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## Active Learning in Computer-based College Algebra

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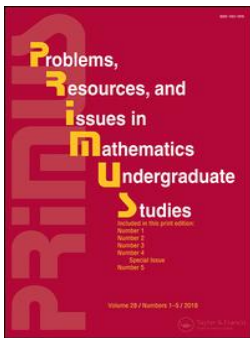
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# Active Learning in Computer-based College Algebra

Steven Boyce  and Joyce O'Halloran

**Abstract:** We describe the process of adjusting the balance between computer-based learning and peer interaction in a college algebra course. In our first experimental class, students used the adaptive-learning program ALEKS within an emporium-style format. Comparing student performance in the emporium format class with that in a traditional lecture format class, we found an improvement in procedural skills, but a weakness in the students' conceptual understanding of mathematical ideas. Consequently, we shifted to a blended format, cutting back on the number of ALEKS (procedural) topics and integrating activities that fostered student discourse about mathematics concepts. In our third iteration using ALEKS, we made use of ALEKS-generated data to design peer-to-peer activities that matched student progress.

**Keywords:** College algebra, technology, procedural and conceptual knowledge

## 1. INTRODUCTION

Mathematics education research in the last few decades has provided evidence of the benefits of supporting elementary and secondary students'

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active engagement in learning mathematics. Recently, the Conference Board of the Mathematical Sciences (CBMS) has concluded that *active learning* should be part of lower-division undergraduate mathematics courses [2]. The CBMS defines active learning broadly, to include “[c]lassroom practices that engage students in activities, such as reading, writing, and discussion.” Although some students (and perhaps a majority of mathematics professors) may be actively engaged in constructing mathematics while attending a lecture, research suggests that many students’ engagement during lecture is passive [7], particularly students in underserved populations such as women or minorities [10].

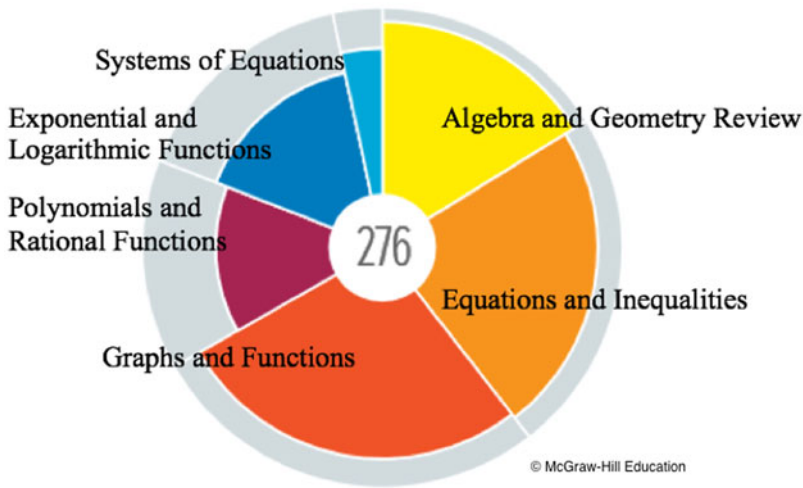
Incorporating *active learning* in mathematics classrooms involves replacing the traditional lecture model with one that supports productive student interactions. For example, norms for mathematical communication may be modified to support students’ engagement in mathematics involving explaining to peers, conjecturing, or justifying. Active learning also involves the consideration of productive intra-student activity, which includes students’ mathematical thinking, students’ written reflections, and students’ working on tasks individually. Although the varieties of tasks that students encounter may focus particularly on procedures, applications, or concepts, each offers opportunities for active learning.

