The Canadian Journal for the Scholarship of Teaching and Learning

Volume 3 | Issue 1 Article 4

April 2012

Patterns and Rates of Learning in Two Problem-Based Learning Courses Using Outcome Based Assessment and Elaboration Theory

Usha Kuruganti
University of New Brunswick, ukurugan@unb.ca
Ted Needham
University of New Brunswick, needham@unb.ca
Pierre Zundel
University of Sudbury, pzundel@usudbury.ca

http://dx.doi.org/10.5206/cjsotl-rcacea.2012.1.4

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Abstract

The concept of "practice makes perfect" was examined in this work in the context of effective learning. Specifically, we wanted to know how much practice was needed for students to demonstrate mastery of learning outcomes. Student learning patterns in two different university courses that use a similar education approach involving problem based learning, outcomes based assessment, and problem sequencing based on elaboration theory were examined. Learning outcomes for each course were explicitly defined and students were repeatedly assessed through sequential assignments. The cumulative proportion of criteria successfully demonstrated for each problem-solving attempt was determined using data retrospectively obtained from instructor grading records. Learning followed a typical growth pattern - it increased rapidly at first and more slowly with succeeding attempts. The precise shape of the learning curve differed between the two courses and is thought to be the result of problem difficulty and problem sequencing. Depending on these two factors, at least one more attempt than the number of times criteria need to be demonstrated is required and often more are needed to demonstrate mastery. This paper presents class-level data and future work should investigate individual performance and particularly why some students learn more quickly than others. Two additional issues for future consideration are the effect of the number of attempts on long-term retention and on the transferability of the learning to other problems.

Les chercheurs se penchent sur le concept selon lequel c'est en pratiquant qu'on atteint la perfection en contexte d'apprentissage efficace. Plus précisément, ils cherchent à savoir à quel point les étudiants doivent s'exercer avant d'atteindre les objectifs d'apprentissage. Les chercheurs ont examiné les modèles d'apprentissage des étudiants dans deux cours universitaires différents qui utilisent une approche pédagogique similaire axée sur l'apprentissage par problèmes, l'évaluation des résultats et le séquençage des problèmes axé sur la théorie de l'élaboration. Les résultats d'apprentissage ont été explicitement définis et les étudiants ont été évalués à plusieurs reprises grâce à des évaluations séquentielles. Les chercheurs ont déterminé la proportion cumulative de critères remplis pour chaque tentative de résolution de problèmes à l'aide de données obtenues rétrospectivement à partir des dossiers de notes de l'enseignant. L'apprentissage a suivi un modèle de croissance typique, c'est-à-dire qu'il a tout d'abord augmenté rapidement, puis 'a un rythme décroissant avec l'ajout de tentatives additionnelles. La forme précise de la courbe d'apprentissage était différente d'un cours à l'autre et les chercheurs pensent qu'elle est attribuable à la difficulté des problèmes et à leur séquençage. En fonction de ces deux facteurs, il faut au moins un essai de plus que le nombre requis pour respecter les critères, et parfois plus, pour démontrer qu'il y a maîtrise des objectifs d'apprentissage. Le présent article présente les données liées à la classe dans son ensemble. Les prochains travaux devraient se pencher sur la performance individuelle et particulièrement sur les raisons expliquant pourquoi certains étudiants apprennent plus vite que d'autres. Les deux autres questions à considérer sont l'effet du nombre d'essais sur la rétention à long terme et sur la transférabilité de l'apprentissage à d'autres problèmes.

Keywords

learning patterns, learning outcomes, problem based learning, elaboration theory, mastery

As our personal knowledge and ability to teach have matured, we have moved to a model of university teaching that is grounded in three important theories that work together to allow and encourage effective learning. In applying these theories, a number of important questions about teaching and learning have surfaced and in this paper we describe and answer the following question related to the concept of "practice makes perfect": How much practice is needed for students to demonstrate mastery of learning outcomes?

Mastery is the philosophy that suggests that under appropriate instructional conditions, most students can learn "well" or master the material taught (Block & Burns, 1976; Kulik, Kulik, & Bangert-Drowns, 1990). In addition, it suggests that teachers can teach in such a way that causes mastery to occur. In this research, we define mastery as a performance level that students can reliably fulfill. Our definition also assumes that mastery occurs when students can repeatedly demonstrate the criteria that define successful performance.

Our traditional model of teaching, one that seems common across many universities, was focused on presenting content, with coverage of the subject matter as the main concern. In our courses, we presented topics in a lecture format and a midterm and final exam were given to evaluate whether students could reproduce the content. We also had students work on an individual project toward the end of the term that required them to apply the content presented. Using this approach, students had three attempts to demonstrate competence and one opportunity for formative feedback (the mid-term exam). The feedback often reflected our overall impressions about the most notable characteristics of their course work. As the course instructors, we had not explicitly articulated learning outcomes nor were we systematically assessing student work using criteria referenced to these outcomes.

