Effect of time spent on active learning on exam performance: A controlled case study on a course with different instructors but identical teaching materials

Xinjian Cen[1¶], Rachel J. Lee[2¶], Jeffrey Maloy[1,3&], Melinda T. Owens[2,4&]

[1] Department of Molecular, Cell, and Developmental Biology, University of California, Los Angeles, California, United States of America

[2] Department of Neurobiology, University of California, San Diego, California, United States of America

[3] Department of Life Sciences Core Education, University of California, Los Angeles, California, United States of America

[4] Joint Doctoral Program in Math & Science Education, University of California, San Diego and San Diego State University, California, United States of America

* Corresponding author

E-mail: jmaloy@g.ucla.edu (JM)

E-mail: mtowens@ucsd.edu (MO)

¶ These authors contributed equally to this work.

& These authors also contributed equally to this work.

Abstract

Active learning, including student thinking and discussion in class, has been shown to increase student learning gains. However, it is less clear how variations in how instructors implement active learning affect student gains. Our study aims to investigate the extent to which the time spent on individual active learning activities influences student performance. We hypothesized that instructors who let students spend more time on individual thinking and peer discussion on practice problems associated with particular learning objectives will have better student exam scores on exam questions addressing those objectives. To test this hypothesis, we obtained a large data set of classroom recordings and student exam scores from an introductory biology course at a large four-year university, where three instructors shared identical teaching materials and exams for different course offerings.

Contrary to our hypothesis, although the three instructors spent significantly different amounts of time on episodes of thinking and peer discussion, there was no correlation between the total time spent on active learning activities and student performance on exam questions. Linear mixed-effects modeling of the effect of length of episodes of student thinking and discussion on exam score found that the amount of course time spent on active learning activities did not reliably predict student performance on associated exam questions. This result held true even when only considering learning objectives with high variations in performance between offerings, difficult exam questions, or within-instructor performance. Although our study was only conducted in one course, our results imply that time spent per individual episode of student thinking or peer discussion may not be the primary factor explaining the positive effects of active learning and that it may be worthwhile to explore other factors.

Introduction

Education in science, technology, engineering, and mathematics (STEM) is crucial for students entering careers necessary for national success [1]. Between 2000 and 2019, the number of STEM baccalaureate degrees awarded in the United States rose from about 400,000 to just under 725,000 [2]. Along with this increase there has been a renewed focus on committing instructors and institutions to adopt evidence-based teaching practices demonstrated to enhance students' understanding of essential concepts in STEM [3,4]. Despite substantial progress in research on what types of teaching techniques most effectively improve student learning, there is still a gap in our understanding about the mechanistic underpinnings of these techniques [5]. As a result, although many instructors may intend to adopt evidence-based teaching strategies, there is considerable variability in instructional practices used by instructors claiming to use similar instructional practices, which may contribute to variable student outcomes [6]. Therefore, it has become vital to identify the mechanistic contributors to the efficacy of evidence-based instructional practices to improve the dissemination and implementation of effective instructional techniques in the classroom.

Many decades of research have shown that learning is more effective when learners actively construct knowledge by assimilating new information into their existing worldview rather than passively taking in information, a well-known framework known as constructivism [7]. “Active learning” refers to a diverse set of teaching strategies inspired by a constructivist framework; these practices involve students in doing things and thinking about what they are doing rather than simply being physically present in an educational environment [8]. Numerous studies have shown that when compared to

traditional lectures, active learning environments increase student performance and decrease fail rates [9,10]. A meta-analysis by Theobald et al. further demonstrated that active learning not only benefits all students but especially helps to decrease grade gaps for minoritized students [11].

While the benefits of active learning have been established repeatedly, it is not always clear what specific teaching practices produce these benefits, as active learning is broadly defined [12,13]. For Auerbach and Schussler, active learning is defined as a student-centered pedagogy that incorporates student engagement and thinking through class activities where students collaborate and explain their understanding of concepts [14]. Others have defined active learning as the act of knowledge synthesis based on constructivism [15–18]. Still others define it as the absence of passive learning, with the goal of active learning being to minimize the time spent passively absorbing information taught through lecture [19–22]. Given such diverse definitions, it is not surprising that teaching strategies as disparate as cooperative learning, clicker questions, worksheets, interactive demonstrations, peer instruction, problem-based learning, and ability-based education are all called "active learning" in different contexts [23,24]. To assimilate these different ideas about active learning, Driessen et al. propose a broad definition of active learning as, "an interactive and engaging process for students that may be implemented through the employment of strategies that involve metacognition, discussion, group work, formative assessment, practicing core competencies, live-action visuals, conceptual class design, worksheets, and/or games" [13].

