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An Experiment in Active Learning: The Effects of Teams

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Abstract: In modern times, the importance of education cannot be overstated. Beyond the acquisition of knowledge, perhaps the most important aim of education may be the development of character in individuals, including vitality, courage, sensitiveness, and intelligence, from which our society may experience increased prosperity, peace, and freedom. In this paper we address the daunting challenge of achieving successful, widespread, and inclusive university education. How do we enliven and engage the students in our classrooms? How can we help each and every student in the class self-actualize and reach the highest potential for learning? Active learning is one well-established and potent solution for accelerating the accumulation of knowledge. In this paper, an experiment in active learning utilizing team-based adaptive online quizzes in an introductory math finance course involving 378 undergraduate students over two years is conducted to explore the potency of this active learning methodology compared to a control group with traditional teaching. We find active learning unambiguously improves knowledge accumulation in the individual students, while simultaneously bolstering inclusive excellence across all students in the class, as measured by a relevant and meaningful quantitative metric. The paper concludes with a discussion comparing the quality of active vs. traditional teaching methods and offers interpretations of the quantitative results. The results of this paper support the widely accepted theme in the literature that active learning has a positive effect on student performance in STEM (Science, Technology, Engineering, and Math) courses.

Keywords: *Active learning, math finance, adaptive learning, traditional learning, inclusive learning.*

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Introduction

Traditionally, education has been dominated by lecture-oriented curriculum with an emphasis on passive learning. Recently, it has become clear that passive learning may inhibit the ability of the student to truly comprehend the scope and meaning of the material, and fail to boost confidence, enthusiasm, and engagement in the classroom (Weiner, 1990). Furthermore, with traditional passive learning, employers often find that despite students believing they are prepared for jobs after graduating, they tend to lack important skills such as communication, teamwork, and collaboration (Jaschik, 2015). Rather than allowing students to be passive recipients of information, educators may rather encourage students to engage in group discussions and be active participants of learning, what Volpe (1984) coined decades ago as "actively knowing, rather than passively believing," or what we now call active learning.

Active learning is a method of learning in which students are actively or experientially involved in the learning process (Bonwell & Eison, 1991). While active learning coordinates with the principles of constructivism which are, cognitive, meta-cognitive, evolving and affective in nature (Anthony, 1996) and has been studied extensively, active learning is really any approach to instruction in which all students engage in the learning process. Student engagement occurs when students are inspired to become deeply curious about the subject being taught and are driven to understand the material and incorporate and internalize it in their lives. There are many methods of student engagement. One method of promoting student engagement is through the use of learning communities, a technique that has a group of students taking the same classes together (Zhao & Kuh, 2004). A more recent innovation in active learning is adaptive learning which strives to individualize learning for each student. This type of active learning tailors instruction to each student's unique needs, current understandings, and interests, in some sense serving as a personal tutor to the student. Sequencing of the curriculum and associated learning experiences are adapted to each student, so the pace of learning is individualized and the cognitive load for each student is regulated intelligently. Other methods of student

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engagement are diverse and may include team-based problem solving, use of clickers or personal response systems, online real-time polling, live tutorials, inquiry-based learning, competitions and hackathons.

Active or student-centered learning is now largely recognized as an effective form of classroom instruction specifically in the Science, Technology, Engineering, and Math (STEM) specialties (Ambrose et al., 2010). Prior literature shows that active learning leads to a significant increase in undergraduate student performance in chemistry (Crimmins & Midkiff, 2017; O'Sullivan & Cooper, 2003), math (Lugosi & Uribe, 2019), computer engineering (Arbelaitz et al., 2015), and biology (Armbruster et al., 2017). Perhaps one of the earliest and most inspiring examples of active learning was that of Jaime Alfonso Escalante Gutierrez (1930-2010), a Bolivian-American educator known for teaching students calculus from 1974 to 1991 at Garfield High School in East Los Angeles and featured in the 1988 book, *Escalante: The Best Teacher in America*, by Jay Mathews and the 1988 film *Stand and Deliver*. Gutierrez described his extraordinarily successful educational achievements as: "The key to my success with youngsters is a very simple and time-honored tradition: hard work for teacher and student alike." In a landmark meta-analysis of 225 studies by Freeman et al. (2014), published in the Proceedings of the National Academy of Sciences of the United States of America, students achieved higher grades in undergraduate STEM courses by half of a letter with active learning methods. Furthermore, traditional lecturing led to an increase in student failure rates by 55% when compared to the rates observed under active learning. In another systematic review of seventeen original studies on Team-Based Learning (TBL) by Sisk (2011), the study concluded that students working in teams were satisfied, engagement was higher, and exam scores were higher as well. Furthermore, additional large meta-analyses have discovered that active learning has positive but variable effects on student learning for biology, chemistry, engineering, and physics (Ruiz-Primo et al., 2011) and that small-group learning methods are effective in promoting positive attitudes toward learning and achieving greater success in STEM courses (Springer et al., 1999)

