background Information 1. Gender 2. Program of Study 3. Calculus Grade in High School
Use of Learning Object 1. Online tracking of website use (written documentation, mini clips, online mastery testing) 2. When did you visit the pre-calculus learning object (1 week before classes, first week of classes, just before the test, after the test) 3. How many times did you use the pre-calculus learning objects? 4. How much time (in minutes) was spent using each of the three components of the learning objects (written documentation, mini clips, online mastery testing).
Written Documentation 1. Did you use the written documentation? Why or why not? 2. Which topics were reviewed? 3. How useful was the written documentation (Not at all, Somewhat, Useful, Very Useful)
Mini-Clips 1. Did you use the mini-clips? Why or why not? 2. Which topics were reviewed? 3. How useful were the mini clips (Not at all, Somewhat, Useful, Very Useful) 4. Using a 5 point Likert scale (Strongly Disagree to Strong Agree) a. The clips were easy to follow b. The math problems were well explained c. I liked doing the "student problem" d. The writing in the clips was easy to read e. Good tips were provided f. The clips were helpful because I could do them on my own time g. The clips helped me understand math concepts better h. I liked using the clips better that a textbook
Online Mastery Testing (Maple T.A.) 1. Did you use Maple T.A.? Why or why not? 2. Which topics were reviewed? 3. How useful was Maple T.A. (Not at all, Somewhat, Useful, Very Useful) 4. Using a 5 point Likert scale (Strongly Disagree to Strong Agree) a. The Maple TA questions were clear b. The syntax required was easy to use c. There was a sufficient variety of questions. d. The solution provided from Maple TA was helpful. e. The practice tests were easy to use. f. I liked being able to try Maple TA questions on my own time g. I liked the varying levels of question difficulty.
Performance 1. Using a 5 point Likert Scale (Very Weak to Very Strong), five areas of pre and post pre-calculus knowledge were self-evaluated a. Functions b. Solving Equations c. Linear Functions d. Exponential and Logarithmic Functions e. Trigonometric Functions

Performance. Students were asked to assess their pre-calculus knowledge before and after using the learning objects (working with functions, solving equations, linear functions, exponential and logarithmic functions, trigonometric functions). They were also asked their pre-calculus diagnostic test score.

Research Questions

The key research questions addressed regarding the use of the pre-calculus learning objects were as follows:

1) When and how often was the pre-calculus learning object used?
2) Were there significant differences among the three learning object components (written documentation, mini-clips, online mastery testing) with respect to use?
3) How useful were each of the three learning object components?
4) How did students rate the overall quality of mini-clips?
5) How did students rate the overall quality of the online mastery testing tool (Maple T.A.)?
6) Did student understanding of pre-calculus knowledge improve as a result of using the learning objects?

RESULTS

Use of pre-calculus learning objects. During the three week period that the learning object was available to students, 8988 hits and 969 unique visits were recorded by the tracking program. The average time spent for each visit was 307.5 seconds (*SD* = 445.8) and the mean number of items (written documentation, mini clips, or Maple T.A. files) looked at each visit was 6.3 (*SD* = 9.0). Thirty percent (n=80) of the students used the learning object one week before classes started , 50 % (n=133) used them during the first week of classes, 29% (n=77) used them just before the Calculus readiness diagnostic test, and 30% (n=81) used them after the diagnostic test.

The mini clips were selected 4681 times (52%), the written summary files 4030 times (45%), and the Maple T.A. assessment tool 277 times (3%). A one-way ANOVA comparing the time spent on each component of the learning objects was significant (F= 83.8, p <.001). A Scheffe's post hoc analysis revealed that students spent the most time using the Maple T.A. feature (*M* =523.5 seconds, *SD* = 604.3), followed by the mini-clips (*M* =357.7 seconds, *SD* = 443.7), and then the written documentation (*M* =237.7 seconds, *SD* = 426.1).

The pattern of learning object component use was consistent with the survey results where students reported using mini-clips most often (68%, n=195), followed by the summary text files (54%, n=154), and the online testing with Maple T.A. (38%, n=107). With respect to the total time spent on each component, students reported spending an average of 70.6 (*SD* = 71.1) minutes using mini-clips, 59.3 (*SD* = 64.5) minutes reading the written summaries, and 44.9 (*SD* = 43.8) minutes participating in the Maple TA online testing.

