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Teaching Quantitative Skills Using Repeated Problem Solving Exercises Combined With Explicit Learning Outcomes

Abstract

"Practice makes perfect" is an old adage. The question is: what is the relationship between the amount of practice and the level of perfection achieved? This paper presents a cyclical teaching approach used in an undergraduate course that provides initial exposure to mathematical and economic reasoning using a problem-based approach involving finite mathematics and basic competence in economic principles. Students were assessed in the following areas: problem definition, solution formation and implementation, solution evaluation, and monitoring. Students were allowed repeated attempts in the form of word problems requiring use of mathematical models to provide evidence that explicit learning outcomes were met. It was found that repeated cycling through the same, explicitly defined problem solving and mathematical modelling process led to a gradual improvement. Detailed criteria were listed under each of the two major outcomes and students were provided with a check mark for each skill that was demonstrated and with detailed feedback on their performance. Each student was required to demonstrate each skill at least twice. The student's final grade was based on the proportion of abilities demonstrated. Data showed that students improved with repeated cycling, and furthermore, that students continued to demonstrate these abilities in subsequent attempts. The mean data showed a 58% improvement in economics knowledge, a 45% improvement in math modelling, and a 33% improvement in problem solving abilities. Individual data showed that even those students who demonstrated limited abilities on a first attempt were able to successfully demonstrate the ability by the last attempt. The findings suggest cyclical teaching helps to achieve demonstrated outcomes and that practice does indeed lead to perfection.

Introduction

Renaissance College is the University of New Brunswick's leadership school. It offers an intensive Bachelor's of Philosophy program in interdisciplinary leadership studies designed for highly capable learners. Generally the students who enter the program are gifted and are used to a traditional high school grading system where many of them are at the top of their class. Generally, the students who enter the program are focussed on arts/humanities/social sciences and less frequently on quantitative and economic areas. One of the required courses is RCLP 1052, Mathematical and Economic Approaches to Problem Solving (MATH/ECON). The course provides initial exposure to mathematical and economic reasoning, primarily through a problems-based approach using finite mathematics and basic economic principles. The operational system that students are used to seeing in high school is very different than the

problem-based system used in the RCLP 1052 course. Specifically, students face three important transitions from the humanities to the mathematics area: 1) the change from the traditional grading system to an outcomes based grading system, 2) the leap between qualitative and quantitative learning, and 3) the assessment of growth in knowledge.

Background and Approach

According to elaboration theory, instruction should be organized in increasing order of complexity for optimal learning. The goal of elaboration theory is to select and sequence content in order to optimize learning. The theory uses epitomes that present the simplest form of an ability and then working up repeatedly by adding the factors or dimensions that make the problem more complex. This idea for sequencing and organizing courses of instruction is one of the most widely used theoretical innovations in instructional design (ID) (Wilson and Cole, 1996). The theory consists of seven major strategic components (Reigeluth and Stein, 1983): an elaborative sequence, learning prerequisite sequences, summarizers, synthesizers, analogies, cognitive strategy activators, and a learner control format. For this paper, the focus is on the elaborative sequence component of elaboration theory. Elaborative sequence suggests that instruction follow a simple to complex sequence with early lessons containing fundamental ideas at a concrete skill level. Layers of complexity are then added sequentially for theoretically organized instruction.

In the MATH/ECON class, the first problem is the epitome. It requires the construction of a mathematical model and its use to solve a simple problem. Table 1 gives problems with the associated learning objectives. Students are provided mathematical indicators (cash flow and ending bank balance) of a single parent family on income assistance. Their goal is to determine if it is financially feasible for the breadwinner of this family to go to work. The focus of Problem 1 is building a model and walking through the steps of the structured problem solving process. In the second problem (Table 1), students are provided indicators again (present net worth and benefit/cost ratio), but are required to do some research about the nature of the problem—comparing horse logging to mechanized logging—thinking about some conceptual ideas like the time value of money in relation to concepts used in the class. Again, they build a model and walk through the problem solving process. In the third problem, students are asked to develop indicators of social, economic, and environmental sustainability—to move from an abstract concept like sustainability to concrete mathematical indicators (Table 1)—again they have to build a model and walk through the problem solving process. In each case students are provided summative and formative feedback referenced to the criteria established at the beginning of the course. The problems presented in MATH/ECON have been found to be very challenging for the first term of a first year undergraduate program.