In this paper we begin with a detailed description of an experiment in active learning utilizing team-based adaptive online quizzes. Then, we compare a posteriori student performance taken from cumulative aggregate data from undergraduate math finance classes involving 378 students over two academic years (2018 to 2019 & 2019 to 2020), spanning six academic quarters. Numerical and graphical student performance results are presented. The paper concludes with a discussion comparing the quality of active vs. traditional teaching methods. We offer interpretations of the quantitative results and suggest how team-based adaptive learning may also improve inclusivity and prepare students for their future careers.

Methodology

Adaptive learning in higher education has been described as an innovative data-driven approach to teaching (Mirata et al., 2020). Inspired by the deluge of recent research on smart learning environments that embrace personalized learning and adaptive learning (Peng, et al., 2019), the specific intervention we study in this paper was to modify the teaching approach as follows: 29 lectures, 1 midterm exam, and 1 final exam was changed to 19 lectures, 10 team-based adaptive online quizzes, 1 midterm, and 1 final exam. The approach introduced in-class team-based quizzes to replace traditional lectures. The content and difficulty of the quizzes was individually and dynamically adapted over the 10 weeks during each quarter to be fine-tuned to each student's specific abilities as the course progressed. For example, if a student was struggling, the difficulty of the questions would scale down, and vice versa, to make the learning trajectory smoother and more efficient. Additionally, team membership was allowed to freely adapt over time voluntarily.

After 3 quarters of teaching the introductory course in math finance during my first year, I launched the intervention to improve my teaching via incorporating active learning. Each quarter of the first year included 41 meetings over 10 weeks: 29 lectures, 10 office hour sessions, 1 midterm exam and 1 final exam. Clearly the teaching was dominated by traditional lectures. Having earned a certificate for advanced training in active learning from the Division of Teaching Excellence and Innovation at my university, I sought to apply my newfound knowledge and improve student outcomes in my class. The crux of improvements focused on reducing the amount of lecturing and increasing the amount of student engagement as much as possible.

Using the learning management system, I set to work designing weekly quizzes that were administered online and auto-graded instantaneously. The quizzes were structured to test the students on material presented in the previous 2 lectures, shifting the composition of the time spent in class to 19 lectures, 10 office hour sessions, 10 online quizzes, 1 midterm exam and 1 final exam. The students were allowed to form their own teams of 2-3 students per team to collaborate and take the quizzes together on the quiz days, fully open book, open notes, and free to use the internet. Immediately I sensed an improved desire to actively participate, increased communication within each team, and increased enthusiasm and vigor. Over the first few weeks, teams learned to split up the questions among team members and then share answers, checking each other's work. There was reduced anxiety in a team collaborative effort compared to a solo quiz-taking effort, and this may have improved their ability to solve the mathematical problems and scores. This was the case in a study by Bjalkebring (2019), where students with high math anxiety relied more on their fellow classmates to help pass the course as compared to students with low math anxiety. In our study, the teams were given the option to merge, and some did naturally and organically with various desires and competitive strategies to improve performance. The whole dynamic of team-based online quizzes took on a life of its own and dramatically improved student engagement in ways we could not have predicted in advance.