The education approach we used in this work shifted from a traditional lecture-based model focusing on content coverage to one that relied on three theoretical constructs. First, our new approach used problem-based learning to engage students. Problems provided relevance and "drove" the learning. Second, we used elaboration theory (Reigeluth & Stein, 1983), which suggests that multiple attempts at problem-solving be allowed and that the respective problems be sequenced from less to more difficult. Third, while it has been shown that providing students multiple opportunities to demonstrate knowledge and develop ability can result in greater acquisition of learning outcomes (Ozogul, Olina, and Sullivan, 2008; Thompson & Grabau, 2004), practice alone is insufficient. Also needed is relevant feedback from instructors. Feedback becomes: (a) relevant when it connects learning outcomes to student performance (Black & William 1998; Gibbs & Simpson 2004; Lizzo & Wilson 2008); and (b) useful when students have an opportunity to apply it (Gibbs & Simpson, 2004). As such, we relied on explicit and clear behavioral learning outcomes with aligned assessment criteria to help us provide systematic criterion-referenced feedback (Zundel & Needham, 2000) as our third theoretical construct.

We applied this three-pronged educational approach to two different undergraduate courses at the University of New Brunswick (UNB). The first course, RCLP 1052: Mathematical and Economic Approaches to Problem Solving (Math/Econ), is a first year undergraduate course in Renaissance College, UNB's Interdisciplinary Leadership Faculty. The course provides initial exposure to mathematic and economic reasoning using social or environmental problems like "whether a person should stay on welfare" as the basis for learning. In this course, students are expected to develop the skills needed to solve problems using finite mathematics and economic principles. The second course, FOR 3005: Silviculture and Stand Intervention Design (Forestry), is a third year undergraduate course in the Faculty of Forestry and Environmental Management and takes a design approach to silviculture. In this course, students are expected to develop intervention plans for the main stages of forest stand development integrating the biology of growing trees, the engineering of conducting operations, and the economics of costing them.

In addition to using a problem-based learning approach with outcomes-based assessment, both courses provided multiple attempts for students to master the learning outcomes. Our central question was "how many attempts were required"? Each attempt is a "costly" endeavor for both student and instructor. Since allowing too many attempts is inefficient and can waste student and instructor time and energy, we wanted to know the marginal return in student learning as a function of providing additional attempts. Students need a sufficient number to become proficient in any activity and instructors need a sufficient number to be confident students had have "mastered" the outcomes. In our judgment, students needed to accumulate at least two successful demonstrations of each criterion to demonstrate mastery.

The purpose of this research was to see whether using a similar teaching approach in two very different courses would lead to similar learning patterns and also to identify factors that affect student learning.

Background

The two courses in this study used the three learning theories or strategies as described earlier – elaboration theory, problem-based learning, and outcomes-based assessment and evaluation. The core of elaboration theory is to select and sequence learning activities in increasing order of complexity in order to optimize learning. The theory uses "epitomes" that present the simplest form of an entire ability and then work up repeatedly by adding the factors or dimensions that make it more complex or challenging. This idea for sequencing and organizing instruction is one of the most widely used theoretical innovations in instructional design (ID) (Wilson & Cole, 1996). In total, the theory consists of seven major strategic components (Reigeluth & Stein, 1983): (a) an elaborative sequence, (b) learning prerequisite sequences, (c) summarizers, (d) synthesizers, (e) analogies, (f) cognitive strategy activators, and (g) a learner control format. These seven strategies are briefly explained in Table 1.

Table 1
Reigeluth and Stein's Elaboration Theory (1983)

Strategic Component	Description
Elaborative Sequence	Simple to complex sequence in which the first lesson epitomizes the ideas and skills to follow. This is considered the most critical component of elaboration theory.
Learning Prerequisite Sequences	Elaborates upon organizing the content from the first strategy. The epitomes are sequenced according to the order of the steps: forward chaining, backward chaining, hierarchical sequencing, general to detailed sequencing and simple to complex sequencing.
Summarizers	In order to review what has already been learned, a "summarizer" is created. A summarizer provides a concise statement of each idea. Two types are used: internal and within-set.
Synthesizers	Integrates and interrelates the ideas taught thus far in order to facilitate deeper understanding, meaningfulness, and retention in regards to the content area.
Analogies	The use of a familiar idea or concept to introduce or define a new idea or concept.
Cognitive Strategy Activators	Imbedded activators use pictures, diagrams and other element to force the learner to interact with the sequence and content. Detached activators cause the learner to employ a previously acquired cognitive skill.
Learner Control Format	Allows the learner to control the selection and sequencing of instructional elements (e.g. content, rate, components and cognitive strategies).

