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Work in Progress: Exploring Before Instruction Using an Online GeoGebra Activity in Introductory Engineering Calculus

Dr. Jeffrey Lloyd Hieb, University of Louisville

Jeffrey L. Hieb is an Associate Professor in the Department of Engineering Fundamentals at the University of Louisville. He graduated from Furman University in 1992 with degrees in Computer Science and Philosophy. After 10 years working in industry, he returned to school, completing his Ph.D. in Computer Science Engineering at the University of Louisville's Speed School of Engineering in 2008. Since completing his degree, he has been teaching engineering mathematics courses and continuing his dissertation research in cyber security for industrial control systems. In his teaching, Dr. Hieb focuses on innovative and effective use of tablets, digital ink, and other technology and is currently investigating the use of the flipped classroom model and collaborative learning. His research in cyber security for industrial control systems is focused on high assurance field devices using microkernel architectures.

Dr. Marci S. DeCaro, University of Louisville

Marci DeCaro is an Associate Professor in the Department of Psychological and Brain Sciences at the University of Louisville. DeCaro's research applies principles of cognitive psychology to study learning and performance in educational contexts.

Dr. Raymond Chastain

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Abstract

This work in progress paper discusses preliminary research testing the causal effectiveness of exploratory learning in undergraduate STEM courses. Exploratory learning is an active-learning technique that has been shown to improve students' conceptual understanding, and is therefore well suited for STEM education. This method reverses the order of traditional lecture-then-practice methods, by having students explore a novel problem prior to instruction. Participants (*N*=150) were first-year engineering students enrolled in an introductory engineering calculus course. Students were taught about two-dimensional vectors in an online, asynchronous learning module. Students were randomly assigned to one of two conditions. In the instruct-first condition, students viewed the instruction and then completed a Geogebra™ activity. In the explore-first condition, students completed the activity and then viewed the instruction. Thus, the exact same activities were given to students, allowing us to test the causal effectiveness of reversing the placement of the activity. Afterwards, all students completed an online quiz and a later Vector test. A number of students opened but did not complete the activity. Of those students, no effects of condition were found. For the students who completed the activity, those in the explore-first condition scored higher on the quiz than those in the instruct-first condition. Scores were trending in a similar direction on the vector test. These results demonstrate the potential of exploratory learning to improve understanding in engineering mathematics, and in an online module format. This research also suggests that Geogebra™ may be a useful tool for developing an exploration activity students can complete online.

Introduction

This paper presents preliminary work testing the causal effectiveness of exploratory learning in a first-year undergraduate engineering mathematics course. *Exploratory learning* is an active-learning method that reverses the typical order of instruction. Traditionally, instructors give students a lecture, followed by problem-solving practice. However, students often experience fluency—thinking they understand the material better than they actually do. Then, students devote superficial attention and effort that does not sustain learning [1-2].

In exploratory learning, students first explore the new topic with an activity, and then are provided with lecture [2]. This method is thought to have both cognitive and metacognitive benefits over traditional instruction. Students become better aware of gaps in their knowledge, motivating them to attend to the subsequent lecture [3-4]. By working through the novel material, students also begin to discern what features are, or are not, important in the problems [2.5]. This process allows students to better understand the deeper structure [6]. In addition, students activate their prior knowledge, which better allows them to integrate what they already know with the new content, creating more organized knowledge [3].

In previous studies, exploratory learning has been shown to improve students' conceptual understanding compared to traditional lecture-first methods [3,7]. Students typically learn procedures equally well from traditional and exploratory learning methods. But with exploratory learning, students gain greater understanding of the underlying concepts and ability to transfer this knowledge to new material [3]. Conceptual understanding is critical in STEM undergraduate education. However, only a few studies have tested the efficacy of exploratory learning in undergraduate STEM courses e.g. [8-9]. No studies have yet been conducted in engineering mathematics courses or on a precalculus topic. There is a need for more controlled experiments, and specifically those testing the efficacy of exploratory learning in engineering education.