Despite the differences between various active learning contexts, one commonality between many of the active learning activities and definitions described above is the presence of students thinking and discussing materials in class [25]. If students are

thinking and discussing, they are not passively listening to the lecture. Instead, they are engaged, thinking, collaborating, and explaining, and at least some portion of class time is spent with the focus on the students instead of the instructor. Such activities can lead to active knowledge construction and the active assimilation of new information into students' existing knowledge structures [26]. Because of the direct tie between student thought and discussion and constructivist ideas about effective learning, it is possible that they may underlie many of the theoretical mechanisms of action describing why active learning benefits students intellectually, motivationally, and socially. For example, when students ponder and explain material to each other in class, these actions may promote advanced levels of cognitive thinking, promoting their conceptual development and helping them uncover their own misconceptions [27,28]. For example, student discussions about complex topics during class may promote advanced levels of cognitive thinking, encouraging conceptual development and helping students to unveil their own previous misconceptions [27,28]. Many of the affective benefits of active learning may also be explained by active thought and discussion by students in class, which stimulates their motivation and increases engagement [29,30]. Finally, as students talk and form connections with each other, it could increase feelings of community and belonging [31,32].

Due in part to increasing professional development opportunities and an overwhelming body of literature describing the benefits of including student thought and discussion during class, instructors are increasingly aware of practices meant to promote these behaviors in class, and a large number of instructors claim to incorporate student thought and discussion at least occasionally in their classes [33–35]. However, observational studies have indicated a large degree of variability in practice [36]. In part, this variability may be explained by the lack of consensus on best practices for implementation of specific active learning techniques. When an instructor includes student thinking and discussion in their class, they need to make numerous decisions about implementation. Even for a basic

clicker question, a commonly-used active learning activity where students use a clicker device to respond to multiple choice questions prompted by the instructor, the instructor needs to decide the difficulty and wording of the question, whether to force students to think about the question individually, whether to allow the students to discuss it with peers, how long students are given to think or discuss, and how to grade responses [36–38]. Different decisions in any of these aspects of implementation may affect how well instructors assess student understanding, provide student-centered feedback, and ultimately help students learn the material.

One understudied aspect of active learning implementation is the amount of time an instructor should spend on individual episodes of student thinking and discussion. In general, the evidence points to a positive correlation between the time spent on active learning and better student outcomes. Elliott et al. found that courses with more clicker questions generally had higher student grades, and Theobald et al. also showed that grade gaps between minoritized and non-minoritized students are the smallest in the courses with the most active learning [11,39]. However, these studies looked at differences attributed to time spent on active learning in general, which includes time that the instructor spends explaining, guiding, and following up after active learning activities, not specifically the time spent on student thinking and discussion. Studies that have looked at the time spent on individual episodes of student thinking and discussion have found that although instructors vary in the amount of time they give students to think about, discuss, and report their ideas, the effect of such differences on student learning is unclear [40]. Another drawback of these studies is that they compared different courses, which were also likely to be different in various confounding factors that may affect student learning, such as learning objectives, lesson plans, class slides, course assignments, and the content and number of questions given to students.

In this study, we controlled for these confounding factors by analyzing a model system where all teaching materials were identical across different offerings, so time spent on student thinking and discussion was one of the only active learning variables that instructors could alter. With this model, we asked whether the time spent on student thinking and discussion correlated with increased student learning as measured by performance on course exams. We hypothesized that instructors who allow students to spend more time on silent thinking and peer discussion associated with particular learning objectives would have better student exam scores on exam questions addressing those objectives.

Materials and Methods

Study Context

The study utilized a large data set of classroom video recordings and student exam scores from an introductory biology course at a large, public, West Coast R1 university. Permission for this study was obtained from the UCLA Human Research Protection Program in certified exempt protocol #19-001554. The course was in person and followed a "flipped classroom" model, where students in the course were assigned pre-class readings and recorded content videos to be completed before class [41]. For the majority of the time in class, students were expected to apply the knowledge obtained from pre-class activities to novel problems. The course had three offerings of 340-380 students each in the specific quarter studied, each taught by a different instructor. All instructors were full-time non-tenure-track instructors with multiple years of experience teaching and coordinating the course who have received professional development on implementing active learning. Each instructor used identical teaching materials, including Powerpoint

slides, clicker questions, and worksheets. They also all used the same comprehensive list of learning objectives, which corresponded to each class unit and aligned with exam questions. They worked together to develop the course teaching materials and agreed to not deviate from them, which was informally confirmed through viewing the video recordings of their classes.

The course had two midterms and a final exam, all in-person. Exams, which were solely multiple-choice to remove subjectivity in grading, were also jointly approved and identical for all three course offerings. All students answered the same questions, although there were two different versions of the exam with the questions shuffled to minimize cheating. Thus, student performance is directly comparable across the course offerings.