This paper focuses on the elaborative sequence component. The elaborative sequence concept suggests that instruction follows a simple to complex sequence with early lessons containing fundamental ideas at a concrete skill level. Layers of complexity are then added sequentially. The epitomes used in both courses were the problems we asked students to solve. Consistent with elaboration theory's concept of epitomes, the whole outcome needed to be expressed in each problem rather than simply some parts. As such, each problem was a complete task that called on the use of all components of an outcome to be learned. The courses differed in one important respect; in the Math/Econ course, the first three problems increased gradually in terms of complexity and the fourth problem was a rewrite of one of the first three (usually the one on which students did most poorly in a first attempt). In the Forestry course, the second problem was significantly more difficult than the first, third or fourth problems. In other words, while the Math/Econ course had a smooth developmental sequence that flattened near the end of the course, the Forestry course had a developmental "hump" with the 2nd problem. That problem required decisions about which tress to leave and which ones to harvest, which has complicated biological, operational and economic interactions.

Both courses used a problem-based learning (PBL) approach. PBL focuses on problem solving with the problem "driving" the learning (Matthew and Hughes, 1994). The problem statement clearly describes the issue, however it is the student that must clearly define and solve the problem. The learning that occurs in PBL is developmental in that there is sequencing and building upon already established skills as the difficulty of the problem increases. This approach is an effective way for students to learn to solve problems by experiencing the process as active participants. PBL is more than problem solving and, as suggested by Matthew and Hughes (1994), a key element of PBL is the learning that students do in addressing the problem. In this regard, while our primary goal was for our students to learn a problem-solving process, we also wanted them to learn disciplinary “content”. Dym, Agogino, Eris, Frey, and Leifer, (2005) and Matthew and Hughes (1994) suggest problem-based learning as a method for developing higher-level cognitive, personal and interpersonal skills. Another strength of PBL is the ability of students to extend what has been learned in one context to other, new contexts (Dym et al., 2005). While the outcomes related to personal and interpersonal skills were not specific outcomes for these courses, they were general objectives of the degree programs as a whole.

Outcomes-based assessment means setting explicit learning outcomes and assessing student performance directly against them. Outcomes describe the knowledge, skills and attitudes we want students to acquire and demonstrate by the end of the course (Zundel & Needham, 2000). It is essential that outcome statements are explicit, hierarchically organized, behaviorally described and given to students (Zundel & Needham, 2000). In both courses, the syllabi described the outcomes in behavioural terms. For example, in the Math/Econ course, one of the outcomes was defined as: “Apply a structured problem-solving framework effectively to solve financial, economic and sustainability problems.” Outcomes were then decomposed into behavioral criteria. Tables 1 and 2 give the outcomes and criteria used in the two courses. The learning outcomes and criteria for each course were explicit, behavioral and hierarchical. When students repeatedly fulfill the criteria, we assume they have mastered the outcome.

In the Math/Econ course, students were provided four attempts to demonstrate competence in the learning outcomes. These attempts took the form of increasingly difficult problems (based on elaboration theory). The first problem provided the students with financial data for a single parent family on income assistance. Their goal was to determine whether it was financially more attractive for the breadwinner of this family to go to work or remain on welfare. The focus of the first problem was building a financial model and learning the dimensions of the structured problem-solving framework. The technical issues were very simple and the decision variables (ending bank balance) were given to the students. In the second problem, students were again provided the decision variable (present net worth and benefit/cost ratio of a logging business investment), but were required to do some research about the nature of the problem (e.g., compare horse logging to mechanized logging, examine conceptual ideas like the time-value of money that are used to calculate present net worth). Again, students built a model and applied the problem-solving framework. In the third problem, students were asked to develop their own indicators of social, economic and environmental sustainability to move from an abstract concept like sustainability to concrete mathematical indicators for a problem of their choice. They again had to build a model and apply the problem-solving framework. Finally, the fourth problem was a rewrite of one of the prior three. After reporting their solution to each problem, students were provided summative and formative feedback on their report which was referenced to the criteria established at the beginning of the course for each learning outcome.

The Math/Econ course had three learning outcomes: (a) problem-solving (PS), (b) mathematical modeling, and (c) economics knowledge. The PS outcome had nine criteria, the mathematical modeling outcome had five, and the economics knowledge outcome had eight

DOI: http://dx.doi.org/10.5206/cjsotl-rcacea.2012.1.4

criteria. These criteria ranged from simple ones like "identify objectives, constraints and resources [of the problem]" to higher order ones like "identify assumptions and predict their effects on the solution". Table 2 gives a complete list of the criteria for the PS outcome for this course. The students had to demonstrate each criterion in at least two separate attempts to indicate their mastery of each. The course grade was based on the percent of mastered criteria, where each was weighted according to its relative importance.

