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Exploration with ellipses helps students learn transferrable isometric drawing skills

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Exploration prior to instruction leads to transferrable isometric drawing skills

Abstract

This Complete Research Paper describes student learning outcomes following a lesson on isometric drawings in a first-year engineering course. We compared learning outcomes between students in an exploratory learning condition, who participated in an activity prior to content instruction, and those who received the instruction first, followed by the same activity. Students in the explore-first condition scored higher on an assessment that required them to repeat the instructed procedure as well as transfer the knowledge onto more complex drawing tasks. These results indicate that exploratory learning can benefit student learning in first-year engineering courses.

Introduction

Exploratory learning is an active-learning method in which students are given an exploration activity (e.g., a novel problem to solve [1]) on a new topic followed by direct instruction [2]. This constructivist-inspired approach allows students to actively build knowledge by interacting with provided materials. The instruction following the exploration avoids the common pitfalls of other constructivist techniques (e.g., the possible incorrect learning and confusion from pure discovery learning, e.g., [3]).

Students are thought to benefit from exploratory learning in several ways. First, exploration is a type of active learning, which results in higher student engagement and greater knowledge acquisition compared to passive lecture (see [4]–[7]). Second, reversing the traditional tell-then-practice order invokes several powerful learning mechanisms. As they explore, students instinctively recall related prior knowledge (e.g., [8]–[10]), which results in stronger connections between old and new information and generates a better organizational schema for long-term knowledge storage and retrieval [11]–[13]. In addition, students become aware of gaps in their knowledge, leading them to attend better to the subsequent instruction [14], [15]. Lastly, exploration gives students an opportunity to observe important problem features within the new topic [16]–[18]. Problem features can be thought of as important elements or characteristics of the concept as well as relationships between these elements. Exploration can help students identify relevant problem features in the new topic and begin to understand the relative importance of each feature.

For example, Schwartz and colleagues studied exploratory learning by teaching density to eighth-grade students [16]. The basic problem features of the concept of *density* are *mass*, *volume*, and *the ratio between them* (*density* = *mass*/*volume*). The exploration activity required students to invent an "crowdedness index" for clown bus lines. A set of contrasting cases was presented to students that varied by the number of clowns (mass), the number of bus cars (volume), and the number of clowns per bus car (mass/volume). In addition, the set of contrasting cases illustrated the idea that density is a material property by having the same clowns/car ratio for different bus companies. Researchers found that students in an explore-first condition (activity followed by instruction) were more likely to recreate the ratio structure in a memory task the following day than students in an instruct-first condition (instruction followed by the activity), indicating that they had obtained greater conceptual knowledge of the ratio structure [16].

In general, when compared to the traditional order of active learning in the classroom (i.e., instruction first), exploratory learning results in higher *conceptual knowledge* (i.e., abstract and relational knowledge [19]), while maintaining *procedural knowledge* (knowledge of stepwise procedures [19]) [1]. In addition, exploratory learning can help with knowledge *transfer* (use of knowledge when learning a new topic; [20]–[22]). In one study, for example, students who explored the concept of standard deviation prior to instruction were better able to compare two calculations of variance than students who were instructed first [20]. In addition, they were better able to transfer their knowledge to data normalization, which is a related concept.

Exploratory learning in first-year engineering courses

Although active learning is now being applied frequently in first-year engineering courses (see [23], [24]), thus far, there is limited work on exploratory learning in this context. Instructional improvements in first-year engineering courses have the potential to better prepare students for future courses, close any existing achievement gaps between minoritized and non-minoritized students, and improve the traditionally low persistence rates in engineering (e.g., [25]). In addition, the benefits to transfer may ultimately contribute to engineering student career success when they are required to transfer their course knowledge to applied, real-world situations.

Existing preliminary work on exploratory learning in engineering education is promising. At a recent ASEE conference, researchers from the University of Louisville presented research examining engineering precalculus students' learning in explore-first or instruct-first conditions [26]. The learning topic was 2-dimensional vectors, and the activity was an interactive graphical user interface that enabled student to move vectors around to create answers to vector addition and subtraction problems. In a following quiz, scores were significantly higher for students who explored-first than for students in the instruct-first condition. Understanding vectors is an important steppingstone to higher level thinking about matrices, forces, and many other directional or dynamic concepts.