Problem	Description	New Skill	Theoretical Concepts
1	Determine whether a family on social assistance would be better off if the single parent were to go to work versus remaining on assistance (time horizon – one year).	• Build a mathematical model with spreadsheet software • Use the model to help make the best decision • Follow structured problem solving approach	• Revenues minus costs must be greater than zero in the long term • Understand relationship between financially "better off" and other quality of life indicators (e.g. medical/dental coverage)
2	Determine whether it is more financially attractive for a logging contractor to use horses or high-tech mechanized equipment to harvest a given volume of wood over a 5-year period.	• As above • Integrate economic theory with mathematical model	• Time value of money (compounding and discounting) • Use of financial indicators (benefit-cost ratio, net present value)
3	Develop quantitative indicators to determine whether horse or mechanized logging is more sustainable in 3 dimensions: • Social • Environmental • Socio-economic	• As above (problems 1 and 2) • Work in a group to solve a problem • Prepare an oral presentation based on quantitative data • Move from broad concept to quantitative indicators on their own	• Sustainability according to Brundtland Commission • Value added generation as a measure of socio-economic sustainability • Quantitative indicators and their strengths and limitations

Table 1: Description of Three Problems

The classic model of teaching focuses on coverage of subject matter. Topics are discussed in a lecture or lab, a test is given, and the lecturer moves on to the next topic until the final exam where students see the subject matter again. This results in students receiving two attempts at demonstrating competence, with only one opportunity for formative feedback. In addition, the feedback often reflects the impressions of the faculty member and what struck them about the

work rather than criterion-referenced feedback that tells the student what to do for the next attempt. An outcome-based assessment approach addresses some of the limitations of the classic model (Zundel et al., 2000) by providing clear behavioural criteria and cycling through repeated attempts at demonstrating competence in them.

The MATH/ECON course was designed with explicit learning outcomes that were clearly described (e.g., solving complex problems, developing mathematical models). Students were provided a description of the outcomes and a Problem Solving/Mathematical Modeling grading sheet the first day of the course. The types of outcomes described for math modelling and problem solving are shown in Table 2. Economics knowledge was measured using three quizzes throughout the term.

Assessment of the specific outcomes consisted of evaluating student performances of particular behaviourally described outcomes. It has been shown that assessment must include appropriate feedback in order to indicate to a student how he or she is doing from an outside (from themselves) perspective and that "giving feedback reconnects the judgement with a learner" (Alverno College Faculty, 1994). Assessment included detailed explicit criteria with the assignment and feedback referenced to the criteria after each attempt. Students were assessed by demonstrating the required criteria a pre-determined number of times—for economics knowledge it was once, for mathematical modelling and problem solving it was twice. Once students demonstrated the given learning outcomes the required number of times, they did not have to make further attempts.

	Outcome
Math Modelling	1. Calculate indicators of financial attractiveness correctly
	2. Use time value of money formulae correctly
	3. Make appropriate inferences about project using indicators of financial attractiveness.
	4. Create a spreadsheet model to carry out analysis on the economics of projects.
	5. Use the model to carry out sensitivity analysis
Structured Problem-solving	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

Table 2: Outcomes indicating competence in mathematical modeling and problem solving