In addition, nearly all previous studies have compared exploratory learning and traditional instruction conditions in face-to-face classes. Instructors are increasingly moving course content online, particularly during the events of the past year. To our knowledge, the work presented here is the first attempt to conduct a controlled study using online asynchronous delivery of exploratory learning. Thus, it is unknown whether the benefits of exploring before instruction extend to online modules.

Current Pilot Study

We conducted a pilot study to test the causal benefits of switching the order of instruction in a first year, introductory calculus course for engineering majors. Students were randomly assigned to instruct-first or explore-first conditions. Students in the traditional, *instruct-first condition* first viewed instruction, and then completed a related activity. Students in the *explore-first condition* saw the same materials in reverse order (activity, then instruction). Controlling the materials given between conditions, and only changing the order, allowed us to determine whether the order of instruction had a causal impact on students' learning. Many prior studies on exploratory learning do not use controlled experiments, which creates an issue in interpreting what specific factors led to the results [3,10-11].

Our primary goals were to (a) design a graphical exploration activity for vectors, and (b) experiment with a method to administer exploratory learning activities asynchronously online. Geogebra™ was chosen as the platform for student exploration. Geogebra™ is a programable graphing calculator and computer algebra system with basic GUI widgets like sliders. Because Geogebra™ runs in a standard browser and is free to anyone, it provides a portable and easily accessible exploration platform. Geogebra™ supports the creation of activities where predefined graphical elements can be manipulated by a user, including moving vectors around on the coordinate plane. These features, combined with the intuitive interface, makes Geogebra™ a good exploration platform.

Although this pilot study was primarily intended to develop and implement these new methods in an introductory calculus course, we also assessed learning outcomes (an online quiz and a later test). We predicted that students in the explore-first condition would show higher conceptual understanding than those in the instruct-first condition. Such preliminary findings would support further use of this activity in subsequent studies. Such findings would also demonstrate the effectiveness of exploring before instruction in engineering education, even when using an online format.

Methods

Participants and Design

Participants (*N*=150) were all students enrolled in a first-year, introductory engineering precalculus course in Fall, 2020 who completed the lesson's primary learning quiz. Additional students (*n*=17) were excluded from analyses, because they spent less than one minute on the quiz (their scores ranged from 0 to .14). Unfortunately, the majority of the students in our sample (*n*=106) opened the exploration activity link but did not actually work on it. Rather than excluding these students from the dataset, we categorized students into two groups and treated this factor as a quasi-independent variable. Thus, we had a 2 (activity completion: completed activity, did not complete activity) × 2 (condition: explore-first, instruct-first) between-subjects factorial design.

Lesson Overview

The course includes many of the traditional precalculus topics, including a review of algebra, functions, rational function, trigonometry, limits and derivatives. The course also includes a brief introduction to 2-dimensional vectors. Introduction to vectors, covered around week 8, was chosen as the topic for the study. Vectors were selected because they are novel for most of the students in the class. The course was taught using a hybrid course structure, where much of the delivery of the course was moved online. Student came to class once a week, provided they felt safe. Class attendance was poor due to many COVID-19 related circumstances.

Nearly all student work was done using MyMathLab, an online multimedia homework, reading, and test platform. For each topic, students had between 2 to 5 lessons. Each lesson consisted of three MyMathLab assignments: 1) ***Lesson Vocabulary and Concepts***, an initial instruction component, where students received summary notes of that lesson's topic and, in many cases, instructional videos, along with short answer questions to test vocabulary and basic concepts, 2) a ***Lesson Quiz***, and 3) ***Lesson Practice***. Using prerequisites, students were forced to complete the assignments in that order. The Lesson Practice was adaptively modified by the Lesson Quiz by removing questions and learning objectives scored correct on the Lesson Quiz. Unlike quizzes, Lesson Practice is a homework assignment, meaning students are told their answer is incorrect when they enter it and can change it while they are still working that question. Lesson Practice often includes resources like additional instructional videos or MyMathLab Learning Aides like "show me an example" and "help me solve this." After completing the Lesson Practice, students could retake the Lesson Quiz up to 3 additional times. A minimum quiz score of 70% was required to proceed to the next lesson in the course. Each major topic area culminated in a test. The tests were also administered in MyMathLab, usually replaying a pooled subset of the quiz questions.

