# The Impact of ALEKS on Student Learning in First-Year University Mathematics for Economics

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**Abstract**

ALEKS, an adaptive learning software (ALS), offers the potential to improve testing and learning by acting like a tutor who curates questions of appropriate difficulty and provides corrective feedback immediately. ALS offer over 300 precalculus topics and diagnose the knowledge state of each student to provide a personalized approach to testing and learning. The adaptive nature of questions discourages cheating and enhances test security. Our research explores the integration of ALS in the first four weeks of a first-year math course over three years. The sample includes information on test scores, software usage, and survey responses for more than 500 students. Students used ALS for both formative and summative assessments. Those students who performed well on ALS assessments also performed well in the calculus component of the course. More than eighty-five percent of students reported a positive learning experience and an increased likelihood to stay in a math-based program. An ordered probit model found that female and ESL students using the software were more likely to report a willingness to stay in a math-based program or increased confidence. These results suggest ALS like ALEKS can improve learning outcomes and promote equal learning opportunities at scale.

## Introducing ALS into a Mathematics for Economics Course

Many first-year students enter university without sufficient preparation in maths to be successful. According to a report by Lawson et al. (2020), this lack of preparation regularly extends to foundational skills such as performing algebraic calculations quickly and accurately, solving problems with multiple steps, and defining a function, limit, or logarithm. These students are at high risk of failing to complete a degree in economics or quantitative business, which require a solid grasp of mathematical concepts and techniques. To remediate this shortcoming, an adaptive learning software (ALS), ALEKS, was integrated into a first-year required mathematics for economics course. ALEKS, like all ALS, is a web-based program that assesses students' current knowledge level and provides them with a personalized learning path of practice problems to help them learn at the right level of difficulty. In our study, students used this ALS for homework, formative assessments, and a summative assessment in the first weeks of class. ALS helped students overcome their lack of preparation by i) identifying specific knowledge gaps early in the semester and ii) assigning a unique learning path of practice problems to help them learn. The combined effect is to mimic a human tutor, which has been shown to increase student performance considerably, and the nature of software allows the intervention to succeed at scale. To incentivize student effort, ALS was integrated into a math for economics course including a summative assessment.

VanLehn (2011) completed a review of experiments and found that a human tutor increased student performance by 0.79 standard deviations, but ALS was able to increase performance by 0.76 putting it on par with the human version. Cowen and Tabarrok (2014) argued this ability has created an opportunity to help students succeed at scale, with a relatively low dollar cost and time commitment from instructors. Kulik and Fletcher (2016) reviewed 50 studies using ALEKS and found that its use increased student performance by 0.66 standard deviations. Eau et al. (2022) found that ALEKS benefited women and suggested that the gender-neutral nature of the software might be the reason. Muralidharan et al. (2019) experimented with an ALS, Mindspark, in an after-school program and found it significantly improved the grades of students with a particularly strong impact on weaker students. Fang et al. (2019) identified 15 studies that adapted ALEKS for at a college-level undergraduate course and found small positive effects that were larger when the intervention was short. Sun et al. (2021) studied the use of ALEKS in 56 independent samples covering 9,238 students in K-12 schools and higher education. They found ALEKS alone was comparable to traditional instruction and even more effective when combined with traditional instruction. The literature shows that ALS, especially ALEKS, is a promising tool for enhancing mathematics learning outcomes and experiences for diverse learners.

Instructors of mathematics for economics at our institution confronted the challenge of teaching students with diverse backgrounds and skills, many of whom were non-native English speakers. Unlike some institutions, incoming students were not required to complete a standardized math test or a high-school calculus course. This resulted in widely varying preparedness among students, which made it difficult for instructors to teach at a level that is helpful to all students and to identify and assist those students who struggled. To address this problem, we sought to leverage the capabilities of ALS by integrating it into our sections of math for economics by integrating math for economics course. ALS can quickly detect students who are at risk of failure and provide them with personalized feedback and a plan to fill their knowledge gaps. Meanwhile, students who are well-prepared can skip the content they already know, save time and effort, and focus on learning new concepts.