In post-medical school surgical residencies, active learning is fully embraced; hence the adage see one, do one, teach one. The phrase reflects a method of teaching in which a resident physician will observe a procedure, perform the procedure on their own, and then teach another trainee how to conduct the procedure. Similarly, in order to learn how to sail you most likely cannot just sit back and watch an expert sailor sail. You must become active. And so is the case with learning math finance. In a team-based learning environment, like the one in this experiment, an educator is able to pair up the weak students with the strong ones so the course practicum naturally becomes more engaging and inclusive. This intuitively provides hope for bringing out the greatest intellectual potential in all students. Indeed, in the 4th week of instruction during the active learning period, a student approached me before class, somewhat in despair, noting that she felt lost and far behind the other students in the class. An adaptive intervention was needed. It was a team quiz day, so I readily assigned her to one of the strongest teams. The student picked up quickly from that day forward and ended up near the top of the class, rising along with her team members.

As noted before, the experiment in active learning includes three quarters of teaching using traditional methods (2019 to 2020) followed by three quarters of teaching using active learning (academic year 2020 to 2021).

In the next section we compare the learning outcomes of the active vs. traditional learning periods, as measured quantitatively with students' cumulative total scores. Typically, the final score that students earn during a course will be a percentage-weighted combination of their homework, quizzes, and exams. For example, the homework total may contribute 30%, the quizzes 30%, and midterm/final exams 40%. For example, in this case for a student who averaged 90% on homework, 80% on quizzes, and 75% on both the midterm and final exam, the final score for the kth student would be s_k calculated as follows:

$s_k = 0.3 * 90 + 0.3 * 80 + 0.4 * 75 = 81$

The quantitative metric we used to gauge student outcomes is the Inclusive Excellence Ratio (IER) (Ludwig, 2021). The IER is designed to simultaneously reflect the two desirable characteristics embraced by inclusive excellence teaching: strong student performance and low variation in performance across all students. The computation of the IER given student test score data is simple and straightforward: it is the statistical sample mean divided by the sample standard deviation. A formulaic description of the IER is as follows: if the total final student scores are s_k, for k = 1 to N with N students in the class, then the Inclusive Excellence Ratio may be computed as follows:

$$\mathrm{IER} = \frac{\mu}{\sigma}$$

$$\mu = \frac{1}{N}\sum_{k=1}^{N} s_k$$

$$\sigma^2 = \frac{1}{N-1}\sum_{k=1}^{N}(s_k - \mu)^2$$

Consequently, the IER is high when the students' sample mean μ of the test scores s_k is high and variance σ^2 of the test scores s_k is low, suggesting it may provide a simple and useful quantitative measure for those educational innovators seeking to experiment with new, effective teaching methodologies that boost inclusive excellence. This descriptive metric will be higher when fewer students are left behind in the classical DFW (final letter grade of D or F or withdraw from the class) category. In sum, teachers who are able to innovate to achieve high IERs will produce educational environments that include as many students as possible in the objective of educational excellence.

It is important to address the validity and reliability of the exams and quizzes we administered during the class. In terms of validity, the quizzes and exams contained mathematical problems related to financial and derivative markets. The aim of the class was to learn about financial markets, investing, and risk management using mathematical tools for analysis. The problems were specifically designed to progressively test knowledge in this arena. Additionally, although we made no specific effort to measure the reliability of the exams, there was an element of assessing consistency and reproducibility in the course curriculum. The final exam was cumulative, testing all new material introduced since the midterm as well as all the material introduced before the midterm. So the material up to and including the midterm was tested twice: once on the midterm and again on the final exam.

Findings / Results

The IER was applied to evaluate a posteriori student performance taken from cumulative aggregate data from undergraduate math finance classes involving 378 students over two academic years (2018 to 2019 & 2019 to 2020), spanning six quarters. The experimental test periods are described in Table 1.

Table 1: Experimental Test Periods

Quarter	Year	Number of Students	Instructional Format
Fall	2018	29	Traditional
Winter	2019	46	Traditional
Spring	2019	78	Traditional
Fall	2019	88	Active with Team-Based Quizzes
Winter	2020	47	Active with Team-Based Quizzes
Spring	2020	90	Active with Team-Based Quizzes

In order to investigate the quality of active learning compared to the quality of traditional learning, the IER was computed for all the students that participated in the traditional learning experimental test periods (total of 153 students from the Fall of 2018 to the Spring of 2019) and compared to the IER for the active learning experimental test period (225 students from the Fall of 2019 to the Spring of 2020). The statistical results are summarized in Table 2 while the histograms of the raw cumulative scores in the traditional and active learning are plotted in Figures 1 and 2, respectively.