The active learning activities in this course consisted of in-class clicker questions, peer discussion questions, and worksheet questions. Typically, the instructors would direct the students to work on the clicker questions or discussion activities with their peers, although occasionally, students were asked to think individually or given no instructions. A certain amount of time was then allotted for students to complete the activity before the instructor regrouped and discussed the question with the students.

Analyzing exam performance

Exam questions were grouped by learning objectives before analysis. Researchers matched all of the exam questions and classroom active learning activities to their corresponding learning objectives. To find the exam performance for a particular learning objective for a particular instructor, we averaged that instructor's students' scores (average correctness) for all the exam questions addressing that learning objective. To compare performance

within instructors, the exam scores for each learning objective were normalized to reflect exam performance of a specific instructor relative to the average exam performance of all three instructors on that objective. This was done by subtracting the aggregate average score of all three instructors from the average score of that instructor's students.

Analysis of time spent on active learning

Time spent on active learning was calculated from video recordings. These video recordings were not recorded for research purposes; instead, they were automatically generated from cameras positioned in the back of classrooms to help students review lectures. Thus, they only captured instructor and screen activity in the front of the classroom. Audio was recorded through the instructors' lapel microphones. Instructors often turned the microphones and therefore the audio-recording off while students were actively thinking or discussing.

To measure time spent in active learning, two researchers hand-coded the length of each active learning opportunity from lecture recordings. More specifically, they used slide transitions and instructor cues to mark the times each clicker question or classroom activity opened and closed (Table S1, S2). The time spent on each episode of student thinking or discussion was calculated from the timestamps. We did not distinguish between episodes of student thinking and student discussion because in this course, instructors often did not ask for only one of these to occur, so it was likely that both occurred in overlapping time periods. The time spent on active learning per learning objective for each instructor was calculated by summing the total time spent on active learning activities (in seconds) for a particular instructor for each question that addressed the learning objective. Inter-rater reliability was established by having both researchers code the same 10% of the active learning activities and checking whether the researchers

coded each timestamp within 5 seconds of each other. If the coders disagreed on the timing of any activity's open or close, the researchers discussed their decisions and tried again until the coders could consistently independently choose timestamps within 5 seconds of each other.

Choosing teaching units to analyze

Because of the volume of exam and active learning questions, specific teaching units were chosen for analysis. Two approaches were taken to select specific teaching units of focus. The first approach was to choose the teaching units with learning objectives that aligned with exam questions where there was, on average, the highest standard deviation of performance between course offerings. One teaching unit was chosen from each third of the course, so that one unit each was tested on Midterm 1, Midterm 2, and the Final Exam. The second approach was to choose units that were particularly difficult for students, as indicated by having aligned exam questions with average correctness of ≤56%.

Statistical analysis

To determine whether the three instructors spent different lengths of time on student thinking/discussion and to determine whether exam scores were different between the instructors, we obtained the p-value from a randomization test using the PlotsOfDifferences tool, to which we then applied a Bonferroni correction [42]. Randomization tests are a way of determining the significance of differences between groups that do not rely on assumptions about the distributions of the data [43]. To determine whether there was a significant correlation between student performance and time spent in student thinking and discussion, we developed a linear mixed-effects model using the "lmer" command in the "lme4" package in R [44]. Statistical test results were generated with the "LmerTest" package, including p-values and summary tables for lmer model fits via Satterthwaite's degrees of freedom method [45].

Results

Because the three instructors observed in this study used identical course materials including clicker questions and active learning segments, we might expect that all instructors spent similar amounts of time on student thinking and discussion. However, statistical analysis via a randomization test shows a significant difference in the lengths of active learning episodes per instructor, with instructor B having much longer active learning episodes than instructor A ($p<0.001$; Cohen's d: 0.827; effect size: 45.593 seconds), who had moderately longer active learning episodes than instructor C ($p=0.048$; Cohen's d: 0.433; effect size: 16.159 seconds) (Fig 1A).

Fig 1. Overall trends in lengths and scores among the instructors.