### Integrating ALS into a First-Year Math Course

Math skills are necessary for success as an economics major. Allgood et al. (2015) found several studies showing a significant link between quantitative or mathematics scores and performance in both introductory and intermediate economics courses. ALS is a tool to learn precalculus algebra, but many student also need an incentive to do the work. Hence, the instructors took care to seemlessly integrate the software into their classes. If the students found ALS was not related to their tests or other course content, then their negative opinions might tarnish their opinion. The course had multiple sections with different instructors. They all followed the same syllabus, but only two instructors adopted ALS. Topics on the software were chosen before class began by participating instrucotors, based on course content and learning outcomes. During the first class, students were instructed to purchase a copy of ALS ($30 USD), complete the initial adaptive assessment, work on their unique learning path, and complete additional assessments when prompted. Students used the software outside class, and class time was spent on instructor-designed activities that reinforced the concepts and skills learned on the software.

The course schedule was matched with the sequence of topics on ALS, so that students would have exposure to the relevant material before attending class. One instructor created video lectures to support student activities on the ALS. These videos were posted on the course website and were accessible at any time. One instructor assigned weekly quizzes and bonus marks on the software. The quizzes consisted of questions selected by the instructor from the question bank. The bonus marks were based on the time spent by students on their learning path. A second instructor encouraged use of ALS with no quizzes or bonuses.

A summative assessment (term test 1) was written on ALS after four weeks of class with questions selected by the instructors. The same test was administered to both course sections. The test was not proctored and was written online. The test results were automatically graded by ALS and reported to the instructors. The integration of ALS into the first-year math course was intended to provide students with an adaptive and personalized learning experience that complemented the classroom instruction.

**Data Collection**

To evaluate the impact of ALS on student learning and performance in the first-year math course, data were collected from pre-course and post-course student surveys, activity on ALS, and calculus grades. The data were analyzed using descriptive and inferential statistics to compare the outcomes of different sections and instructors. The pre-course survey was administered online during the first week of class. It asked students about their demographic information, prior math experience, a Big-5 personality test, and attitudes towards math and ALS. The post-course survey was administered online at the end of the term. It asked students about their satisfaction, engagement, motivation, and perceived learning gains with ALS and the course.

Activity on ALS was recorded throughout the semester. It included the score on the initial adaptive assessment, which measured student baseline knowledge of precalculus topics; the score on the final adaptive assessment, which measured student mastery of precalculus topics at the end of the term; the time spent on the unique learning path, which indicated student effort and engagement with ALS; and the score on the precalculus term test, which assessed students' understanding and application of precalculus concepts.

The calculus grades were obtained from the course records. They included the score on calculus term test 2 and final exam, which evaluated students' proficiency in calculus topics; and the score on calculus low-stakes formative assessment scores, which reflected students' progress and participation in calculus activities. The sample size for this study was 830 students who completed term test 1 and the pre-course survey. Of these, 593 students also submitted a post-course survey. Only students who gave consent to use their data for research purposes were included in the analysis.