In this paper, we describe a three-term progression at Portland State University (PSU) for replacing a lecture format for a College Algebra course to support students’ active learning. We describe how the interactions among students, the curricula, and the instructor changed during each of the iterations. In a first experimental section, students used the adaptive-learning program ALEKS (<http://www.aleks.com>) within an emporium-style course. In the next version, the instructor adjusted the topics and sequencing of topics in ALEKS to make room for problem-solving sessions focused on mathematical concepts. In the third version, the instructor began to integrate data from ALEKS within the topics of the problem-solving sessions and negotiated classroom norms valuing mathematical discourse. We discuss lessons that were learned along the way, outcomes for students, and the next steps.

## 2. BACKGROUND

### 2.1. Computer-based Learning and ALEKS

A computer-based learning (CBL) environment is defined broadly as an educational environment in which computers are a key component of the educational environment. Two widely-used CBL platforms in undergraduate mathematics courses are Pearson’s MyMathLab (



*Figure 1.* Sample ALEKS pie.

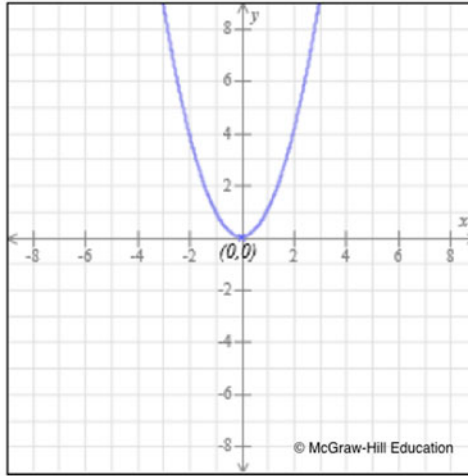
[mymathlab.com](http://mymathlab.com)) and McGrawHill’s ALEKS. ALEKS is the acronym for Assessment and LEarning in Knowledge Spaces. It was initially developed at the University of California, Irvine, as the result of formulating hierarchical dependencies of mathematics curricular proficiencies and implementing adaptive computer-based assessments to assess students’ mastery of elementary and secondary mathematics. It is now used for mathematics placement testing and for internet-based content delivery ([https://www.aleks.com/about\\_aleks](https://www.aleks.com/about_aleks)).

PSU initially started using ALEKS for mathematics placement testing. Immediately after implementing placement testing using ALEKS, our department noticed improvement in lower-division mathematics courses [4]. This led to some CBL sections of developmental (pre-college) courses using ALEKS; compared with traditional lecture sections, the CBL sections had higher student retention rates. These parallel successes motivated us to offer CBL courses in College Algebra using ALEKS.

The ALEKS pie (Figure 1) is a tool for displaying student progress. The pie in Figure 1 indicates that a student has completed a total of 276 topics. The student has the most remaining work to complete in the domains of “Polynomial and Rational Functions” and “Exponential and Logarithmic Functions.” There is a pie chart for each student, and the instructor can also view a class average pie chart. Underlying the ALEKS pie is a web of probabilities of student mastery, computed from student responses and the proprietary knowledge space theory [3]. The instructor chooses particular topics and prerequisites to include in a

Below is the graph of  $y = x^2$ .

Translate it to make it the graph of  $y = (x+3)^2 + 1$ .



*Figure 2.* Example topic in ALEKS.

course; the software determines the relationships between the topics so that students can encounter topics that they are “ready to learn.”

“Topic” is the ALEKS word for exercise/exam question. “Assessment” is what we might call an exam; however, assessment plays a greater role than typical exams do, in that topics on which a student is unsuccessful during an assessment are listed for further study and re-assessment at a later time. Topics selected for use in the course include “course topics” and “prerequisite topics.” For example, prerequisite topics for exponential functions would include algebraic properties of exponents. The topics in ALEKS are assessed with free-response question types that go beyond fill-in-the-blank items; for instance, consider the topic (translating the graph of a function) shown in [Figure 2](#).

ALEKS includes online assistance, so students can access online resources to help them on exercises that are not clear to them. ALEKS provides feedback immediately after completing a topic. A student can get the answer and an explanation for completing an exercise, including instruction on how to check an answer (see [Figure 3](#)). The quick feedback provides an opportunity for students’ autonomy in their learning. Students can proceed non-linearly, allowing them to move between topics they find straightforward and those they anticipate will take more time to master.