(A) Length of the individual active learning episode lengths for each instructor. (B-D) The percent scores of all individual students on midterm 1, midterm 2, and the final exam, respectively. * $p\leq0.05$, ** $p\leq0.01$, *** $p\leq0.001$, ns $p>0.05$

Based on previous literature indicating that more active learning leads to better outcomes for students, with these differences in the amount of student thinking and discussion, one might also expect large differences in exam performance between each instructor's students [11]. However, there were no significant differences in the overall exam scores for any instructor on either midterm. For the final exam, instructor A had slightly higher scores than instructor B ($p=0.036$; Cohen's d: 0.112; effect size: -2.69%) (Figs 1B-D). Because overall exam performance was similar between course offerings, to address our question of whether increased active learning time contributes to improved student

outcomes we categorized the exams questions into discrete learning objective units and analyzed these units separately. Since students in each course offering performed similarly on many of the learning objectives on the exams, we first decided to focus on the learning objectives with high variability in performance between course offerings. Using linear mixed modeling, for these learning objectives, we observed no correlation between time spent on student thinking and discussion and exam scores ($p=0.5299$) (Fig 2A). However, we noticed that the two learning objectives in this sample that were particularly difficult for students, as indicated by average correctness of ≤56%, did show a strong correlation between exam score and time spent on student thinking and discussion, as seen by the gold and black lines in Fig 2A ($r^2=0.948$).

Given this observation, we hypothesized that increased time spent on student thinking and discussion might be beneficial for students specifically in the context of particularly difficult learning objectives. This would show up in our dataset as there might be a correlation between exam score and time spent on student thinking and discussing for a subset of learning objectives corresponding to very difficult exam questions. Thus, we applied linear mixed modeling to study teaching units that contained learning objectives corresponding to difficult exam questions, which we defined as questions with average correctness below 56%, which corresponds to the highest average score where we saw a possible correlation in our previous analysis. We still found no correlation between the length of time spent on active learning and student performance in for difficult exam questions ($p=0.67$) (Fig 2B).

Fig 2. Effect of length of student discussion on exam score.

Each line represents one learning objective. (A) Exam questions with high variability between instructors (p=0.5299). (B) Exam questions with <56% average correctness (p=0.6741)).

Finally, we investigated the possibility that within a given instructor, topics where students were given more time to think and discuss might contribute to increased learning versus other topics taught by the same instructor with less active learning time. whether there might be an effect within each instructor's teaching. In other words, given that the class only lasted a fixed amount of time, perhaps an instructor's students learned better on concepts where that instructor happened to allow the students to spend more time thinking and discussing. Therefore, we correlated the effects of time spent on active learning and student exam performance per instructor for the difficult learning objectives, normalized for each exam's average score. None of the instructors showed a significant correlation (Fig 3).

Fig 3. Normalized lines of regression per instructor (normalized score v. time spent on active learning) (95% confidence intervals are shown as shaded areas and p-values are labeled on each plot). A data point above the x-axis indicates that an instructor's exam score on a particular learning objective is above the average exam score for a particular learning objective across all three instructors.

Discussion

Our case study is a controlled observational study in which different offerings of the same course had different instructors but the same set of teaching materials. This setup means

that instructors could only vary on their implementation of the teaching material, one aspect of which is the amount of time spent on student discussion and thinking. Overall, somewhat surprisingly we found no effects of spending more time on student thinking and discussion on exam performance. Although the three instructors gave substantially different amounts of time to student thinking and discussing (Fig 1A), that variation was not reflected in student exam performance. In fact, instructor A had higher Final Exam scores than instructor B despite giving students shorter amounts of time to think and discuss (Fig 1D). There was no relationship between exam performance and time on student thinking and discussion even when only considering learning objectives with high variations in performance between offerings (Fig 2A), difficult exam questions (Fig 2B), or within-instructor performance (Fig 3).

This result was unexpected and is difficult to explain. Constructivism as well as a host of individual studies show that active learning, which includes student thinking and discussion, generally promotes student learning [9]. A previous study documented that in a similar system where two instructors shared common instructional materials, the instructor who spent more class time on having students discuss questions also had higher exam scores [46]. However, those two instructors had much larger differences in how much time they spent in student discussion (roughly 5% compared to roughly 30% of class time) than we saw, which may account for the larger differences they saw in student outcomes.

Implications for Education

One possible way to reconcile our results with existing literature is to separate the effects of giving students more time on fewer clicker questions as opposed to giving students more questions. For example, Elliott et al (2016) did find a correlation between student

learning gains and classroom time spent in active learning [39]. However, this study correlated having more active learning questions with greater student performance, not spending more time on discussion of each question. It is not clear how an instructor can tell how much time students should get when discussing questions, especially if they give questions of varying difficulty [40]. When thinking about how to use a limited amount of class time, our results combined with existing literature suggest that instructors may want to err in the direction of providing more questions and problems and spending less time on each one.