It should be noted that a total of 36 out of 288 students (13%) of the students who filled in the survey did not use any of the learning object tools. Reasons given by students for not using written documentation included they did not know it was available (n=29 comments), they had no time (n=28 comments), they preferred the mini clips (n=22 comments) or they did not need any help (n=8 comments). Reasons offered for not using the mini-clips included not knowing it was available (n=15 comments), not needing any help (n=12 comments), having no time (n=14), technological problems (n=6 comments) or preferring written documentation (n=4 comments). Finally, reasons for not using the online mastery tool were as follows: not knowing it was available (n=46), not knowing how to use the tool (n=25 comments), having no time (n=22 comments), not needing any help (n=8 comments), preference for another method (n=7 comments).

Usefulness of learning object components. Overall, students rated the mini clip (87%), written summary (79%) and Maple T.A. online testing (69%) components of the learning objects as useful or very useful. A one-way ANOVA comparing the usefulness among learning object components was significant ($F = 13.2$, $p < .001$). The Scheffe's post hoc analysis showed that mini-clips (M =3.38, SD = 0.72) were rated significantly more useful than written documentation (M =3.12, SD = 0.75) or the online mastery testing (M =2.93, SD = 0.82).

With respect to the mini-clips, students commented that the videos were clear, easy to follow, well explained, provide useful visual supports, and helped improve understanding. They also enjoyed being able to proceed at their own pace. Student comments about the written documentation indicated that this feature was easy to use and follow, improved understanding, and provided a helpful review of concepts. Regarding the online mastery tool, students noted that it helped them understand and review concepts, and provided helpful practice to re-enforce concepts.

Evaluation of mini-clips. Students rated the mini-clips highly (Likert scale from 1 to 5) noting that they were easy to follow, helpful because they could be viewed on the student's own time, and well explained. Students also preferred the mini-clips to working through a textbook. A summary of the mini-clip ratings is provided in table 2.

Table 2
Summary of Rating for Mini-Clips

Item	Mean	Standard Deviation
a) The clips were easy to follow	4.46	0.68
b) The math problems were well explained in the clips.	4.31	0.74
c) I liked doing the "student problem" in the clips.	3.87	1.02
d) The writing in the clips was easy to read.	4.30	0.75
e) Good tips were provided in the clips to help me understand the problem.	4.10	0.76
f) The clips were helpful because I could do them on my own time.	4.40	0.74
g) The clips helped me understand math concepts better.	4.16	0.77
h) I liked using the clips better that using a textbook to work through examples.	4.17	0.99

Evaluation of online mastery testing (Maple T.A.). When rating the online mastery testing tool, students rated the following qualities relatively high: varying level of question difficulty, being able to use the tool on their own time, clarity of questions, and the variety of questions. Ease of use and the syntax required to use this component were rated somewhat lower than the other features. A summary of the online mastery tool ratings is provided in table 3.

Table 3
Summary of Rating for Online Mastery Testing Tool (Maple T.A.)

Item	Mean	Standard Deviation
a) I liked the varying level of question difficulty offered by Maple T.A.	3.86	0.83
b) I liked being able to try Maple T.A. questions on my own time.	3.84	0.91
c) The Maple T.A. questions were clear.	3.82	0.74
d) There was a sufficient variety of Maple T.A. questions available for me to practice on.	3.76	0.80
e) The solution provided from Maple T.A. was helpful.	3.66	0.87
f) I found Maple T.A. practice tests easy to use.	3.63	0.94
g) The syntax required to give answers to Maple T.A. questions was easy to use.	3.32	1.14

Impact of pre-calculus learning object on understanding. While a formal pre-post test analysis was not conducted, students self-rated five areas of pre-calculus knowledge before and after using the learning objects. Paired t-tests revealed significant gains in all five pre-calculus knowledge areas assessed. The effect sizes (based on Cohen's d) ranged from 0.14 to 0.44 and are considered to be small to moderate (Thalheimer & Cook, 2002).