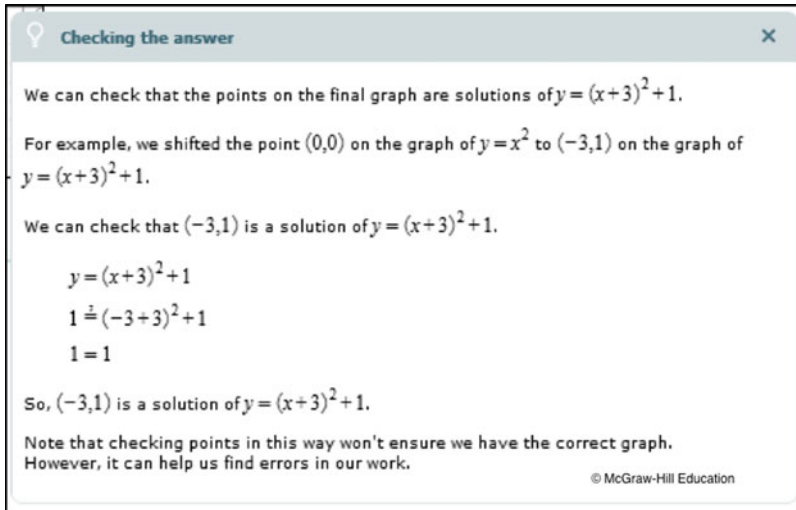


Figure 3. Sample explanation of checking an answer.

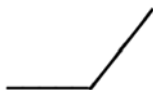
## 2.2. Math Emporium Format

Implementation of a CBL approach can take multiple forms. A Math Emporium (ME) format is a CBL approach that replaces lectures with interactive software and on-demand personalized assistance. First established at Virginia Tech in 1997 [11], there are now many variants of ME throughout the country [9]. The main differences in ME implementation are whether attendance is required or flexible and the ways that lectures are replaced by other forms of personal interactions.

Benefits to students of ME courses include online assistance, instant feedback, and self-pacing. Such benefits can lead to higher pass rates for some students [12]. However, concerns about the appropriateness of the ME format for college students remain. In a series of papers, Krupa, Webel, and McManus researched the outcomes of a college algebra ME employing the use of MyMathLab. They found that:

students with high incoming math SAT scores were advantaged [on their final exam] by being placed in a [Math Emporium], while students with lower incoming math SAT scores performed better when they were placed in face-to-face classes [6, p. 16].

They also found that the emporium improved students' ability to recall and use formulas for familiar task types, but it had limited impact for helping students to develop meanings for symbols or abilities to solve similar tasks in new contexts.



*Figure 4.* Graph of continuous piecewise growth.

### 2.3. Procedural and Conceptual Knowledge in College Algebra

As noted in [13], there is ample evidence in the mathematics education research literature that “instructional approaches emphasizing procedural knowledge at the expense of conceptual understanding results in student knowledge that is inflexible, difficult to retain, and in some cases, mathematically flawed” [p. 360]. Moreover, becoming proficient with the tools of mathematics independent of underlying concepts can lead students to believe that mathematics consists entirely of tool-mastery and that a question embedded in a particular context is to be addressed by choosing the “correct” tool and applying it. If your only tool is a hammer, all you see are nails! Conversely, mistaking screws for nails may prompt you to grab a hammer when a different tool is called for.