Table 2
Math/Econ Problem-Solving (PS) Outcome and Associated Criteria

PS Outcome	**Criterion Description**
By the end of this course, students will be able to apply a structured problem-solving framework effectively to solve financial, economic and sustainability problems.	1. Rephrase or describe problem accurately. 2. Identify constraints, objectives and resources. 3. Define key terms subject to ambiguity. 4. Define several possible solutions. 5. Predict performance of each solution in terms of objectives and constraints. 6. Select optimal solution. 7. Identify assumptions and predict their effects on the solution. 8. Reflect on what parts of solution process or product were best/worst. 9. Identify what personal skills or /knowledge limited or /helped most during implementation.

The Forestry course had four outcomes: (a) effective writing (EW), (b) primary information acquisition (PIA), (c) stand intervention planning (SIP), and (d) display of stand intervention technical knowledge (K). Stand intervention planning has 18, effective writing has eight criteria, primary information acquisition has five, and display of stand intervention technical knowledge has seven. As an example, Table 3 gives a complete list for the SIP outcome for the Forestry course.

Table 3
Forestry Stand Intervention Planning (SIP) Outcomes and Associated Criteria

SIP Outcome	Criterion Description
By the end of this course, the student will be able to construct a site specific SIP that incorporates all relevant criteria and is specific to the issue presented.	1. Frame problem by providing goals. 2. Transform goals into objectives. 3. Describe stand and site condition. 4. Describe intervention. 5. Describe implementation. 6. Identify and describe ancillary resources. 7. Predict resource consumption. 8. Predict immediate benefits. 9. Illustrate yield prediction. 10. Describe primary and secondary impacts. 11. Describe monitoring plan. 12. Stand description is reasonable. 13. Intervention is reasonable. 14. Implementation methods are reasonable. 15. Resource consumption is reasonable. 16. Immediate benefit prediction is reasonable. 17. Yield prediction is reasonable. 18. Monitoring plan is reasonable.

Students learned and demonstrated competence in the Stand Intervention Planning criteria through four problems. The first problem was the simplest and required students to develop a stand intervention plan (something akin to a doctor's prescription for a patient but aimed at treating a forest area) for a pre-commercially thinned, 15-year old, dense stand of trees. The second, a much more complicated problem required a commercial thinning plan, the third was a regeneration plan, and the fourth problem was a harvest plan. The third and fourth problems have a similar, but slightly lower, degree of difficulty than the second problem which is technically the most difficult. This problem difficulty sequence does not strictly follow elaboration sequencing theory but was created to ensure students encountered the concept of commercial thinning early in the term for logistical reasons and before they had accumulated enough criteria which would exempt them from it. Given that students only need to complete problems until they have mastered criteria, it is possible that some students will not attempt problems given late in the course as they will have demonstrated the criteria the required number of times in earlier problems. This represents a trade-off of the principles of gradual incline in difficulty suggested by elaboration theory in favour of a curricular need to ensure mastery of key content.

Assessment of student learning in both courses and corresponding instructor feedback consisted of examining student reports in terms of the criteria that define each outcome. It has been shown that assessment and appropriate feedback need to show the student how s(he) is progressing in ways that "connect the judgment of student performance with the outcomes students are expected to acquire (Alverno College, 1994)." When each assignment was given, the assessment criteria were provided and subsequent feedback was referenced directly to them. Students earned grades by demonstrating mastery of the criteria (i.e., that they had fulfilled the required criteria at least two times). Once a student had demonstrated the criteria twice they did not have to demonstrate them again, although solving the problems to demonstrate the remaining criteria often required others previously demonstrated be addressed again since many criteria are inter-related. When students were not able to demonstrate a criterion twice, they did not receive the marks associated with it.

Methods

In this paper, we show the data for the most important outcome in each course (the outcome with the highest grade weighting). These are also the ones with the greatest "granularity" of information about student performance. That is, problem solving for Math/Econ and stand intervention planning for the Forestry course had the largest number of criteria and provided the greatest resolution of information relative to the questions we wanted to answer. Including the two courses in this research allowed us to see whether using a similar teaching approach in two very different courses would lead to similar learning patterns and it allowed us to identify factors that affect student learning that we might not see otherwise.

Class records were obtained from instructor grading records for two cohorts for the Math/Econ course (academic years 2003 and 2004), and four cohorts for the Forestry course (2000 to 2003 academic years). The records were stripped of their student names and the following variables were calculated for each attempt: (a) cumulative average proportion (%) of criteria successfully demonstrated at least once, and (b) cumulative average proportion (%) of criteria demonstrated at least twice (for attempts 2 – 4). The calculations involved pooling data for all the cohorts for each course (i.e., two for the Math/Econ course and four for the Forestry course). The courses were not modified to carry out this research; rather aggregate class data from offerings 5-10 years prior to the research were used. No linkage was possible between the records used and individual students. The consequence of this approach is that the data illustrates class mastery rather than individual student mastery of the criteria. This level of analysis informs decisions about how to conduct a class rather than providing information about individual student performance.