Results

Growth in Abilities

Figure 1 gives the percent of abilities demonstrated for each outcome of each problem. When examined across attempts, Figure 1 illustrates the mean improvement in economics knowledge, math modeling, and problem solving by all students. The proportion of abilities was similar across the three outcomes in Attempt 1. A dramatic increase in the proportion of abilities demonstrated is seen between Attempts 1 and 2, particularly in the economics knowledge. This is not surprising as the economics knowledge outcome is low on Bloom's taxonomy (recall, definition, application) and the assessment of this outcome was different than that of math modeling and problem solving. The economics knowledge was assessed using in-class quizzes rather than a problem based approach. The increase in growth is less between Attempts 2 and 3. The growth from Attempts 2-3 seems modest, but individual data shows a range of patterns. In addition, the score for Attempt 3 is actually a cumulative score and includes any rewrites. The third attempt also builds upon previous skills although the problems get more difficult over time. Therefore the performance shown in Figure 1 is actually an underestimate of learning. The data shows that from Attempt 1 to Attempt 3 there was a 58% increase in the abilities demonstrated in economics knowledge, a 45% increase in the abilities demonstrated in math modeling, and a 33% increase in the abilities demonstrated in problem solving.

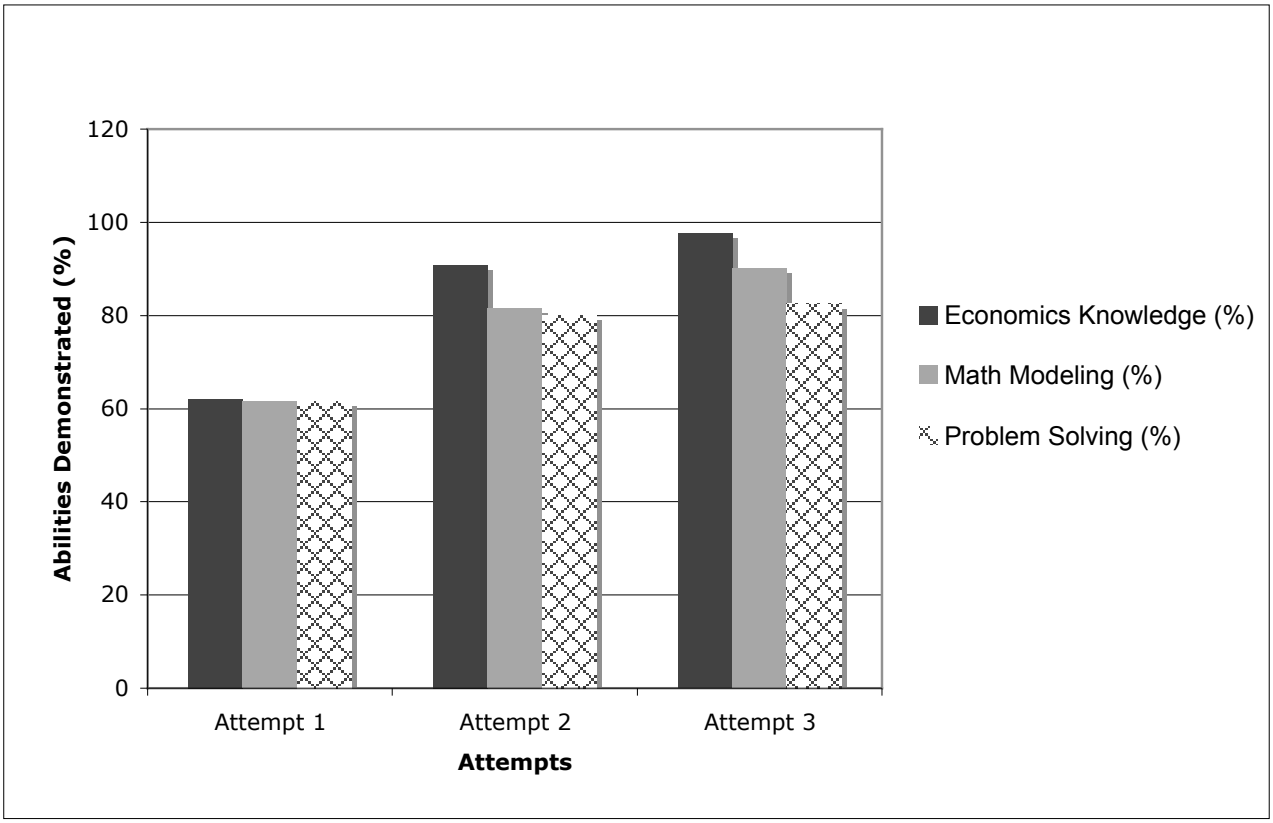

Figure 1: Percent Abilities Demonstrated Across Each Growth Ability

The larger jump from Attempt 1 to Attempts 2 and 3 are indicative of the significant feedback that the students received. The grading sheets provided a significant amount of criteria based feedback. We noticed that students made greater effort for help outside class time and during tutorials after receiving feedback on Attempt 1 as compared to before submitting the first assignment. The first assignment and the feedback provided gave them detailed information on how to achieve success at each of the three abilities. A sample feedback sheet provided to a student after Problem 1 is shown in Figure 2.

Outcome	Criterion Description	Adequate	Comments
Math Modelling	1. Calculate indicators of financial attractiveness correctly.	√	