A stumbling block for many mathematics students is the tendency to grab the first tool that comes to mind or grab the right tool by the wrong end [13]. As a result of interaction and reflection, these can be learning opportunities for students. Consider the following precalculus activity that was designed to engage students in thinking about piecewise functions:

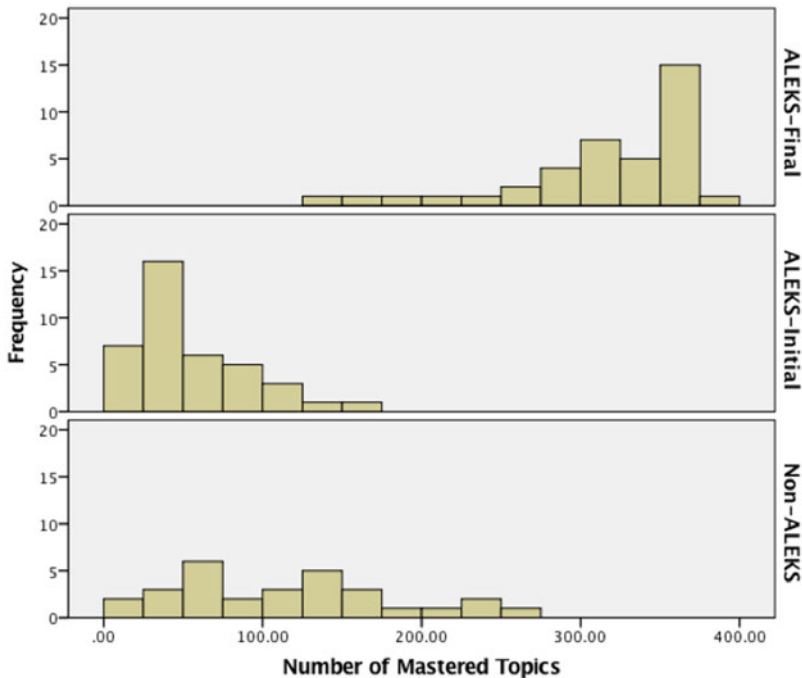
*Activity:*

A parking lot charges \$3 for the first hour and \$1.50 for each hour or partial hour thereafter. Draw a graph which shows the amount paid in terms of time.

In our experience, students often correctly graph points corresponding to the amount paid at the end of each hour and recognize that the dots (starting in the second hour) lie along a line. They next grab their “linear tool” and draw a line with slope 1.5. This makes sense to them in terms of the phrase “\$1.50 for each hour”. They conclude that, after the first hour, the function is linear, and thus draw the graph shown in [Figure 4](#).

If students are expected to display these graphs and explain their reasoning, their reflection on the product of their mathematical activity can foster a rich opportunity for introducing step functions and developing students’ *concept* of linear function. We view “conceptual understanding” as “understanding and interpreting concepts and the relations between





**Figure 5.** Comparison of ALEKS end of course, ALEKS beginning of course, and non-ALEKS end of course performance on an ALEKS knowledge-check.

concepts” [1] and “to know *why* something happens in a particular way” [5]. As we implemented the emporium format course, we were concerned that the students who were interacting with the ALEKS curricula would not have ample opportunities to develop their conceptual understandings of key prerequisite topics for calculus.

### 3. ITERATION 1: PURE EMPORIUM FORMAT

At PSU, precalculus is a two-quarter sequence consisting of a College Algebra course followed by a trigonometry course. In Fall 2015, we tested an ME implementation of ALEKS in the College Algebra course. The topics concentrate on polynomial, exponential, and logarithmic functions; manipulating them: combining, translating, finding inverses; and problem solving involving these functions. Our ME classes were synchronous: all of the students who were registered for a class met in a computer lab at the same time. A maximum class size of 40 was maintained for the College Algebra sections.

In the initial ME implementation, all of the students' work was individualized within the ALEKS system. Students were expected to maintain a pace of completing at least 10% of the 405 course topics each week of the 10-week course, either during class time or as homework. We required students to create notebooks that included scratch work and notes to themselves about approaches to topics, and we periodically checked that students were maintaining their notebooks. We also allowed them to use notes on proctored assessments (a limited number of pages, typically consisting of reminders to themselves about procedures that they thought they might not remember correctly). Allowing notes on assessments encouraged students to review for assessments, and it is typical in our department to allow use of notes on exams.