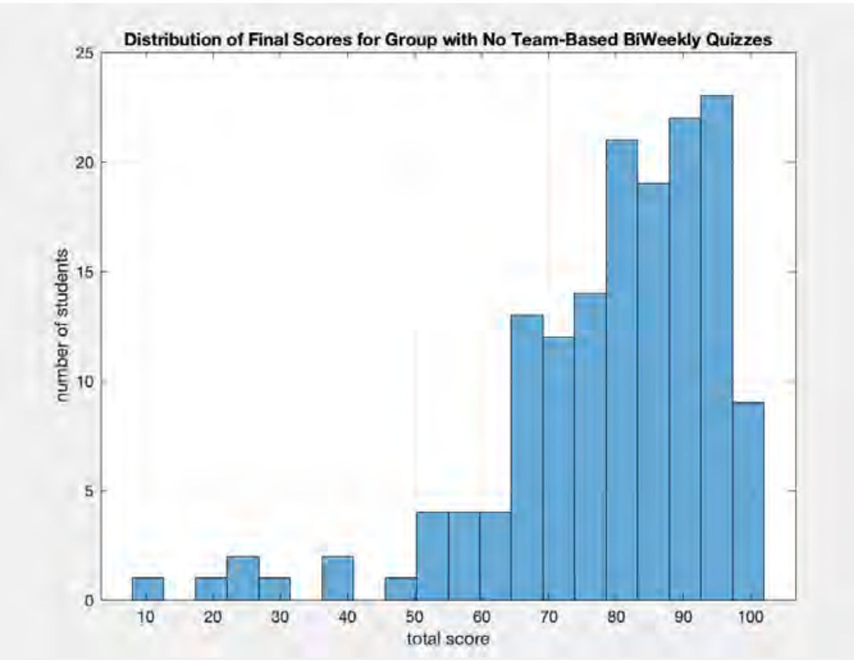

Figure 1: Distribution of Final Scores for Traditional Learning Group with No Team-Based Quizzes

Table 2: Summary of Active Learning vs. Traditional Learning Experimental Results

Number of Students	Instructional Format	Mean μ	Variance σ^2	IER
153	Traditional	79.27	277.08	4.76
225	Active with Team-Based Quizzes	82.56	250.09	5.22

Clearly by inspecting Figures 1 and 2, the distribution of final scores for the student group with team-based quizzes has a lower variance and higher mean than the distribution of final scores for the student group with no team-based quizzes. This is a compelling quantitative result, and something that innovative educators may be interested in as tangible evidence for improving both teaching effectiveness and efficiency.

By performing statistical hypothesis testing, we found there to be evidence of a significant difference between the active learning group and the traditional group for the mean final score. The sample mean final score for the active group was 82.56, while the sample mean final score for the traditional group was 79.27. The sample standard deviation for the traditional group was 16.6. We use this sample standard deviation as an approximation for the population standard deviation. Thus, an approximation for the standard deviation of our sampling distribution is 16.6 / $\sqrt{153}$. This leads to the estimate that the sample mean of the active group was 2.4 standard deviations above the sample mean of the traditional group, corresponding to a p-value of 0.007. This establishes firmly that there is a significant difference between the active learning and non-active lecture course terms for the average final score metric.

Additionally, we may compute a measure of the effect size to compare the sample means between the two distinct cohorts. We use Cohen's *d* to calculate the standardized mean difference between the two groups. Accordingly, we subtract the sample mean of the non-active group from the sample mean of the active group and divide the result by the pooled standard deviation of the total population of students from which the groups were sampled. Numerically, we compute

Effect Size *d* = ([Mean of Active Group] - [Mean of Non-Active Group]) / STD,

where STD is the pooled standard deviation of the total population of students from which the groups were sampled. This results in an effect size of 0.21. This magnitude of effect size was originally suggested by Cohen as "small,'' (Cohen, 1988; Sawilowsky, 2009). Effect size complements our statistical hypothesis testing results. The reporting of effect size facilitates the interpretation of the importance of a research result, in contrast to its statistical significance.