	2. Use time value of money formulae correctly.	√	
	3. Make appropriate inferences about project using indicators of financial attractiveness.	√	
	4. Create a spreadsheet model to carry out analysis on the economics of projects.	*Partly*	
	5. Use the model to carry out sensitivity analysis.	*Not evident*	
Structured Problem-solving	1. Rephrase or describe problem accurately.	*Limited*	*The problem could be described more fully.*
	2. Identify constraints, objectives and resources.	*Limited*	*There was mention of constraints within assumptions, however the terms were not differentiated.*
	3. Define key terms subject to ambiguity.	*Not evident*	*No ambiguous terms were defined.*
	4. Define several possible solutions.	*Limited*	*One solution was analyzed in the spreadsheet.*
	5. Predict performance of each solution in terms of objectives and constraints.	*Limited*	
	6. Select optimal solution.	*Limited*	
	7. Identify assumptions and predict their effects on the solution.	*Limited*	*A good attempt to identify assumptions and predict their effects. However, towards the end of your analysis you made the opposite assumption and did not provide enough detail on their effects.*
	8. Reflect on what parts of solution process or product were best/worst.	*Partly*	*Ask yourself what part of the process you think you would address differently for the next project and comment on those thoughts.*
	9. Identify what personal skills or knowledge limited or helped most during implementation.	√	

Figure 2: Sample Problem 1 Grading Sheet

Individual Data–Economics Knowledge

Figure 3 shows how 3 different students performed in the Economics Knowledge ability over three attempts. These data illustrate the degree of variation in the way different students learned the information. The data is based on performance on three quizzes. Student #1 demonstrates few abilities on the first attempt, demonstrates a greater proportion of abilities on Attempt 2 and has a slight drop off at Attempt 3. Student #2 clearly has achieved the skills early (Attempt 1) and stays strong through Attempts 2 and 3. Student #3 demonstrates limited abilities on Attempt 1, displays further abilities on Attempt #2 and clearly masters the skills on the third attempt (87.5%) achieving competence.