### 3.1. Assessing Student Outcomes

We collected three types of data to understand student outcomes in the emporium format. We administered a paper-and-pencil assessment to students in the emporium section that had been used as a first midterm in a non-ALEKS section of the course. We also administered an ALEKS knowledge check to students in that non-emporium section, at the end of the term. Lastly, we compared final course grades in the College Algebra course and two downstream (subsequent) mathematics courses.

Across the two course formats, student outcomes were similar in terms of final course grades: both grades in College Algebra and students' enrollment and performance in subsequent mathematics courses (Trigonometry and Calculus I) were not substantially different across the two course formats. For instance, 78.1% of students using ALEKS and 77.2% of students not using ALEKS passed College Algebra with a grade of C- or above; of those students who continued on to enroll in Trigonometry and Calculus I, 78% of non-ALEKS students were subsequently successful in Calculus I, and 80% of ALEKS students were successful in Calculus I. However, the performance on the two common assessments revealed differences in the mathematics that the students were learning in College Algebra.

Comparing the histograms in [Figure 5](#) reveals that students in the non-ALEKS section did not perform as well on the ALEKS aspect of the common assessment: their mean performance of 114.5 topics learned more closely matched the performance of the ALEKS students on their "initial knowledge check" (mean 56.2 topics) than the mean of the ALEKS students on their "final knowledge check" (mean 315.7 topics). Note that as part of the ALEKS knowledge check assessment, students first complete a tutorial on entering responses and using calculators and graphing tools within ALEKS. PSU's use of ALEKS for placement testing also offered

students previous exposure to ALEKS. Still, it is possible that lack of familiarity with the format may have negatively influenced the performance of some students in the non-ALEKS section on the ALEKS assessment.

Examining the ALEKS “pie” on the assessments suggests that students in the ALEKS emporium section had learned about more mathematics topics than students in the non-ALEKS section. For instance, conversations with the instructor of the non-ALEKS section revealed that students in the ALEKS emporium section had been exposed to matrices and factoring problem types that appeared on the ALEKS knowledge-check assessment, but were not included in the non-ALEKS instruction. On the other hand, students in the ALEKS emporium section performed worse on the written common midterm assessment, particularly on questions that focused on elementary function concepts. For instance, consider the two questions below:

1. Does the relation  $x^2 + y^2 = 25$  describe  $y$  as a function of  $x$ ? (circle one) Yes or No.  
Explain your answer.
2. Consider the relationship where the set of inputs is the people in this class and the rule is to match them with their university ID number. Would this relation be a function? Explain why or why not.

Students in the ALEKS emporium section were much more likely to answer these questions incorrectly than students in the non-ALEKS section, and the former were also more likely to provide incomplete or incorrect explanations for correct answers. In the non-ALEKS section, 33% of the students had a correct response and correct explanation to the first task, versus 5% in the ALEKS emporium section. For the second task, 87.5% of the non-ALEKS section responded correctly with a correct explanation, but only 47.4% of the ALEKS emporium section did so.

The task below revealed further differences in students’ understandings across the two sections. Students in each section were equally successful at parts (b) and (c), which involve a unit conversion and the solving of an equation (across both sections approximately 75% of students were correct on part (b) and 35% on part (c)). Part (a) involves writing an algebraic expression. Students in the non-ALEKS section were much more likely to answer this part correctly (58% correct in the non-ALEKS section versus 24% correct in the ALEKS section):

3. A truck enters a highway driving at a constant rate of 60 miles per hour. A car enters the highway at the same place 12 minutes later and drives at a constant rate of 75 miles per hour. Let  $m$  represent the number of minutes from the time that the car enters the highway until it passes the truck.

- a. Write an expression involving  $m$  for the number of minutes that the truck has driven on the highway up to the time when they pass.
- b. What is the speed of the car in miles per minute?
- c. From the time that the car enters the highway, how many minutes will it take the car to pass the truck (show your work).