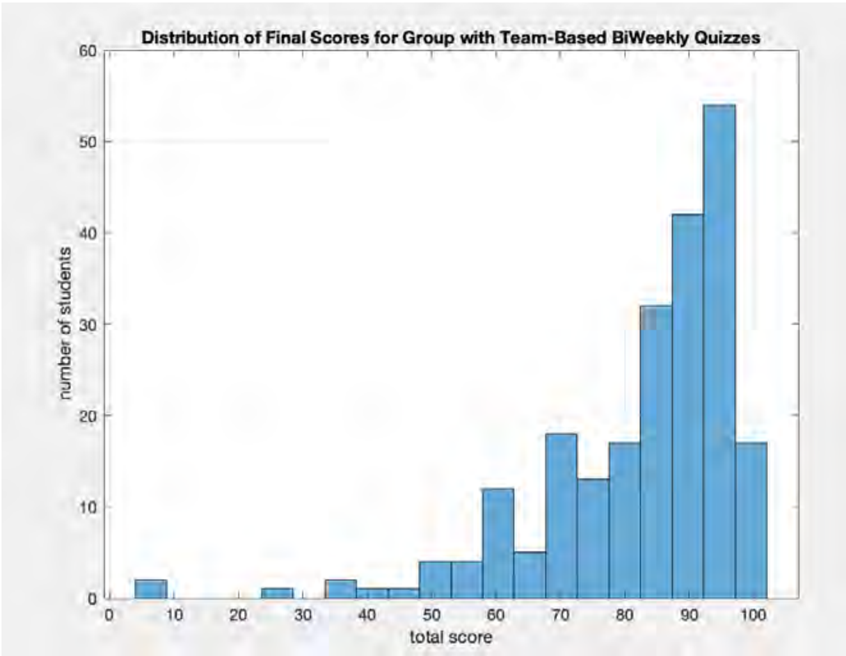

Figure 2: Distribution of Final Scores for Active Learning Group with Team-Based Quizzes

Discussion

In this study we compared the final scores of cohorts utilizing active learning and non-active learning methodologies. We found a statistically significant improvement in the educational outcomes of the students in the active learning group over the students in the non-active group which is supported by past literature (Armbruster et al., 2017; Crimmins & Midkiff, 2017; Freeman et al., 2014; Lugosi & Uribe, 2019; O'Sullivan & Cooper, 2003;). Prior literature in large meta-analyses found that students' exam performance with active learning compared to traditional learning attained effect sizes of 0.47, 0.50, and 0.51 (Freeman, et al., 2014; Ruiz-Primo et al., 2011; Springer et al., 1999), respectively. In comparison, our effect size was 0.21.

Unique to this study was the combination of adaptive learning with team-based quizzes and adaptive team membership. During each quarter the individual members of each team were able to freely change. This component of adaptation introduced a distinct element of inclusivity. Students with low team-based quiz scores were free to seek out a different team, if desired, and strive to improve learning. As shown in prior studies, active learning in undergraduate STEM courses decreases the achievement gaps (Haak et al., 2011) for underrepresented minorities (Urton, 2020) and also for first-generation college students (Eddy & Hogan, 2014). Additionally, further studies show that active learning not only benefits everyone, but disproportionately benefits individuals from underrepresented groups (Theobald, et al., 2020) and students with the lowest academic achievement (Crimmins & Midkiff, 2017). While our study did not isolate the effects on underrepresented groups, our results show that the overall variation in student performance decreases with active learning. Thus, active learning may help eliminate gaps in achievement and promote inclusive excellence.

Furthermore, while active learning promotes inclusive excellence, testing in particular has been shown to improve long-term retention. This phenomenon is known as the testing effect studied by cognitive psychologists. Roediger and Karpicke (2006a; 2006b) state that testing students on material will directly improve their memory for the material as compared to just studying the subject. Frequent testing may help boost educational achievement. This may partly explain why our test-intensive active learning intervention improved educational outcomes.