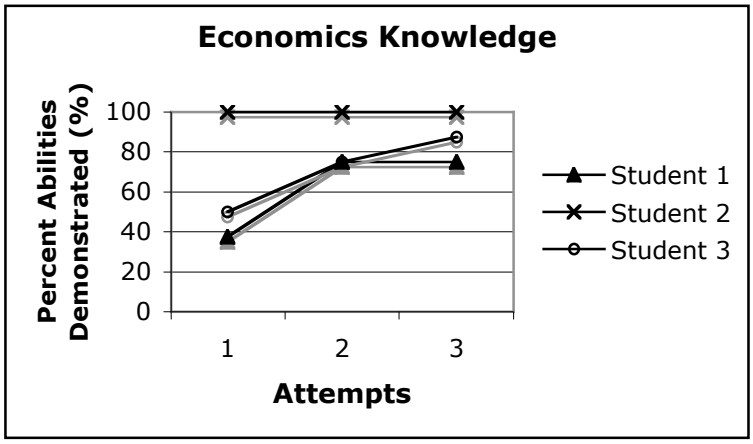

Figure 3: Individual Data for Economics Knowledge Growth Ability

Individual Data–Math Modeling

Figure 4 illustrates the same three individuals' data for math modeling which is more variable than economics knowledge. This is most likely because this is a more difficult ability. Student #1 demonstrates limited abilities on Attempt 1, demonstrates more abilities on Attempt 2 and masters the skills on Attempt 3. Student #2 demonstrates a good proportion of the abilities on Attempt 1 (80%) and demonstrates theses abilities successfully on Attempts 2 and 3. Student #3 demonstrates a good proportion of abilities on Attempt 1 (80%), however this student has a significant decrease in Attempt 2 and then an increase for Attempt 3.

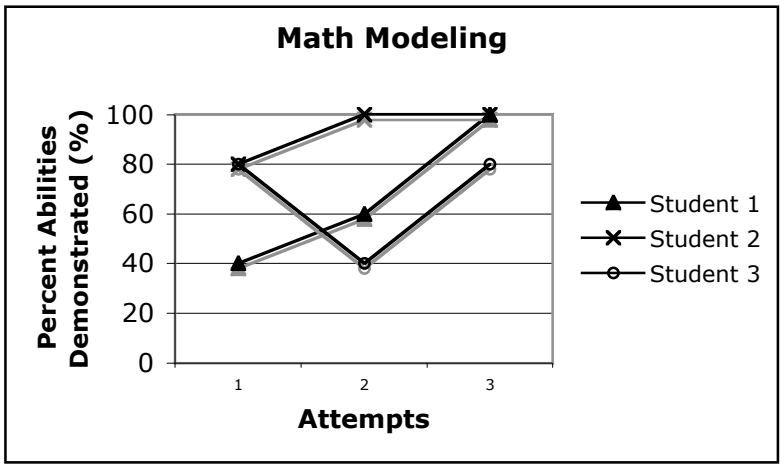

Figure 4: Individual Data for Math Modeling Growth Ability

Individual Data–Problem Solving

Figure 5 illustrates the same three individuals' data for problem solving. This data is similar to the math modeling data. Student #1 starts with limited abilities demonstrated on Attempt 1 and is able to demonstrate more skills on Attempts 2 and 3. However, notice that this student had a much greater growth in math modeling (Figure 4). Student #2 is strong throughout the attempts (similar to their data in Figures 3 and 4). Student # 3 demonstrates limited abilities on Attempt 1, drops significantly on Attempt 2 and then returns to the level that they started at. Student #3 displays the same trend for math modeling (Figure 4), however the percent of abilities demonstrated is much lower for problem solving.