Table 4

Pre vs. Post Ratings of Pre-Calculus Knowledge (n=252)

Topic	Pre-LO Mean (SD)	Post-LO Mean (SD)	Significance t value	Cohen's d
Operations with Functions	3.36 (0.90)	3.63 (0.82)	- 5.58 **	0.31
Solving Equations	3.61 (0.91)	3.74 (0.83)	- 2.44 *	0.14
Linear Functions	3.49 (0.97)	3.72 (0.84)	- 4.26 **	0.25
Exp. and Log Functions	2.89 (0.96)	3.27 (0.84)	- 6.85 **	0.42
Trigonometric Functions	2.96 (1.01)	3.38 (0.89)	- 7.56 **	0.44

* $p < .05$
** $p < .001$

Correlations between use of written summaries or mini clips and self-reported changes in pre- calculus knowledge were positive and significant for all five pre-calculus concepts. Correlations between the use of the online mastery tool and change in pre-post test scores were not significant for any of the five pre-calculus concepts assessed (Table 5).

Table 5

Correlation between Use of Learning Objects Components and Change in Pre-Calculus Knowledge (n=288)

Topic	Written Summaries	Mini Clips	Online Testing
Operations with Functions	0.21 **	0.27 **	0.08
Solving Equations	0.20 **	0.14 *	0.04
Linear Functions	0.17 **	0.22 **	0.09
Exp. and Log Functions	0.23 **	0.27 **	- 0.01
Trigonometric Functions	0.20 **	0.25 **	0.06

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

A regression analysis assessing the relative contributions of the three learning tools indicated that the impact of mini-clips and written documentation were both significant predictors of the total change in pre-calculus knowledge. This means that the impact of these two tools appears to be cumulative. In other words, the contribution of either mini-clips or written documentation in isolation is less than the combined contribution of both tools.

Students who used the written summaries noted that they provided a good overview of concepts (30 out of 102 comments), helped with understanding and review (56 out of 102 comments), and were useful (16 out of 102 comments). Students who viewed the mini clips reported that the step-by-step explanations were helpful (40 out of 149 comments), the clips were helpful for understanding and reviewing concepts (51 out of 149 comments), the visual representations helped learning (30 out of 149 comments), and that the tool was useful (21 out of 149 comments). Finally, students who chose to engage in online mastery testing thought Maple T.A. was helpful for understanding and reviewing concepts (30 out of 68 comments), believed they were required to learn this tool for the course (22 out of 68 comments), felt Maple T.A. was useful (9 out of 68 comments) or simply wanted to explore the program (7 out of 68 comments).

DISCUSSION

Overall Use of Pre-Calculus Learning Objects

One can be reasonably confident that the students in this study were active participants in using the learning object tools. Even though they were introduced to the clips before class officially started and the concepts covered were not being directly evaluated for marks, the learning object web site received almost 9000 hits in a three week period. In addition, only 13% of those students surveyed did not use any of the tools. It appears that the use of learning objects is an attractive option for students who want to upgrade their mathematics skills.

Differences in Use Among Learning Object Components

With respect to the three tools offered, students preferred using interactive mini-clips most followed by the written documentation. This appears to be a reasonable choice for students who are reviewing concepts they may have forgotten. It seems unlikely that a student would jump directly to an online mastery test, unless he/she felt confident in his/her knowledge.

If one sets aside the frequency of use, it is interesting to note that students spent the most time using the online mastery tool, followed by the mini clips and then the written documentation. The online mastery tool is the most complicated to learn and would require extra time to answer a wide range of review questions. The mini-clips would take extra time too as the students had to view clips and complete the student problems. Written documentation could be downloaded quickly and read offline. More research is needed, perhaps in the form of interview or focus groups to confirm the reasons why students selected specific tools.