Our study also adds to the literature about educational "fidelity of implementation," which has implications for curriculum development [47]. We found that even when instructors were given identical teaching materials, instructors implemented them differently (Fig 1A). That also accords with the results of Lo et al., who found that two instructors who co-created and used identical teaching materials spent significantly different amounts of time allowing students to discuss questions, answering student questions, and personally stimulating and supporting student discussion [46]. Many groups have tried to create instructional change by disseminating curricula, but there is significant controversy over whether these efforts are effective, in part due to instructor variability in implementation [47, 48]. Our study's results suggest that although instructors do indeed make their own decisions regarding implementation and variability is introduced between instructors when they are using co-constructed materials, this variability may not necessarily lead to different outcomes for students.

Finally, our study suggests that we cannot blindly assume that more student thinking and discussion automatically equates to better learning. This caution is especially important given that there are several established classroom observation tools that measure the

amount and percentage of class time spent on various active learning activities like peer discussion. Examples include the Classroom Observation Protocol for Undergraduate STEM (COPUS), which uses a set of codes to categorize student and instructor behavior within every two minutes of class time [49], and Decibel Analysis for Research in Teaching (DART), which analyzes the volume and variance of classroom audio-recordings to estimate the percentage of time spent in active learning [50]. Although the creators of such protocols are clear in stating that they only measure the classroom activity, not the quality of instruction, there has been a tendency among users to over-interpret observation protocol findings and assume that teaching styles with more active learning are inexorably better [51,52]. While it is clear that pure lecturing typically produces poor learning compared to many kinds of active learning, there are many other factors that influence teaching effectiveness [9,52]. Our study adds to the literature showing that "more time" may not always mean "better" and that although protocols like COPUS and DART give useful information, their results should ideally be put in greater context especially in high-stakes situations like instructor evaluations.

Limitations

The nature of this study presents several limitations. One is that given that the majority considerable amount of class time was already spent on students doing active learning, so the differences in time spent on student thinking and discussion between offerings may not have had a large effect. It is true that when only considering time on student thinking and discussion, the effect sizes were large to moderate based on Cohen's d. However, because of the "flipped" format of the class, all instructors gave many clicker questions and spent little time lecturing on new materials. It is possible that increased student outcomes

due to active learning were already “baked in” to the course design and that any additional variation in time spent on active learning by specific instructors produced diminishing returns compared to the effect of the overall course structure.

The fact that this study analyzed real courses also meant that there were many factors that could not be controlled for. The course offerings were held at different times of day, which may have affected student attendance or engagement with the learning activities. Students likely varied in how much time they spent and what techniques they used to study the course material outside of class. In addition, we did not analyze teaching techniques used during graduate TA-led discussion offerings or out-of-class exam review sessions. However, given that we did not see large differences between instructors in exam scores, it is likely that these factors did not lead to systematic differences between course offerings.

We also did not consider the quality of active learning. The audio recorders were typically turned off during active learning activities, preventing researchers from observing or hearing student activity. This raises questions about how engaged students were, as some of them may have been doing off-topic activities during the thinking and discussion period. This research study also did not take into account the quality of the questions posed by instructors and whether they would have provoked substantial discussions that needed more time. It is possible that questions asking students to engage in more complex thinking might benefit from more discussion time while questions testing lower order cognitive skills may not (CITATION). Since the clicker and activity questions were not classified according to their complexity and specificity, all questions, regardless of their difficulty levels, were treated the same in this study.

Lastly, this is a case study, and the curriculum and setting of the course were specific to the university of interest. Thus, findings may not generalize to other courses. More work will be needed to determine whether there may be benefits of student thought and discussion time that are context specific.

Future directions

There are many possible future directions to this study. Since questions of all types and difficulty levels were treated equally in this study, it would be worthwhile categorizing the active learning questions using Bloom's taxonomy, a classification system used to differentiate between different levels of cognitive skills [53]. With this information, it would be possible to see whether the amount of time spent on particular types of active learning questions, such as those that require students to comprehend versus evaluate information, has a differential effect on student performance.

Another factor that can be explored would be the type of behavior that students were engaged in during the active learning time period. For instance, if this study can be conducte such that there are recorders where the students are, then the student's behaviors (whether they are engaged in peer discussion, individual thinking, or studying independently), can be coded. Studies have shown that students who engaged in peer discussion/instruction showed better learning outcomes than students who completed activities individually [54,55].

Instructor feedback post active learning activities can also be considered to further study th impact of various aspects of teaching and learning on student performance. Previous studies

have shown that students reported appreciating extra time spent in the follow up phase of clicker questions to address correct and incorrect questions in order toto help them develop their understanding of concepts [56]. Instructor feedback has also been shown to improve student performance and learning [57,58]. Thus, it may be beneficial to look into instructor feedback to explore other potential factors in the classroom that affect student learning.