Geogebra™ Activity

The vector topic was broken into two lessons. Lesson 1 was an introduction to 2-dimensional vectors focused on geometric and algebraic vector addition (subtraction), scaling of vectors, slope and the length (magnitude) of a vector. Lesson 2 focused on the operations of dot product and vector projection. Lesson 1 included the target material for this study; Lesson 2 was given in a traditional instruction format. For Lesson 1, an activity was developed in Geogebra™ that provided students some key definitions and visualizations for 2-dimensional vectors, and then facilitated an exploration with geometric vector addition and subtraction using the parallel displacement and scaling. Some elements of the activity are shown in Figure 1. In Panel 1, students are given the definition of a vector and use the interactive figure to explore the change in direction and length of a vector. In Panel 2, students could move vectors around with their mouse, replicating parallel displacement. The first activity then asked them to identify which vector equations they thought were true based on the vectors in Panel 2. They could check to see if their answer were right. A second activity followed a similar interactive figure that allowed students to visualize scaling of a given vector. The second activity asked them to use the information in Panel 4 to pick the correct statement for $\vec{v} + \vec{w}$, where the statements result of $\vec{v} + \vec{w}$ was in terms of $\hat{\imath}$ and $\hat{\jmath}$.

Geogebra™ allows for tracking of student results on the activity. To access the activity, students were required to click the link from MyMathLab. However, they did not receive points for working through the activity. Therefore, many students opened the activity but did not actually work through the panels. Students who did, and did not, complete the activity were separated into different groups for analyses.

Instruction

The instruction component had students first open a set of prepared lecture notes that have definitions and theorem explanations along with a few worked examples. Next, students viewed three instructional videos that included more detailed explanation of the concepts in the notes, explained the examples in the notes, and worked additional examples. Some questions followed this content delivery component that asked students to recall key definitions and terms from the content (e.g., the definition of magnitude of a vector, what is a unit vector).

Lesson Quiz and Vector Test

After completing both the activity and instruction (in different orders depending on condition), both groups took the Lesson Quiz for the first time. After their first attempt at completing the Lesson Quiz, students did the lesson practice and could retake the quiz (the typical practice in this course). Then, students completed Lesson 2, which was not the target lesson for this experiment and therefore was the same for both conditions.

After completing both Lessons 1 and 2, which was achieved by scoring above 70% on each lesson quiz, students took the topic test on vectors. The vector test included questions from Lessons 1 and 2. Items on the vector test were divided between target items and non-target items. ***Target items*** tested on material provided during Lesson 1, the explore-first/instruct-first intervention. These target items were written to test conceptual understanding of geometric and algebraic vector addition, by asking students to solve problems that combined features of the lessons. For example, one question asked students to, "Find a vector of length 3 in the opposite direction of $\bar{v}$." This item draws on students' conceptual understanding of how length and directioncan be combined.. The testing platform allowed students to input numeric and algebraic expressions rather than selecting the correct response from a list of choices, limiting students' ability to reverse engineer answers. ***Non-target items*** tested the material given in Lesson 2, the lesson following the intervention. Target and non-target items were intermixed on the vector test.

Procedure

Students were randomly assigned to one of the two conditions using the "rand" function in excel. Students in the ***instruct-first condition*** began with the Lesson 1 Instruction, and then did the Lesson 1 Geogebra™ Activity. Students in the ***explore-first condition*** were assigned to complete the Geogebra™ Activity followed by the instruction. After completing both parts of the lesson, all students attempted the Lesson Quiz, and then did the Lesson Practice. Students could retake the Lesson Quiz up to four times. Analyses of the lesson quiz used only results from the first attempt. Students then completed Lesson 2 on the dot product and vector projection. Afterwards, students took the Vector test, which included items from both Lesson 1 (target items) and Lesson 2 (non-target items). At the end of the semester, students were debriefed about the study and given the option to remove their data from analyses. No students chose to do so.