Table 1: Descriptive Statistics

| | | Instructor 1 | | | Instructor 2 | | |
|---|---|---|---|---|---|---|---|
| | All | F'20 | W'21 | F'21 | F'20 | W'21 | F'21 |
| ALEKS Topics Assigned | - – | 246 | 333 | 333 | 246 | 333 | 333 |
| Lecture | | asynchronous recordings | | | asynchronous recordings | | |
| Activities | | weekly, live on Zoom | | | asynchronous | | Live on Zoom |
| Incentives on time | | bonus points, quizzes | | | encouraging messages | | |
| Age (in years) | 20.98 | 20.98 | 21.54 | 20.92 | 21.05 | 21.35 | 19.86 |
| Female (%) | 34.54 | 30.42 | 41.24 | 39.17 | 33.05 | 39.02 | 32.89 |
| Male (%) | 65.09 | 69.58 | 58.76 | 60.00 | 66.95 | 59.76 | 65.79 |
| English (%) | 28.13 | 27.74 | 22.22 | 25.83 | 39.22 | 16.44 | 36.99 |
| Chinese (%) | 51.07 | 56.67 | 50.68 | 55.00 | 42.16 | 69.86 | 32.88 |
| Other (%) | 20.80 | 15.59 | 27.10 | 19.17 | 18.62 | 13.70 | 28.13 |
| Freshman (%) | 55.16 | 55.33 | 60.44 | 56.67 | 47.79 | 53.33 | 58.67 |
| Softmore (%) | 30.46 | 32.30 | 27.47 | 26.67 | 37.17 | 29.33 | 24.00 |
| Junior (%) | 7.97 | 6.19 | 6.59 | 7.50 | 8.85 | 10.67 | 13.33 |
| Senior (%) | 6.41 | 6.19 | 5.49 | 9.17 | 6.19 | 6.67 | 4.00 |
| HS Adv. Func. (%) | 75.87 | 74.84 | 71.13 | 75.00 | 81.51 | 75.61 | 78.95 |
| HS Calculus taken (%) | 66.13 | 66.13 | 72.92 | 63.33 | 61.34 | 65.85 | 69.74 |
| A's (%) | 40.36 | 53.92 | 33.96 | 26.67 | 24.19 | 42.35 | 38.16 |
| B's (%) | 19.88 | 18.18 | 19.81 | 17.5 | 29.03 | 17.65 | 18.42 |
| C's (%) | 15.06 | 10.97 | 18.87 | 21.67 | 18.55 | 11.76 | 14.47 |
| D,F,WD (%) | 24.7 | 16.93 | 27.36 | 34.17 | 28.23 | 28.24 | 28.95 |

Note: Only consenting student data displayed.

Table 1 presents some descriptive statistics of the students involved. A majority of the students were male by a ratio of approximately 2:1 and half spoke Chinese at home. Two-thirds of students took high school calculus even though it was not required to enter an economics program at this institution. The university campus was closed from Fall 2020 to Fall 2021, so tests were written online without an invigilator.

## Methodology and Results

To examine the relationship between students' performance on ALS and their performance in calculus, we employed a regression analysis with two different dependent variables: (i) the score on the precalculus test (term test 1), which assessed students' mastery of precalculus topics at the end of week 4; and (ii) the mean score on the calculus summative assessments, which evaluated students' proficiency in calculus topics from week 5 onward. The grade scores were normalized to account for differences in grading scales across sections and terms. Various student characteristics were controlled for such as age, academic stage, language, sex, and other self-reported information that might affect their performance. Additionally, we included fixed effects for term and instructor to capture any unobserved heterogeneity related to these factors.

Table 2 reports the results of three regressions. The dependent variable in Regression 1 is the score on the term test based on ALS. The main predictors of term test performance are high school (HS) calculus grades and the most recent adaptive assessment score. The coefficient of HS calculus grades implies that a one percentage point increase in HS calculus grades is associated with a 0.013 standard deviation increase in term test scores, conditional on taking HS calculus. The coefficient of the adaptive assessment score indicates that a one standard deviation increase in this score leads to a 0.437 standard deviation increase in term test scores. These results suggest that the adaptive assessment score is a strong predictor of term test performance, even when the assessment itself does not count towards grades. This finding is expected, but it confirms that the adaptive assessment reflects students' mastery of the course material.

Regression 2 and 3 use the student score on the calculus component of the course as the dependent variable. The calculus score is computed as a simple average of term test 2 and the final exam. Regression 2 replicates Regression 1 with the new dependent variable. The coefficient of the adaptive assessment score shows that it is a significant predictor of calculus performance, even though ALS only covers precalculus topics. A one standard deviation increase in the adaptive assessment score is associated with a 0.252 standard deviation increase in the calculus score. Regression 3 adds the score on the term test based on ALS, ALEKS, as an additional regressor. This score is a stronger predictor of calculus performance than the adaptive assessment score. A one standard deviation increase in the term test score is associated with a 0.372 standard