Lastly, although different instructors had differences in discussion timing, it is not clear why such variations arise. Are these differences coming about because instructors are attending to different classroom cues, like the amount of noise; doing different activities, like spending time with individual student groups during the discussion period; or making different decisions about what percentage of the students have submitted answers [40,46]? If so, how do such differences relate to differences in instructor ideas about learning, teaching, and diversity? Understanding why instructors make implementation decisions will greatly benefit faculty development efforts.

Conclusion

Overall, our results imply that time spent in student thinking and discussion may not be the primary factor explaining the positive effects of active learning. It would be worthwhile to explore other variables that might explain those positive effects, such as number of clicker questions or activities or how instructors support or follow up on student discussions. Additionally, we show that student learning is robust to some differences in implementation of active learning techniques, suggesting that dissemination of shared teaching materials between instructors with similar levels of training and experience with active learning techniques may be an effective means of reaping the benefits of active learning in more classrooms. Moving forward, similar studies using co-constructed and shared materials with controlled deviations per instructor may help to discern the possible mechanisms by which active learning activities impact students in the undergraduate classroom.

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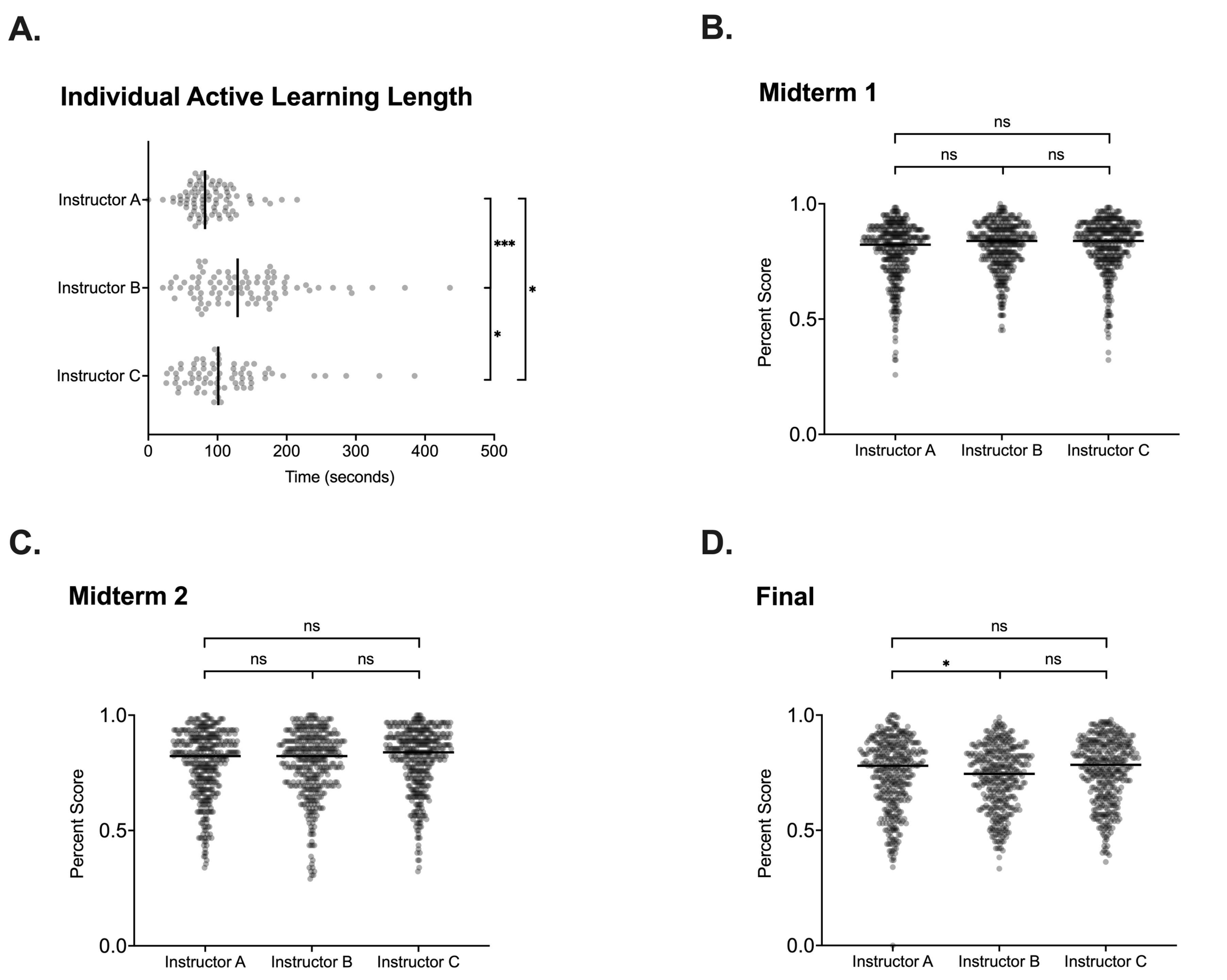
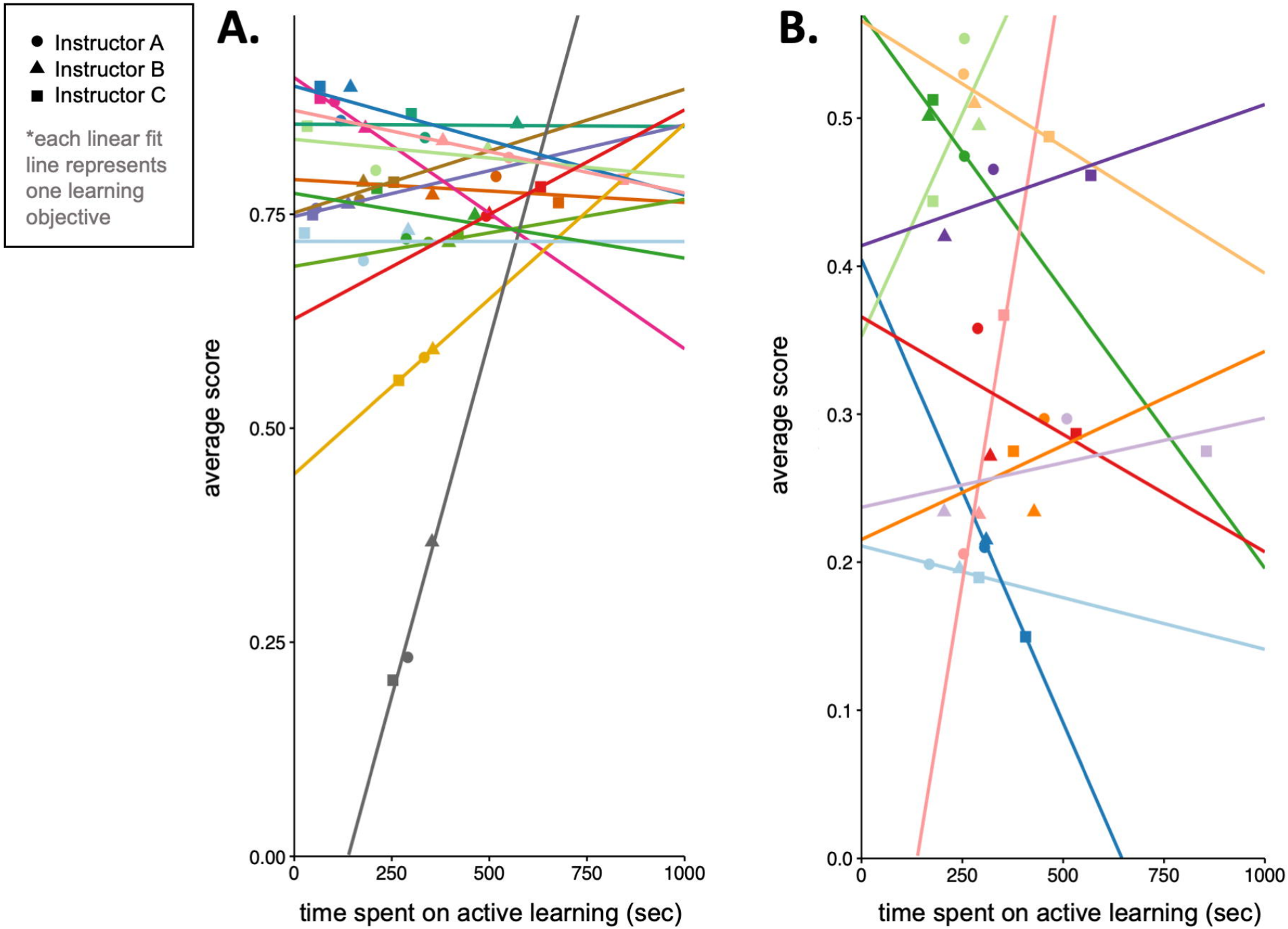
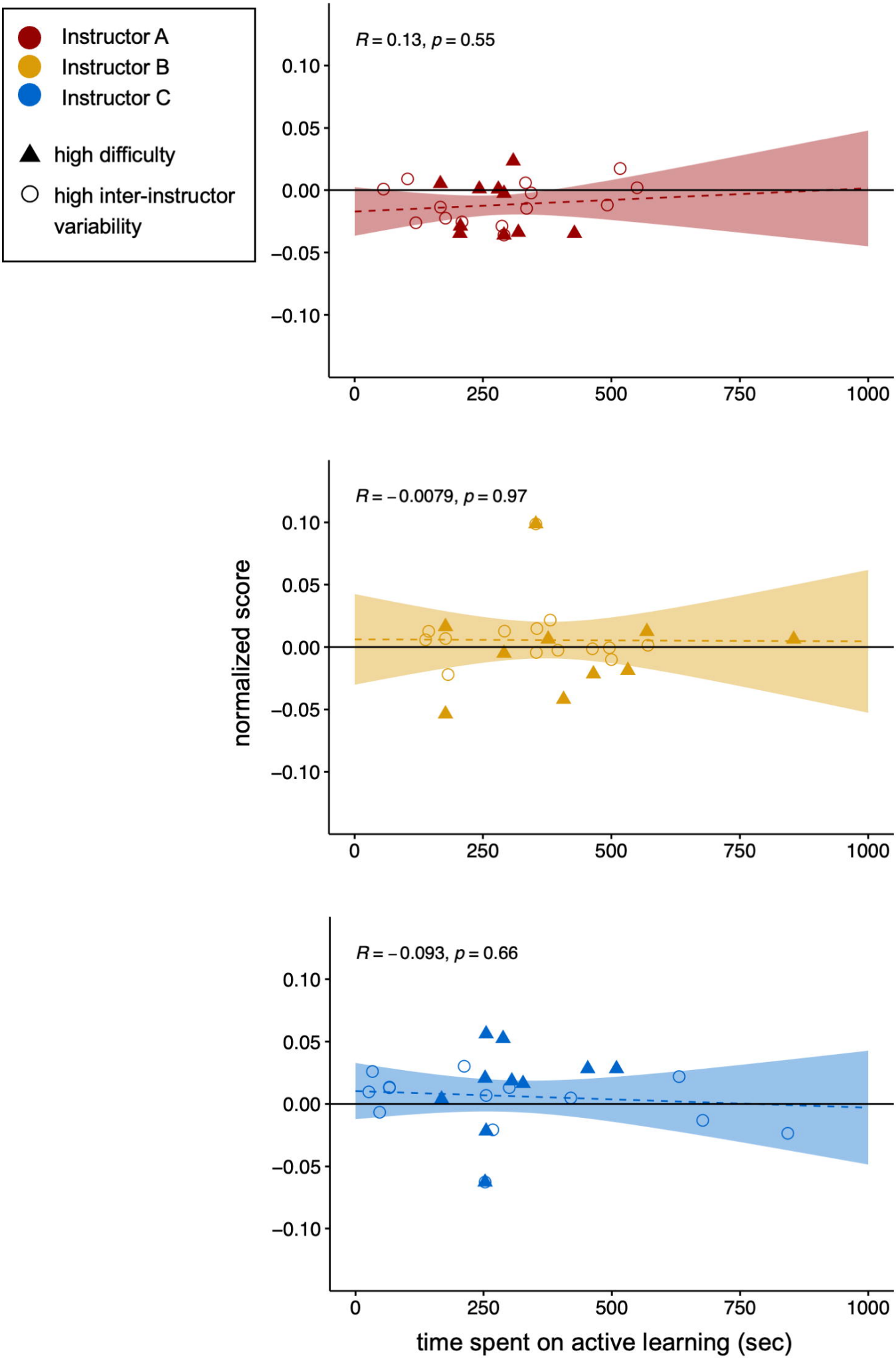
Supporting information