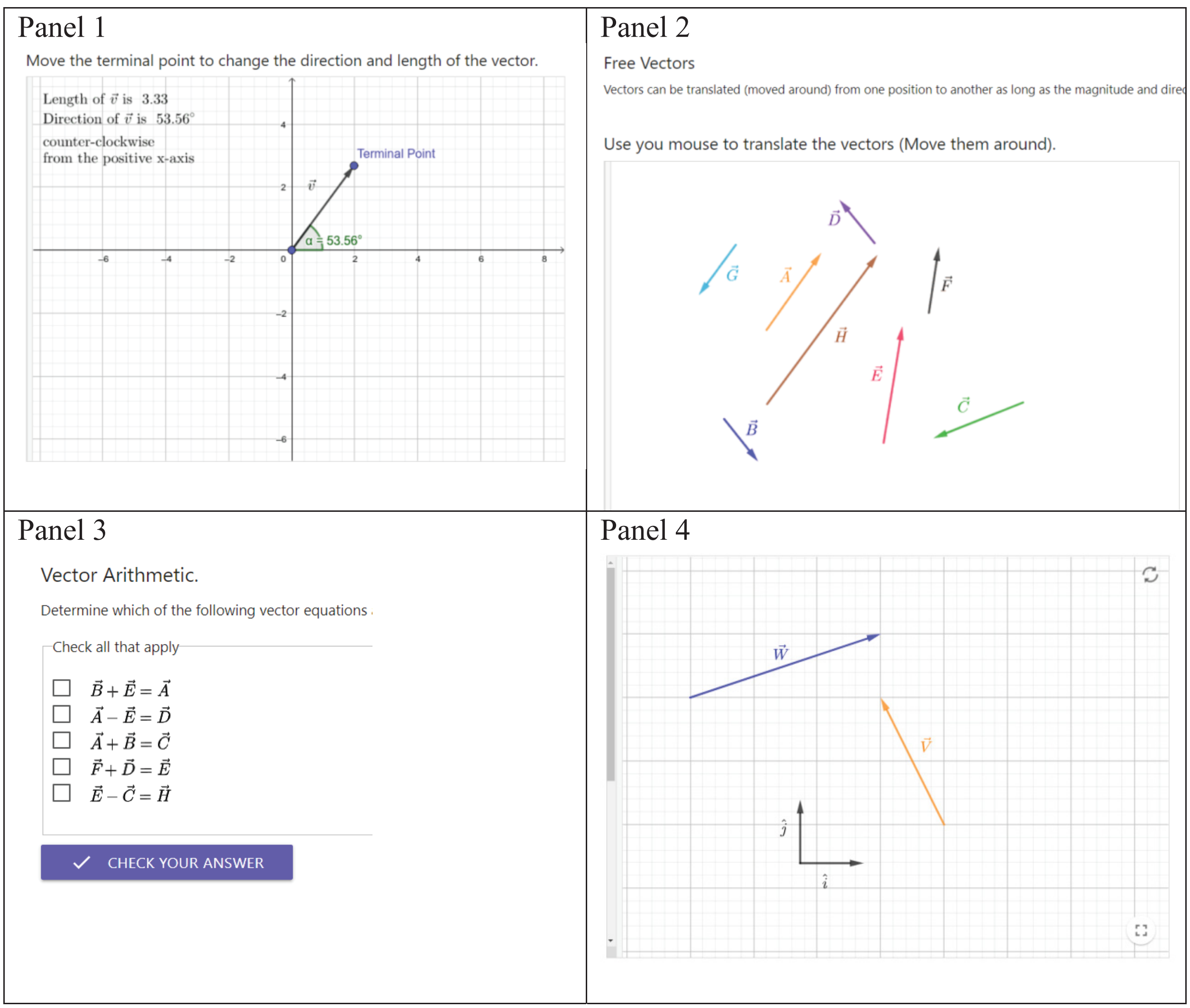

Figure 1. Elements of the Geogebra™ exploration activity.