In addition to the differences noted in the course learning outcomes, we considered the ALEKS emporium instructor's [Author2] reflections of the implementation of ALEKS in the College Algebra course. With respect to our students' use of ALEKS in the ME format, we observed the following:

- Emotional support: Though some found the “cheerleading” components of ALEKS to be corny, other students liked that emotional support.
- Choice of topics: Using flexible computer learning systems, students can proceed non-linearly, jumping from one topic to another, allowing them to move between the topics that they find straightforward and those with which they struggle.
- Adaptive learning: Once a student has demonstrated mastery of prerequisite topics, the software gives them access to more topics, allowing some students to move ahead quickly and preventing others from working on material for which they were not ready.

The drawbacks of a “pure” (computer only) ME format that most concerned us were:

- little to no development of underlying mathematical ideas,
- superficial mathematical experiences,
- no involvement in challenging problem solving,
- dearth of student discourse.

#### **4. ITERATION 2: INITIAL BLENDED EMPORIUM FORMAT**

Based on the experiences with the ME in the Fall 2015 quarter, several changes were implemented in the following quarter. First, to address the dearth of discourse and the need to focus on conceptual understanding of mathematics topics (particularly functions), the revised course included cooperative learning activities of approximately 1-hour duration each week (one-quarter of in-class time). Second, the topics in ALEKS were assigned in weekly modules, so that more students would be working on topics related to that week's activity. For example, the week we did the “Climate Change” activity (described below), the module

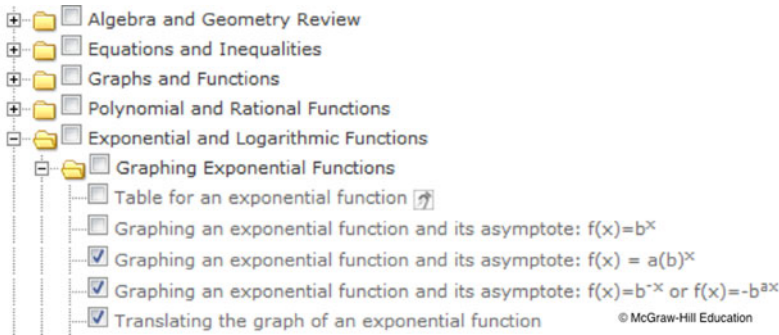


Figure 6. Example of part of the ALEKS list of topics.

included such topics as finding the slope of a line, graphing a line, and finding an equation of a line through two points:

Climate Change: Temperature, Ocean level, and CO<sub>2</sub>

Give symbolic and graphical representations of each of the following facts:

- a. A temperature increase of 1.8° F corresponds to a 1 foot rise in ocean level.
- b. An increase in CO<sub>2</sub> concentration of 1ppm corresponds to an increase in global temperature of .0193° F

From the facts above, determine the relationship between CO<sub>2</sub> concentration and the rise in ocean level.

**4.1. Reducing the Number of Required Topics**

In order to allow enough class time to implement these activities, we reduced the number of topics required from 405 to 365. ALEKS sorts topics in each pie slice into a list with subcategories (see Figure 6), and the instructor selects from this list. The original selection of topics was based on the department course outline. The paring down of that list of topics was determined by eliminating topics that can be easily derived from other topics (for example, using the quadratic formula to factor quadratics) and by eliminating elementary prerequisite topics.

Reducing the number of required ALEKS topics provided more time for cooperative learning activities in class. In both Iteration 1 and Iteration 2, daily attendance and participation during class was required

and counted as 15% of the final grade. In Iteration 2, when this participation grade was based on completing the weekly activity, the students often left the class early after finishing the activity. Without the time spent in class working in ALEKS, the students' completion of the ALEKS assignments suffered. In the subsequent iteration we were more focused on communicating with students about their progress. We also made modifications to the activities to increase expectations for the cooperative learning activities and to improve the implementation of active learning.