Table 2: Regression Table

| Dependent Variable: | Test on ALS | | Calculus Grades | | | |
|---|---|---|---|---|---|---|
| Regression: | (1) | | (2) | | (3) | |
| | Coef. | Std. Err. | Coef. | Std. Err. | Coef. | Std. Err. |
| Instructor 2 | -0.012 | 0.071 | 0.049 | (0.077) | 0.068 | (0.073) |
| 2021W term | -0.062 | 0.077 | -0.250** | (0.097) | -0.223** | (0.090) |
| 2021F term | 0.133 | 0.111 | 0.053 | (0.122) | 0.025 | (0.116) |
| ESL | 0.014 | 0.096 | 0.059 | (0.118) | 0.024 | (0.113) |
| Softmore | 0.095 | 0.072 | 0.070 | (0.083) | 0.021 | (0.078) |
| Junior | 0.008 | 0.125 | 0.059 | (0.141) | 0.04 | (0.142) |
| Senior | -0.038 | 0.130 | -0.054 | (0.154) | -0.032 | (0.142) |
| Female | -0.034 | 0.065 | 0.046 | (0.077) | 0.069 | (0.073) |
| Re-taking Course | -0.073 | 0.153 | 0.217 | (0.153) | 0.250* | (0.148) |
| Part-time student | 0.072 | 0.220 | 0.011 | (0.186) | -0.113 | (0.163) |
| Previous Post-Secondary | -0.139 | 0.093 | -0.082 | (0.108) | -0.041 | (0.101) |
| International Student | -0.126 | 0.146 | 0.109 | (0.155) | 0.149 | (0.143) |
| ESL & International | 0.239 | 0.164 | 0.257 | (0.182) | 0.198 | (0.168) |
| Agreeableness | -0.04 | 0.024 | -0.054* | (0.030) | -0.036 | (0.028) |
| Conscientiousness | -0.027 | 0.022 | 0.013 | (0.025) | 0.022 | (0.024) |
| Extraversion | -0.013 | 0.022 | -0.003 | (0.022) | 0.001 | (0.021) |
| Neuroticism | 0.002 | 0.018 | -0.007 | (0.022) | -0.005 | (0.022) |
| Openness | 0.012 | 0.025 | -0.044* | (0.025) | -0.049** | (0.025) |
| Age | -0.008 | 0.012 | 0.022 | (0.015) | 0.026* | (0.013) |
| HS Adv Functions 1=Yes | -0.453 | 0.361 | -0.657 | (0.470) | -0.468 | (0.415) |
| HS Adv. Functions Grade | 0.006 | 0.004 | 0.008 | (0.006) | 0.005 | (0.005) |
| HS Calculus 1=Yes | -0.797 | 0.282 | -0.405 | (0.415) | -0.100 | (0.390) |
| HS Calculus Grade | 0.013*** | 0.004 | 0.008 | (0.005) | 0.003 | (0.005) |
| Initial Adaptive Assessment | 0.01 | 0.108 | -0.026 | (0.072) | -0.026 | (0.066) |
| Latest Adaptive Assessment | 0.437*** | 0.123 | 0.252*** | (0.088) | 0.101 | (0.083) |
| Time on Learning Path | 0.002 | 0.004 | 0.003 | (0.003) | 0.002 | (0.003) |
| Test on ALS | – | – | – | – | 0.372*** | (0.046) |
| Observations | 741 | | 703 | | 703 | |

Note: ALS, ALEKS, appears as the dependent variable in Regression 1 and an independent variables in Regression 3.

deviation increase in the calculus score. We can conclude that success on ALS is correlated with success in calculus.