The data were examined using Minitab Statistical Software (Minitab Inc., 2010) graphically and using an analysis of variance (ANOVA) with Tukey post-hoc analysis to determine if differences in the proportion of criteria students demonstrated between attempts was statistically significant. The alpha level was set to 0.05.

Results

The results for both courses are illustrated in Figures 1 and 2 with the corresponding data in Table 4. Figure 1 illustrates the percentage of criteria successfully demonstrated for each problem for each course when students were required to demonstrate the criteria one time (1X), and Figure 2 provides similar information when criteria needed to be demonstrated twice (2X). We refer to the problems as "Attempts" in this analysis.

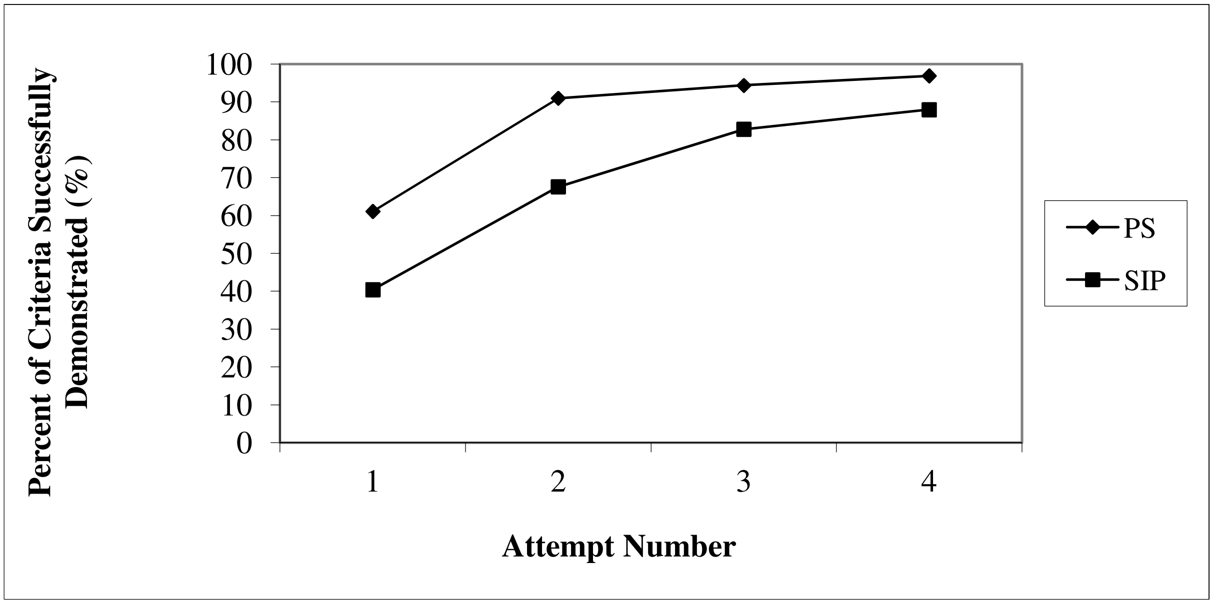

Figure 1. One time demonstration pattern for the PS and the SIP Criteria. PS – Problem Solving outcome for the Math/Econ course, SIP – Stand Intervention Planning outcome for Forestry course.