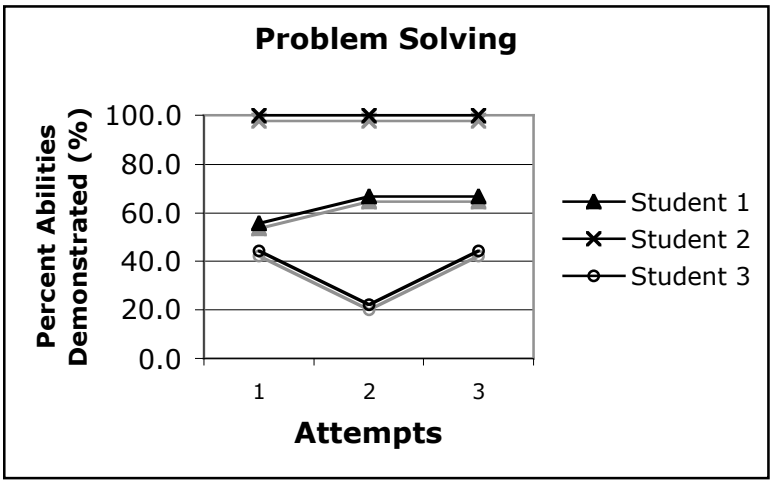

Figure 5: Individual Data for Problem Solving Growth Ability

The individual data suggests at least three scenarios of student performance. The first scenario is that students understand the information early and retain their skills through the various problems (Student #2). The second is that a student may demonstrate the information early on

one attempt, but is not able to retain the skills for demonstration on subsequent attempts (Student #3). The third scenario is that a student may require time to obtain the skills, however overall they are able to finish much better than if they had only had two attempts (Student #1).

Student Perception Versus Observed Growth in Ability

In addition to the grading sheets, students were provided with a survey at the end of the course to measure their perception of the course in each growth ability. One of the questions that was asked of the students was, "Which outcome do you feel you learned the most about?" Twenty-three responses were collected and this data is shown in Figure 6. Students clearly felt that they grew most in economics knowledge and this matches what we observed in the demonstration opportunities (see Figure 1). In their individual comments, students expressed some uncertainty about their ability to judge as clearly the level of learning in problem solving and math modeling compared to economics knowledge. This is to be expected as economics knowledge is low on Bloom's taxonomy (recall, definition, application) and is formal declarative knowledge—factoids and concepts. Problem solving and math modeling involve procedural knowledge and are harder to assess success in. In addition, the difficulty level in problem solving and math modeling problems increased substantially in a short period of time (see Table 1) while the economics knowledge was kept constant. This might have led some students to feel that they knew more about the economics than about problem solving and math modeling.

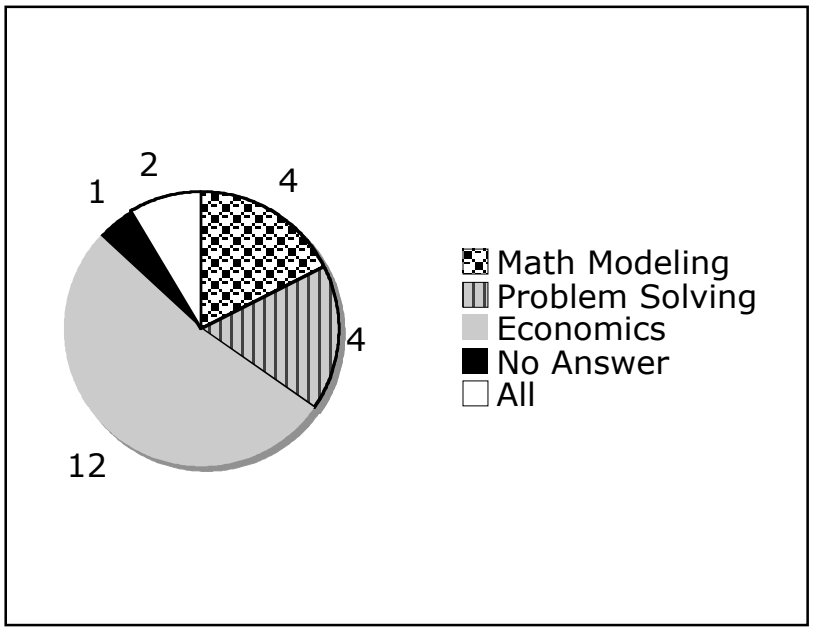

Figure 6: Student Perception of Outcome Learned Most About

Instructor Grading Load

One of the concerns of assessing specific outcomes over several attempts is the workload for the instructor. Examining the number of questions that were evaluated over the three quizzes provided a rudimentary indicator of grading load called "person-question." The "person-question" involves grading one question on one person's test. Therefore, if 10 students write 3 answers each, this represents 30 person-questions. Students were required to demonstrate their abilities a set number of times which decreases the marking load as students demonstrate an ability (Figure 7). This is an advantage for the instructor and tends to mitigate the additional workload associated with providing multiple demonstration opportunities. Once a student demonstrates an ability, the instructor does not mark those ability-related questions in subsequent attempts.