Results

Lesson Quiz

We examined performance on the Lesson Quiz using a 2 (activity completion: completed activity, did not complete activity) × 2 (condition: explore-first, instruct-first) between-subjects factorial ANOVA. No main effects of activity completion or condition were found, Fs<1. However, a significant interaction emerged, $F(1,146)=4.06$, $p=.046$, $\eta_p^2=.03$. Planned comparisons revealed that students who did not complete the Geogebra™ activity showed no differences on quiz scores as a function of condition (instruct-first $M=.43$, $SE=.07$; explore-first $M=.40$, $SE=.05$), $F<1$ (Figure 2). In contrast, for students who did complete the Geogebra™ activity, scores were higher in the explore-first ($M=.63$, $SE=.07$) compared to the instruct-first ($M=.43$, $SE = .07$) condition, $F(1,42)=4.62$, $p=.037$. In addition, in the explore-first condition, scores were higher for students who completed the Geogebra™ activity compared to those who did not, $F(1,71)=8.37$, $p=.005$. There were no differences in scores in the instruct-first condition as a function of completing the activity, $F<1$.

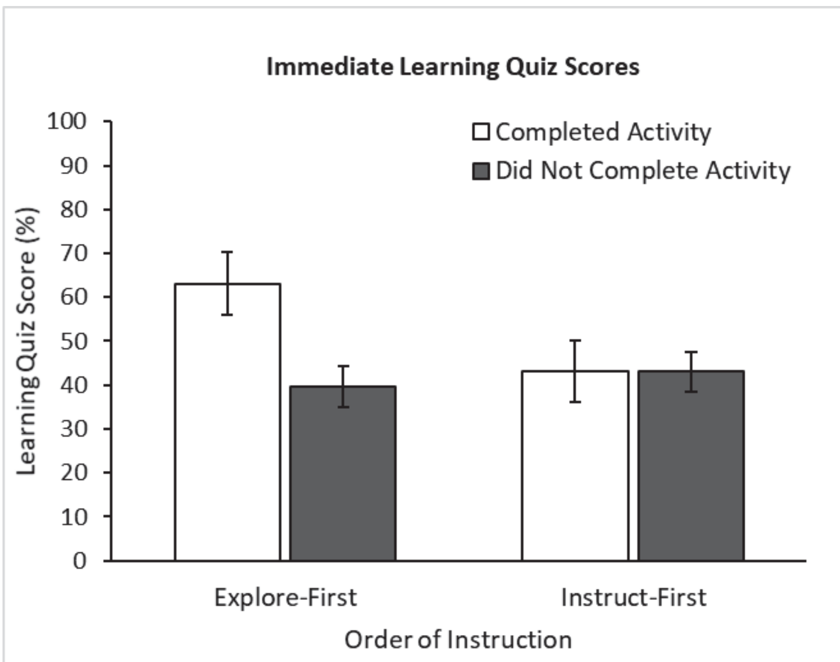

Figure 2. Immediate learning quiz scores (percent) as a function of condition and whether students completed the Geogebra™ activity.

Vector Test

Performance on the vector test was examined using a 2 (activity completion) × 2 (condition) × 2 (item type: target, non-target) mixed-factorial ANOVA, with item type as the within-subjects factor. No main effects were found, $F_{\text{item type}}=2.88$, $p=.092$, $\eta_p^2=.02$, all other Fs<1. In addition, no significant two-way interactions were found, $F_{\text{item type}\times\text{condition}}=2.65$, $p=.106$, $\eta_p^2=.02$, $F_{\text{item type}\times\text{activity completion}}<1$. However, a significant three-way interaction emerged, $F(1,146)=4.80$, $p=.030$, $\eta_p^2=.03$ (Figure 3).

On the target items, for students who did not complete the Geogebra™ activity, scores did not differ as a function of condition, $F<1$. For students who completed the activity, scores were generally higher in the explore-first condition, but this finding was not significant, $F(1,42)=2.18$, $p=.147$. On the non-target items, no differences were found as a function of activity completion for either condition, *F*s<1.