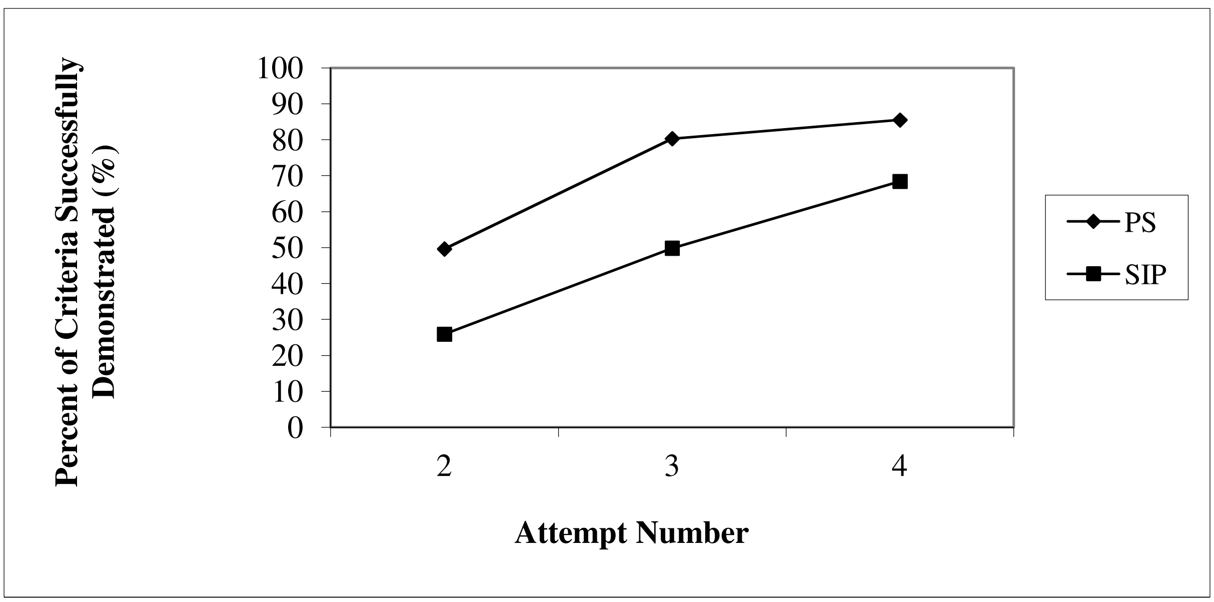

Figure 2. Two-time demonstration pattern for the PS and SIP criteria. PS – Problem Solving outcome for the Math/Econ course, SIP – Stand Intervention Planning outcome for Forestry course.

DOI: http://dx.doi.org/10.5206/cjsotl-rcacea.2012.1.4

Table 4
Percentage of Abilities Demonstrated Once (1X) and Twice (2X) for Outcomes of Both Courses

Attempt Number	Mean ± Standard Deviation			
	Problem-Solving Ability (Math/Econ)		Stand Intervention Planning Ability (Forestry)	
	1X	2X	1X	2X
1	61.1 ± 25.8	--	40.4 ± 17.9	--
2	91.0 ± 16.3*	49.6 ± 24.8	67.6 ± 18.9*	25.9 ± 15.5*
3	94.4 ± 14.1*	80.3 ± 22.3*	82.8 ± 17.4*+	49.8 ± 22.7*+
4	96.6 ± 11.7*	85.5 ± 21.7*	88.0 ± 18.2*+	68.4 ± 27.8 *+

* - Indicates statistically significant difference with first attempt (p<0.05)
+ - Indicates statistically significant difference between Attempts 2 – 4 (p<0.05)

The ANOVA was conducted to determine if there were differences in the proportion of criteria demonstrated between attempts. Results of the ANOVA are found in Table 4.

Post hoc analysis revealed that for the Math/Econ data, there were differences between Attempt 1 and all other attempts (p=0.000), however there were no significant differences between Attempts 2, 3 and/or 4. There were statistically significant differences between Attempt 2 and both attempts 3 and 4 (p=0.000) for the 2X demonstration. However, attempts 3 and 4 were not statistically significant from one another.

For the Forestry data, the ANOVA results showed that there were differences between all four attempts. Attempt 1 was statistically different from all other attempts (p=0.000). In addition, the post hoc analysis revealed that there were statistically significant differences between Attempts 2 and each of 3 (p=0.0004) and 4 (p=0.000) for the 1X demonstration. There were statistically significant differences between Attempts 2, 3 and 4 (p=0.000) for the 2X demonstration.

Figure 1 shows that 61.1% of the criteria in the Math/Econ course were successfully demonstrated on Attempt 1 and this increased to 91.0 % at Attempt 2. There were slight increases in the third and fourth Attempts (problems 3 and 4) to 94.4% and 96.6% respectively, but these were not statistically significant. In other words, by the fourth problem, on average, students had demonstrated 96.6% of the criteria at least once.

The Forestry course had a similar pattern although the demonstration curve shifted down. The percentage of criteria demonstrated in the first Attempt (Problem 1) was 40.4%, which then increased to 67.6% on Attempt 2, 82.8% on Attempt 3, and to 88% on the 4th Attempt. The difference between Attempt 3 and Attempt 4 was not significant when criteria were demonstrated one time.

Figure 2 shows the proportion of criteria demonstrated at least twice - in other words "mastered". Obviously, this variable only has meaning after the second attempt. By increasing the required number of successful demonstrations from one to two, the degree of certainty that a student has in fact 'mastered' the criteria increases. In the Math/Econ course, students were able to demonstrate 49.6% of the criteria a second time on Attempt 2. Interestingly, 11.5 % fewer criteria were demonstrated on the second attempt than originally demonstrated during the first attempt (61.1 vs. 49.6, see Table 4). In effect, while students demonstrated more criteria on the second attempt overall, they failed to demonstrate 11.5 % of them a second time. By the Attempt 3, the number of criteria demonstrated twice increased 30% to 80.3%, and by the 4th attempt 85.5

% of the criteria had been demonstrated twice. This is 11.1 % less (85.5% vs. 96.6%) than the number demonstrated one time. It should be noted that the percent of criteria demonstrated between the third and fourth attempts is not statistically significant.