Table 3: Scored Responses by Students

| | Total | Fall '20 | Winter '21 | Fall '21 | Fall '20 | Winter '21 | Fall '21 |
|---|---|---|---|---|---|---|---|
| | | Instructor 1 | | | Instructor 2 | | |
| 1.Improved my overall learning | 4.32 | 4.45 | 4.26 | 4.43 | 4.16 | 4.23 | 4.06 |
| 2.Helped me learn. | 4.16 | 4.30 | 4.11 | 4.13 | 4.21 | 4.19 | 3.58 |
| 3.Gave me more confidence. | 4.09 | 4.26 | 4.04 | 4.02 | 4.08 | 4.15 | 3.56 |
| 4.Prepared me for future courses | 3.99 | 4.17 | 3.88 | 4.01 | 3.90 | 4.03 | 3.48 |
| 5.Online lecture videos were helpful | 4.06 | 4.20 | 4.14 | 4.18 | 3.96 | 4.01 | 3.40 |
| 6.More Likely to Stay in a Math-Based Program | 3.91 | 4.07 | 3.97 | 3.87 | 3.75 | 4.01 | 3.38 |

Note: Students were asked how much they agreed with these statements with 5 being strongly agree and 1 being strongly disagree. Responses are on a likert scale of 1-5.

Table 3 summarizes feedback from student surveys. In absolute terms, the overall averages are strong. Students found that ALS improved their overall learning and many reported that using the software increased their likelihood of staying in a math-based program. These survey questions were based on a 5-point likert scale. Since the responses are discrete rather than continuous, table 4 uses an ordered probit model to analyse student characteristics. Female students are more likely to report that the ALS improved their overall learning, and ESL students are more likely to report a higher likelihood of staying in a math-based program. Students who may struggle following a traditional lecture in a new language or who feel uncomfortable in an English-speaking classroom may benefit more from the ALS. The software is gender-neutral, which might benefit female students in a predominantly male classroom.

## Conclusion

The study was successful in demonstrating that students enjoyed using an ALS as part of a first-year university math for economics course. While the experiment cannot demonstrated a causal increase in learning, the students self-reported increased learning and their performance on ALS predicted their success in the calculus component of the course. Female and ESL students had a particularly positive experience

Table 4: Ordered Probit Models (Abbreviated)

| Dependent Variable | 1. Overall Learning | | 2. Stay in Math | |
|---|---|---|---|---|
| | Coef. | P-value | Coef. | P-value |
| HS Calculus (Yes=1) | 0.759 | 0.141 | -0.275 | 0.007 |
| HS Calculus Grade | -0.009 | 0.148 | 0.003 | 0.561 |
| English Not Spoken at Home | 0.122 | 0.481 | 0.642** | 0.000 |
| Sophomore | 0.190 | 0.111 | -0.082 | 0.461 |
| Junior | -0.344✓ | 0.056 | -0.016 | 0.931 |
| Senior | 0.044 | 0.850 | -0.220 | 0.305 |
| Female | 0.269* | 0.015 | 0.063 | 0.542 |
| Previous College Attended | -0.045 | 0.765 | -0.314* | 0.024 |
| International | -0.064 | 0.769 | 0.130 | 0.535 |
| International-ESL | 0.002 | 0.994 | -0.031 | 0.900 |
| Age | 0.024 | 0.236 | 0.020 | 0.262 |
| B5_Agreeable | -0.011 | 0.791 | 0.030 | 0.444 |
| B5_Conscientious | -0.007 | 0.857 | -0.028 | 0.422 |
| B5_Extrovert | -0.012 | 0.740 | -0.006 | 0.856 |
| B5_Neurotic | -0.076** | 0.020 | -0.082** | 0.007 |
| B5_Openness | 0.027 | 0.504 | 0.015 | 0.679 |

✓, *, ** represent statistical significance at the 10, 5, 1 percent level, respectively,

with the software. The project employed several strategies to facilitate students' engagement and learning. First, the recorded lectures provided clear guidance and examples on how to solve problems on ALS. Second, the students were motivated to use ALS regularly by assigning grades to the term test based on ALEKS. Third, the topics covered in-class were aligned with the topics on ALEKS, making it easier for students to transfer their knowledge and skills. Fourth, the project was designed as a short, focused intervention that lasted for four weeks, avoiding potential fatigue, procrastination, or distraction from other topics. These strategies contributed to the positive outcomes of the project, as evidenced by the regression results and student feedback.

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