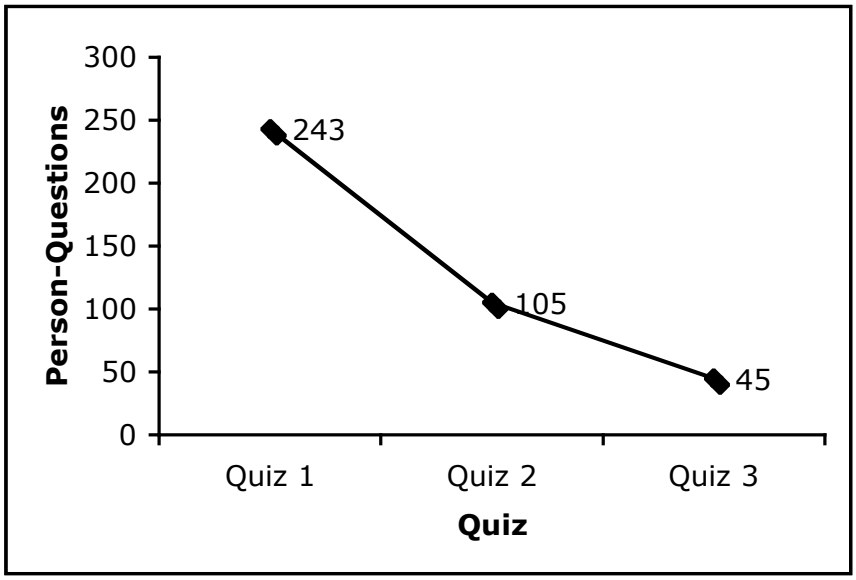

Figure 7: Grading Load

Discussion

Generally, it was found that students improved with repeated cycling and continued to demonstrate abilities in subsequent attempts. One of the challenges of this type of instruction is that it can be difficult to explain the grading system to students. It also requires significant commitment on the part of the instructor in order to set up multiple demonstrations. The amount of time that is required in the set up also impacts the overall volume of material that can be "covered" and requires that the instructor accept that some coverage will be given up in favour of durability of learning. It was also found that the students found it difficult to self assess the course material. In addition, some students were not challenged in this system since they may obtain the skills early in the process. However, this is also a benefit to those students, as they could elect to transfer their time into some other subject area resulting in improved time management overall.

The benefit of this type of instruction is that overall there is more learning and better retention of concepts. This is shown in the ability of students to build on previous knowledge and continually demonstrate the outcomes. The requirement to demonstrate abilities multiple times also compensates for the apparent lack of student incentive to do well early. The advantage of using a grading sheet with clear outcomes and providing significant feedback to students is that they are able to see their learning and have a map of the learning objectives. While the majority of the students in this class were humanities majors, Figure 1 clearly shows that by the end of the course approximately 90% of the class demonstrated the mathematical abilities indicating that they were successful in transitioning from the arts to mathematics.

Conclusions

This study found that, on average, students improved with repeated cycling and continued to demonstrate their abilities in Mathematical and Economic Approaches to Problem-Solving, an undergraduate course. Three outcomes were assessed in the course: mathematical modelling, structured problem solving, and economics knowledge. It was found that repeated cycling through the same, explicitly defined problem solving and mathematical modelling process led to a gradual improvement. It was also found that the instructor's grading load decreased over time. Finally, the students' perception was that they learned the most in the economics knowledge ability, however the data clearly shows that they improved in all three abilities. The findings suggest that the cyclical teaching approach provides sufficient opportunities for students to demonstrate competence in defined outcomes and achieve success.

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