In the Forestry course, students demonstrated 25.9 % of the criteria twice by Attempt 2, which was 14.5 less than on Attempt 1 (40.4% vs. 25.9%, see Table 4). By Attempt 3, the percentage increased to 49.8%, and by Attempt 4, 68.4% of the criteria had been demonstrated twice by the class, down 19.6 % from the number demonstrated once. Differences in the average student performance were statistically significant for all attempts.

Discussion

Our results show similarities in the learning patterns in the Math/Econ and Forestry courses despite different course content. That is, students' ability to demonstrate the problem solving outcome in the Math/Econ course and the stand intervention planning outcome in the Forestry course grows rapidly in the first two attempts, and then tapers off as they get more practice with course content and the problem-solving tasks. Despite the courses' general similarity in pedagogical approach, there are specific differences in the learning curves between the two courses (Figures 1 and 2). One difference is the location of the curve. The Forestry performance curve is lower than the Math/Econ course curve (Figures 1 and 2). In effect, the amount of learning in the Forestry course relative to the expectation as defined by the criteria is lower than in the Math/Econ course. The second difference is the precise shape of the two curves. The rate of learning differs between the two courses with students demonstrating criteria faster in the Math/Econ course than in the Forestry course.

We believe that there are several factors that affect the location and shape of the learning curves. The primary ones are the inherent difficulty of the problems and the timing or sequencing in which increasingly difficult problems are presented to students. Relatively speaking, the Forestry problems appear to be more difficult for the forestry students than the Math/Econ problems are for the Renaissance College students. This may be due to the fact that the forestry problems require specialized technical knowledge and are more complicated because they involve more and a wider spectrum of types of information (e.g. biological, financial and operational data) than the Math/Econ problems.

The sequencing of problems also affects student success. Increasing problem difficulty at too fast a rate stifles or reduces the number of criteria students demonstrate. Problem 2 is an example of this in the Forestry course and it becomes evident when students needed to demonstrate a criterion a second time. In this course, the second problem is much more difficult than the first and more difficult than the third. This is in contrast to the Math/Econ course in which problem difficulty rises smoothly through the first three problems before stabilizing at the fourth. What the results show is that the type of sequencing used in the Math/Econ course is associated with a pattern in which mastery occurs more quickly with a plateau reached earlier compared to the Forestry course. The latter had the most difficult problem placed second and showed a "shallower" learning curve through the second problem.

The challenge that students face with a difficult problem is amplified when two demonstrations are required (see Figure 2). If students are marginally competent at a given criterion, it is more likely that they will fall below the minimal competence if they have to demonstrate it several times using different theoretical and technical content. For example, a Math/Econ student who successfully demonstrates her ability to predict the financial attractiveness of multiple solutions to a given problem may fail, in the next problem, to do the cognate task of assessing the sustainability of several problem solutions because of the latter's greater technical complexity. Table 4 shows that student learning in the Math/Econ course increased from 49.6% in Attempt 2 to 80.3% at the conclusion of Attempt 3 and this increase of 30.7% is 6. 0% greater than the 23.9% increase observed with student performance between the second and third Forestry problems (25.9% to 49.8% respectively).

While elaboration theory suggests increasingly difficult problems need to be used, Scardimalia and Bereiter (1994) indicated that as expertise develops, skills and concepts that were initially challenging become routine, thereby freeing up mental capacity for further development. One of our challenges as teachers is to determine if and how we can enhance the rate of learning as students progress through the course, and maintaining an appropriate developmental incline is one component of this.

In both the Forestry and Math/Econ courses, prompt criterion-referenced feedback was provided to students. We believe that the substantial increase in the number of abilities demonstrated between the first and second attempts is partly due to the feedback students receive relative to the criteria. They learn what they need to "know and do" to be successful and try to do it since there is close alignment between the criteria, the outcomes, and the grading scheme. This would be consistent with the findings of Black and William (1998) and Gibbs and Simpson (2004).

Repeated demonstration of the criteria was important for us to be comfortable that students had reliably mastered the outcomes. The 'percentage of criteria demonstrated' data presented for both courses showed differences in criterion mastery when the standard for mastery required two demonstrations rather than one. Figure 2 shows that for the Forestry course, the 2X learning curve is linear and continues to increase without a plateau or leveling off. This suggests that more attempts may be needed so students can integrate what they know and focus on fulfilling criteria they struggle with.

We can conclude from the results of our analysis that providing only two attempts to master learning in both the mathematics and forestry courses is insufficient and would result in students demonstrating a much lower level of ability by the end of the course than providing four attempts. With only two attempts (e.g. a mid-term and final examination), students in Math/Econ would have demonstrated 91.0% (average) of criteria at least once but only 49.6% twice. It took Math/Econ students on average four attempts to reach 85.5% of criteria demonstrated twice, though the difference between Attempt 3 and Attempt 4 was not statistically significant. This implies substantial growth and more certain mastery of the criteria in the third attempt and less so in the fourth. A different pattern is evident for Forestry, where the average student demonstrates 88.5% of the criteria once for the SIP outcome and 68.4% twice after four attempts, with statistically significant growth on all attempts when two successful demonstrations are required to achieve mastery.