Usefulness of Learning Object Components

Overall, the vast majority of students rated all three learning tools as useful or very useful. The consensus, based on student comments, was that the tools provided a useful review and helped to improve understanding. A comparison among the three learning object tools indicated that almost 90% of the students thought mini-clips were useful and rated them significantly higher than written documentation or the online mastery tool. This result is consistent with previous research reporting that students respond very positively to the visual supports and interactivity of learning objects (e.g., Bradley & Boyle, 2004; Concannon et al., 2005; Lim et al., 2006). Both the written documentation and online mastery tools were predominantly based on the display of static text. It is also possible that students appreciated the auditory component of the mini-clips, a communication mode that was not available in either the written documentation or online mastery tools.

Evaluation of mini-clips

Students rated all aspects of the mini clips highly, averaging four or better on a five-point Likert scale. Top rated features were that the clips were easy to follow and provided clear explanations. Student also appreciated the fact that they could use them on their own time. The qualities that students appreciated in the mini-clips were similar to those reported in previous research on learning objects (e.g., Docherty et al., 2005; Kenny et al., 1999; Lim et al., 2006; Schoner et al., 2005). Overall, the mini-clips were a highly rated tool in the pre-calculus learning object.

Evaluation of Online Mastery Testing (Maple T.A.)

Ratings of the online mastery tool were, on average, a half-point to one point lower than those for the mini-clips. Students liked the varying level of question difficulty offered and working on their own time. Obstacles, based on the survey data and student comments, appeared to be the syntax involved in using this tool. Some students found the tool difficult to use. Overall, comparatively fewer students used online mastery testing, however those students who used this tool thought it was effective in terms of testing their knowledge and practicing questions. More research is needed on how to encourage students to use this tool.

Impact of Pre-Calculus Learning Object on Understanding

There is considerable indirect evidence that students experienced significant gains in the knowledge areas targeted by the learning object. Differences in pre and post learning object scores show significant gains for all five categories of knowledge assessed. The effect size was considered small to moderate. It is important to note that this data came from student's self assessment of their own skills. A more rigorous analysis would have students do a pre- and post diagnostic test. Nonetheless, the data indicates that, at the very least, students believe their knowledge of pre-calculus concepts increases.

It is important to note that while the use of written documentation and mini clips were significantly and positively correlated with change in pre- and post- scores, the use of online mastery testing was not significantly related to perceived changes in pre-calculus knowledge. One possible explanation is that the written documentation and mini-clips are designed to teach whereas the online mastery tool focuses more on assessment. Of course, students could learn by attempting the online mastery questions and responding to the feedback given, but perhaps this more indirect form of instruction was not as effective. Interview data would be helpful in sorting out why online mastery tools did not appear to have a short-term impact on improving pre-calculus knowledge.

Finally, the impact of mini-clips and written documentation appears to be complementary. In other words, students did better if they used both tools as opposed to only one. However, adding the use of the online mastery tool to the use of mini clips and the written documentation did not significantly improve pre-calculus knowledge in this study.

Caveats and Future Research

This study is a first attempt at using learning objects to address the deficits in pre-calculus that students have when entering a first year calculus course. A large sample combined with triangulation of data collection tools was used to assess the impact of learning objects. Nonetheless, several caveats remain that are worth addressing for future research. First, students were not interviewed in this study. This type of data would have been particularly useful in providing information on why online mastery tools were used less frequently and appeared to have a minimal impact. Second, a formal pre- and post- test on precalculus concepts would provide stronger data on supporting the effectiveness of the learning objects used in this study. Third, since this study was a formative analysis, the reliability and validity of the survey instruments were not provided. Fourth, students had limited time to use the learning objects prior to the start of classes. It would be interesting to investigate whether earlier access to the learning objects would result in increased use of the online mastery tool, and perhaps a larger impact on student pre- and post- learning object scores.

Summary

Previous research suggests that students have a weak understanding of the kinds of mathematical concepts required to be successful in university Calculus courses. A set of learning objects was designed to help students augment their pre-calculus knowledge. Three tools were used: written documentation, interactive mini-clips, and online mastery testing. Students accessed and used these tools of almost 9000 times in a three week period. Most students rated all three tools as useful for review and improving understanding. Students reported significant pre-calculus knowledge gains as a result of using mini-clips and written documentation, but not the online mastery tool. Overall, it appears there is evidence to support the effectiveness of learning objects in improving the pre-calculus knowledge of first-year university students.

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