S1 Table. Guidelines for how to determine starting times for each active learning activity.

S2 Table. Guidelines for how to determine ending times for each active learning activity.


A.
Individual Active Learning Length
Instructor A
Instructor B
Instructor C
***
*
*
0
100
200
300
400
500
Time (seconds)
B.
Midterm 1
ns
ns
ns
1.0
0.5
0.0
Percent Score
Instructor A
Instructor B
Instructor C
C.
Midterm 2
ns
ns
ns
1.0
0.5
0.0
Percent Score
Instructor A
Instructor B
Instructor C
D.
Final
ns
*
ns
1.0
0.5
0.0
Percent Score
Instructor A
Instructor B
Instructor C


Instructor A
Instructor B
Instructor C
*each linear fit line represents one learning objective
A.
average score
0.00
0.25
0.50
0.75
0
250
500
750
1000
time spent on active learning (sec)
B.
average score
0.0
0.1
0.2
0.3
0.4
0.5
0
250
500
750
1000
time spent on active learning (sec)


Instructor A
Instructor B
Instructor C
high difficulty
high inter-instructor variability
R = 0.13, p = 0.55
R = −0.0079, p = 0.97
R = −0.093, p = 0.66
normalized score
0.10
0.05
0.00
−0.05
−0.10
0
250
500
750
1000
time spent on active learning (sec)