### 5. ITERATION 3: REVISED BLENDED EMPORIUM FORMAT

Fall Quarter 2016 was our first “scaled-up” ME implementation of College Algebra, with 75 students in each of two sections (two “traditional” 40-student sections also remained). In the ME implementation, two instructors (with one section each) were assisted by a graduate teaching assistant; this team of three developed additional activities with more intentional goals. These activities were designed to improve the students' abilities to find a reasonable mathematical model for a narratively-posed question, check the model against the given information, and evaluate the reasonableness of any conclusions drawn from the model. Using open-ended explorations allowed students to discover concepts and hone their problem-solving skills.

In order to promote active learning, many of the activities used in Iteration 2 were replaced by those with more cognitive demands and included prompts designed to generate more reflective thinking and more productive discourse. For instance, the climate change activity described above was replaced with a modification of Dan Meyer's adaptation of Jere Confrey's Gas Pump Ripoff activity [8]:

Someone has hacked into the gasoline meters and you might be getting ripped off.

Go to the link listed under “Gas Pump Video” <https://youtu.be/2BhOWOGV-Pw>

Watch the video of the meters on 3 gas pumps and answer the following questions:

1. Which pump(s) might be ripping you off?
2. For the ripoff pump(s), how badly are you being ripped off?
3. Is the graph corresponding to each pump a line? For the graph(s) that are lines, draw the graph(s) and find the corresponding equation.
4. For each pump that is not a ripoff, how much would you pay for 10 gallons of gas?

### 5.1. Classroom Conformation, Design, and Culture

Our emporium-format classes remained synchronous: All of the students who registered for a class met in the computer lab at the same time. We allocated 50 to 75% of the class time to work in ALEKS in an emporium format. By completing a significant amount of ALEKS work in class where an instructor is available to facilitate progress, we found that most students were able to complete the required weekly ALEKS assignment.

Due to the self-paced nature of ALEKS, a student was rarely working on the same topic as nearby students. In order for cooperative learning activities to align with student progress through ALEKS, we again arranged the ALEKS topics into weekly modules. By using a module format, students were often working on similar topics at the same time, allowing us to base cooperative learning activities on topics many of them were about to work on or were working on at that time. In order to see how well the activities lined up with the topics that the students were studying in ALEKS, the instructor checked student progress on selected topics the day before the related activity.

For example, consider the following activity:

The function  $P=f(n)$  gives the retail price of a Toyota Camry  $n$  years after 2010. The following table provides some values for this function:

|                                  |        |        |        |        |        |
|----------------------------------|--------|--------|--------|--------|--------|
| $n$ , number of years since 2010 | 0      | 2      | 4      | 6      | 8      |
| $P$ , retail price (in \$)       | 21,330 | 22,083 | 22,863 | 23,670 | 24,505 |

1. Sketch a rough graph of this information and use this to estimate when the price of a Camry will be over \$25,000.
2. In terms of percent increase, verify that the price of a Camry increases at about 1.75% each year.
3. Find an equation for a function that models this information and use the function to calculate when a Camry will cost more than \$25,000
4. Based on the estimate you made in question #1, is your calculation reasonable?

Figure 7 shows an ALEKS-generated table.

If the table in Figure 7 were generated before this activity, (observing a “critical mass” familiar with exponential functions, but not with exponential function models or solving exponential equations), we would precede the activity with a “preparatory activity” consisting of generating

|  | P   | R   | A  |
|--|-----|-----|----|
| Graphing an exponential function and its asymptote: $f(x) = a(b)^x$  | 87% | 10% | 1% |
| Graphing an exponential function and its asymptote: $f(x) = ab^{-x}$ | 84% | 8%  | 0% |
| Writing an equation that models exponential growth or decay          | 72% | 21% | 0% |
| Solving an exponential equation by using natural logarithms          | 51% | 25% | 1% |

P = Progress

R = Ready to learn

A = Attempted, not yet learned

(In this context, "Progress" means that the student has demonstrated proficiency in this topic on an assessment.)