Our results indicate that in some cases, mastery of a high proportion (e.g., over two-thirds) of the criteria requires at least four and maybe five attempts when mastery is defined as demonstrating criteria twice. Clearly, the rate of getting to mastery is affected by problem difficulty and sequencing. Although not obvious by the data presented here, student performance was also affected by the difficulty of the individual criteria. Anecdotal student comments indicated that certain criteria in both courses were simply harder to understand and fulfill than others, and more attempts to reliably demonstrate them were required. For example, in the forestry course, providing "reasonable yield predictions" was difficult for many students. For those criteria where the standards are too high, student performance starts off lower and grows at a slower rate. As such, one of our challenges as instructors of this course is to establish criteria that are challenging but attainable given the time, energy, and constraints faced by both students and instructors. Some of the ways we can do this are by simplifying, clarifying or illustrating the criteria more fully, reducing the expected performance level by relaxing our standards, being more precise about criteria so students know exactly what to do, or subdividing criteria into more sub-criteria. This latter approach was used in the Forestry course and had been integrated into the course syllabus before the period studied here. The number of criteria was doubled with half being inclusion of an item and half being a requirement that those inclusions be "reasonable" (Table 2). While this increased the number of criteria students needed to demonstrate, it also reduced complexity of individual criteria and was simpler for students. A final strategy can be to reduce the number of learning outcomes dealt with in the course to allow for more time and effort to be devoted to the remaining ones.

Conclusion

Overall, we found both similarities and differences in learning patterns from two dissimilar courses in two unrelated faculties with very different learning outcomes and students. One of the similarities was that students' ability to demonstrate outcome criteria increased rapidly at first and then declined with an increasing numbers of attempts. Differences included the presence of a plateau in student learning after Attempt 3 in the Math/Econ course and the absence of a plateau in the Forestry course. Additionally, the absolute level of the student performance was higher for the Math/Econ course and, finally, that the slope of the Math/Econ course was initially higher than for the Forestry course.

Course-related factors which may have affected the precise shape of the performance curve included problem difficulty, problem sequence, criteria specification, and the number of times students had available to demonstrate them. Since the students were different in the Math/Econ and Forestry courses, performance differences may simply be due to inherent differences in the students themselves.

Difficult problems limit the number of criteria students demonstrate and, as a consequence, more attempts are required for students to reach mastery. Problem sequencing interacts with problem difficulty to affect mastery. In the Math/Econ course, where problem sequencing followed a smooth developmental incline through the first three problems followed by a leveling off in the fourth problem was associated with a more rapid and higher level of mastery before a plateau was reached than in the Forestry course which had a more difficult problem placed earlier in the course (Problem 2) and was associated with lower and slower learning. However, the difference in demonstrated ability in the two courses is evident from the very first problem and therefore cannot entirely be attributed to the second problem in the Forestry course. It is possible that the first problem in the Forestry course was inherently more difficult than the first problem in the Math/Econ course. It is also possible that the two student populations also had inherent differences such as entering grade point averages. Lastly, the forestry course required a higher level of prior technical knowledge and was placed in the third year whereas the Math/Econ course was placed in the first year and had no specific prerequisites. Further research would be required to tease out the relative importance of these features and the interactions among them. However, the results presented here suggest that at least five attempts will be needed to reach a plateau in the Forestry course. Providing fewer attempts clearly means

DOI: http://dx.doi.org/10.5206/cjsotl-rcacea.2012.1.4

some criteria will not be mastered by a significant proportion of the class (e.g., one-third). Three attempts were needed in the Math/Econ course.

The finding that sufficient attempts are needed in order for students to demonstrate mastery learning is consistent with the literature on the role of practice in student learning in higher education (e.g., Myers & Myers, 2007). It would be helpful in subsequent research to determine why and how additional practice helps students learn, something that this study by its quantitative nature could not assess. This would involve an investigation of how students experience our approach to learning, and which of the course structures and practices lead to the learning that is reflected in increasing mastery.

In this paper, we have presented class-level data only. It would also be interesting to investigate the distribution of individual performance in the class. For example, it would be interesting to know why some students learn very quickly, some more slowly, and some almost not at all. This could point the way to course designs in which individual students receive additional help when they demonstrate slow initial growth patterns.

Two other important questions that this work raises are the issue of long-term retention and transferability. Future work should critically and systematically examine whether and to what extent this is achieved. Specifically, the question is whether the probability of demonstrating the criterion in repeated attempts in one course is a good predictor for the ability of the student to demonstrate the criterion again later (e.g., in five years) in similar contexts or to transfer it to other domains (e.g., in community problem solving rather than economic decision making).

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DOI: http://dx.doi.org/10.5206/cjsotl-rcacea.2012.1.4