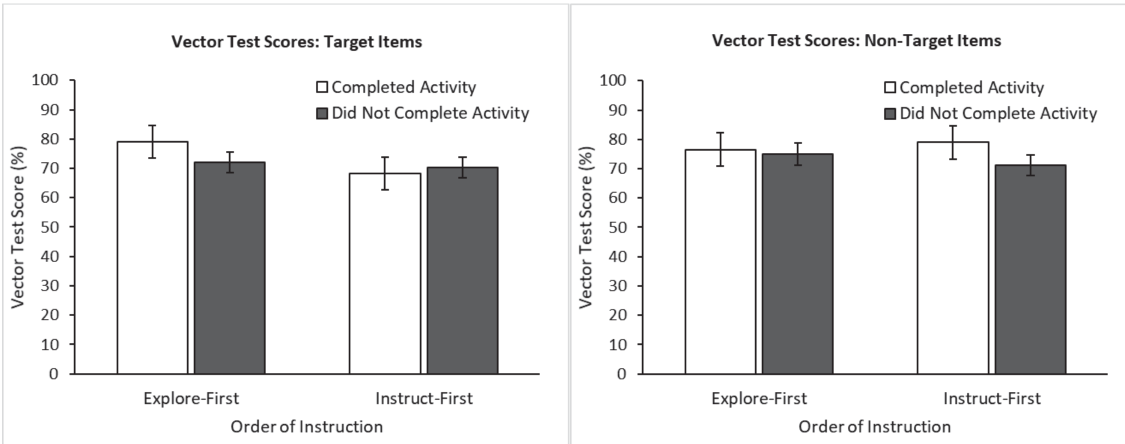

Figure 3. Vector test scores (percent) for items targeted by the intervention activity (target items; left graph) and items given in a different lesson (non-target items; right graph), as a function of condition and whether students completed the Geogebra™ activity.

Discussion

Students who completed a Geogebra™ activity to explore a new concept before instruction had higher scores on an immediate lesson quiz than students who completed the same activity after instruction. Students who explored also trended towards higher scores on a later vector test. However, the sample was relatively small, which likely limited power to detect the latter effect. These results show promising evidence for the use of exploratory learning activities in an asynchronous, online learning module on an undergraduate engineering mathematics topic.

However, more research is needed to replicate these findings. Because students were given credit on the Geogebra™ activity regardless of whether they actually worked on the problems, many students did not actually complete the activity. These students showed no differences in learning scores as a function of condition. Interestingly, students assigned to the explore-first condition who did not actually complete the Geogebra™ activity also scored significantly lower on the learning quiz than students who did explore the Geogebra™ activity. This result could be due to a selection effect, in that students who opted to explore the activity may also be more engaged learners in general. However, these students did not show higher scores on unrelated, non-target items on the Vector Test. Taken together, these findings suggest that the exploration activity led to improved learning on the targeted knowledge, rather than individual differences. These findings also suggest that simply seeing the activity (but not interacting with it) does not elicit these same benefits.

We only analyzed results from students' first attempt on the Lesson 1 Quiz. After taking this quiz, students were able to practice the problems and then retake the quiz. Students were required to earn 70% to move on to the next lesson. Therefore, scores on all but the first quiz were relatively high, leading to a restricted range in the data. We reasoned that the first quiz attempt reflected knowledge gained after the activity and instruction, which were the target of our intervention. However, students were aware that they would be able to retake the quiz, potentially impacting their motivation on this assessment. In our future research using these materials, we may make the first quiz worth more points, to incentive effort on this quiz and ensure our results reflect knowledge rather than other learning strategies.

This is the first study to examine the use of exploratory learning in undergraduate engineering mathematics. We randomly assigned students to experimental condition, and used the exact same activities across conditions—just switching the order of activity and instruction. These features strengthen the causal conclusions we can make about the benefits of exploring before instruction. We plan to replicate and extend these findings with new samples and new topics, with adjustments to the procedures as needed (e.g., requiring students to complete the Geogebra™ activity).

To our knowledge, this is also the first study to use an online, asynchronous learning module to implement an exploratory learning activity. Thus, this study provides promising evidence that exploratory learning can be implemented in online learning modules completed by students at their own pace. This study also suggests that Geogebra™ may be a useful tool for designing an exploratory learning activity for calculus topics, especially when using an online learning format.

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