In a prior study by Oishi et al. (2017), a series of five in-class scenario-based quizzes were performed instead of traditional lectures to aid student understanding of complex math-intensive engineering concepts. Students worked in groups of three to solve math problems in the way of collaborative quizzes. Oishi et al. (2017) found that the collaborative quizzes helped the students who began with low scores rise to the top and eventually gain scores comparable to their higher-scoring peers. Our study, conducted in a similar manner, corroborates with the findings of this prior study.

Active learning naturally fosters an inclusive and collegial environment. For example, in one study (Lahdenpera & Nieminen, 2020) a mixed-methods analysis established that student-centered active learning environments may be helpful in improving the students' sense of belonging to the community. Similarly, we feel that the adaptive team-based quizzes boosted students' sense of belonging and helped build a learning community in this study. Additionally, Kogan and Laursen (2014) assessed the long-term effects of active learning in a case study from college mathematics and demonstrated that active learning provided benefits to particularly women and underrepresented groups.

We have shown in this study that active leaning has improved educational outcomes as measured by average final score. An important issue is to discuss is how content knowledge increased with active learning. In a mathematics course, we believe that content knowledge, or "command of the subject" is best measured by numerical scores achieved on homework, quizzes and exams containing problems relevant to the course material. In sum, a high final score indicates a mastery of the content knowledge specific to math finance.

Cooperative and collaborative work in the classroom actively prepares students with the essential skills needed to succeed in their future careers. A recent poll (Hart, 2007) showed that the number one skill is the ability to work well in teams, especially with people different from yourself. This is exactly the focus of the team-based quizzes introduced in this study, illuminating an additional third benefit of increased "life skills." The first two benefits of our active learning intervention, namely improved final scores and reduced variation in final scores, were measurable quantitatively. This third benefit of team-based active learning cannot be measured in class. We hope that it will provide a boost to our students' careers as they venture into post-graduation professional activities.

Conclusion

In this study, the student group with adaptive team-based quizzes had final scores with a lower variance and higher mean than the student group with traditional lecture-style learning. This constitutes a vote of confidence for active learning, and something that innovative educators may be interested in as tangible evidence for active learning in STEM improving educational outcomes. In sum, this study demonstrates that team-based active learning is both more effective and inclusive. Active learning in the form of adaptive team-based quizzes provides a potent solution for accelerating the accumulation of knowledge in the individual students, while achieving more inclusive excellence across all students in the class. This experiment validates results previously established in the literature (Sisk, 2011; Theobald et al., 2020).

Recommendations

Knowing that the class was ultimately graded on a curve, some of the higher-performing students may have been reluctant to pair up with the lower- performing students for the quizzes. Thus, for self-selected teams including the scenario with our study, the benefits to the lower-performing students may depend on the willingness of the higher-performing students to collaborate and share their problem-solving ideas with others. Further studies may be done to encourage educators to assign teams according to performance throughout the quarter to maximize inclusivity.

Limitations

There are many limitations to the conclusions that may or may not be drawn from this experimental data analysis. First and foremost, the number of students in the traditional learning cohort was roughly two-thirds of the number of students in the active learning group. Therefore, the statistical parameter estimates used to compute the IER may differ in precision (the variance of the sample variance used to compute the IER is proportional to $1/N$, so as the sample size decreases the variance of the sample variance increases accordingly.)

Secondly, it would be a more precise measurement of educational outcomes to compare the two distinct cohorts' performance on identical test questions between years. This may be a fruitful area of continued research in active learning.

Thirdly, the students self-selected their own teammates for the adaptive team-based quizzes. This process may bias the results such that the more sociable and outgoing students may have an advantage over the more introverted students who are unable to aggressively seek out strong teammates. A few students desired to complete the quizzes on their own, whereas some teams of 2 to 3 students began to merge once or twice throughout the 10-week quarter with other teams, creating super-teams who may or may not have had a competitive advantage.

Lastly, there may be multiple confounding factors that blur our results, such as the COVID-19 pandemic that hit college campuses in the spring of 2020 and generated much psychological stress.

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