*Figure 7.* Example of a progress table.

functions which model exponential growth and decay, as well as practice with using logarithms to solve exponential equations.

## 6. RESULTS

In assessing the results of blending the ME format our focus is comparing the outcomes of Iteration 1 and Iteration 3 (the Fall sections of College Algebra). Outcomes for students in the Fall 2016 cohort showed several aspects of improvement in comparison with Fall 2015. Although the passing rate for the students using ALEKS decreased slightly from the Fall 2015 implementation (78% versus 75%), a larger percentage of passing students went on to be successful in the next course in the precalculus sequence. The success rate in Trigonometry for students who had completed and passed College Algebra using ALEKS increased from 67% to 88%. Additionally, the percentage of students who continued on to Calculus I was higher for students that used ALEKS in their College Algebra course than those who completed a more traditional course that did not use ALEKS. Seventy percent of the students in College Algebra with ALEKS that were successful in Trigonometry went on to enroll in Calculus I, compared with 46% of the students who were successful in College Algebra without ALEKS in Fall 2016.

We attribute the positive changes in the retention to having more integration between course topics and problem-solving activities. Including problem-solving activities focused on the topics that students were about to encounter, or had recently encountered in ALEKS, was beneficial for their learning of connections between those topics. In particular, students' discussions of mathematics, their public presentation of their work (on posters displayed around the room) and their write-ups of solutions fostered important mathematics practices such as justification and communication of mathematical reasoning that would be expected in subsequent courses.



## 7. CONCLUSIONS AND NEXT STEPS

Using ALEKS helps our students spend their time focusing on learning and practicing skills they have not yet mastered. Due to the adaptive aspect of the software, students are actively engaged in reading and working through the material; they are not passively listening to or taking notes on a lecture. We have described our perspective that the purpose of the ALEKS assignments is for students to learn how to use mathematical tools. However, knowing how to use a mathematical tool is arguably less important than knowing how to use the right tool to solve a problem, knowing how tools are related to one another, or knowing how to communicate mathematics with others.

Regarding the three iterations of the ME format using ALEKS in College Algebra, our goal has been to continue to improve the balancing of opportunities for students to learn the appropriate tools and opportunities for students to understand and use such tools. Our challenges in implementing computer-based instruction included supporting students' understanding of the concepts of mathematics, promoting student discourse, and engaging students in challenging problem solving. To this end, we have included activities that are more structured to be challenging and to focus on using mathematics to model and solve problems. An ongoing difficulty is balancing student autonomy (in terms of the choice of topics that students are working on in ALEKS) with curricular coherence that supports the development of a classroom community that values mathematical discourse.

In the most recent iteration, each module in ALEKS included most of the topics from previous modules, so that topics would not disappear at the end of a week. In the future, we plan to configure modules so that each one closes at the end of its week, somewhat restricting students' choices (but when a student finishes the current week's module, all of the modules are available for them to catch up). We expect this to allow for further improvement in aligning cooperative activities with students' work in ALEKS. We also plan to use ALEKS class data to identify those topics with which students are struggling on a given day, and designate parts of the room on that day for those topics (for example, the left front quarter of the room for inverse functions and the right back quarter of the room for logarithms). Lastly, we also plan to be even more explicit in framing the learning goals in the group activities in terms of using and understanding the tools encountered in ALEKS.

Finally, we note that we believe determining the balance of individualized and common assignments for students is likely to be institution-specific. As many of our students are employed or have families, their time for completing assignments outside of class is quite limited. The

adaptive aspect of the ALEKS software allows for our students to focus their limited time outside of class on reviewing and practicing individualized content. However, it also constrained our blended CBL implementation, because students were working on different topics from one another. For instructors of more traditional college student populations considering a blended CBL course for College Algebra, non-adaptive CBL assignments (or platforms) may be more useful for maintaining curricular coherence and better support active learning.

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