In addition to the success observed in precalculus, positive results have also been observed in introductory chemistry and physics courses—common prerequisites for most engineering disciplines that are often taken in the first year. These experiments demonstrated the benefits of exploratory learning in students' conceptual understanding of gravitational field [17] and atomic structure [27]. This research has also been extended to synchronous remote learning [28].

The studies suggest that exploratory learning can benefit student learning in first-year engineering courses, compared to lecture-then-practice methods of learning. However, more studies are needed in order to generalize and support an evidence-based practice [29]. Examining exploratory learning across more topics and courses is critical to understanding the range and applicability of the practice.

Current Study

The current study investigated exploratory learning in the topic of "isometric holes" in *Engineering Tools, Methods, and Practice I*, a first-year engineering course at the University of Louisville's J. B. Speed School of Engineering. This introductory course is taken by engineering students in all disciplines, typically in their first semester of engineering school. A variety of topics are introduced focusing on the essential methods, tools, and skills for success in engineering, including graphics, programming, spreadsheets, critical thinking, ethics, communication, and teamwork.

The engineering graphics unit is taught at the beginning of the semester and lasts for 6 weeks. During this time, students learn to read, understand, and create multiview and isometric drawings of simple objects. All drawings are completed by hand. Isometric drawings are more challenging than multiview drawings for some students, and drawing holes in the isometric view is a difficult skill for many. We thus selected "constructing holes in an isometric drawing" as a key concept to test out exploratory learning, with the hope that students could learn this difficult topic better from exploration. Our research question was as follows:

> *Does an exploratory learning order improve student learning above the traditional instruction-first teaching order for drawing isometric holes, a difficult topic in a first-year engineering course?*

We implemented *explore-first* and *instruct-first* conditions when teaching this topic to all students enrolled across multiple sections of our first-semester engineering course in Fall 2021. We then compared performance on a learning assessment.

Methods

Participants

Participants were first-year engineering undergraduate students at the University of Louisville's J. B. Speed School of Engineering ($N = 435$) enrolled in *Engineering Tools, Methods, and Practice I* in Fall 2021. Participants were included in the study if they attended class on the day of the experiment and completed all phases of the experiment. Additional students were excluded from analyses if they came late to class, missing important content ($n = 1$), or received help on the assessment from another student or teaching assistant ($n = 4$).

Procedure

In Fall 2021, there were six course sections and two instructors, who each taught three sections of the course (see Table 1). Students were divided into 2 groups by course section: the experimental group, explore-first, and the control group, instruct-first (see Table 1).

Table 1

Experimental condition by course section

	Instructor 1		Instructor 2	
Section	1	Instruct-first	4	Explore-first
	2	Explore-first	5	Instruct-first
	3	Instruct-first	6	Explore-first

Students in the *instruct-first condition* (n = 219) received instruction on how to draw holes in an isometric view, followed by an activity, as practice of what they just learned. Students in the *explore-first condition* (n = 216) received the exact same materials in reverse order. First, they completed the activity, as a novel exploration activity. Then, they received instruction. After the instruction and activity, students in both conditions completed a short survey, followed by a drawing assessment to evaluate their learning. The purpose of the survey was to assess student attitudes about the activity; however, the current paper is focused on learning outcomes, and will not report the results of this survey.

Students were allowed to work with peers on the exploration activity but were instructed to work alone (silently) on the assessment. Students received participation credit for attempting the assessment, regardless of their performance. All activities (instruction, exploration activity, survey, assessment) were completed within one 50-minute class period. Following the experiment, the assessments were graded to determine how well students had learned the topic.

Materials

Instruction

The lecture explained how to draw holes and circular features in an isometric drawing of an object. Students first learned that circular holes, depicted in a two-dimensional multiview drawing, are drawn as ellipses in an isometric view. Students then learned that there were three problem features they need to assess in order to draw proper elliptical holes in the isometric view: position, size, and orientation.

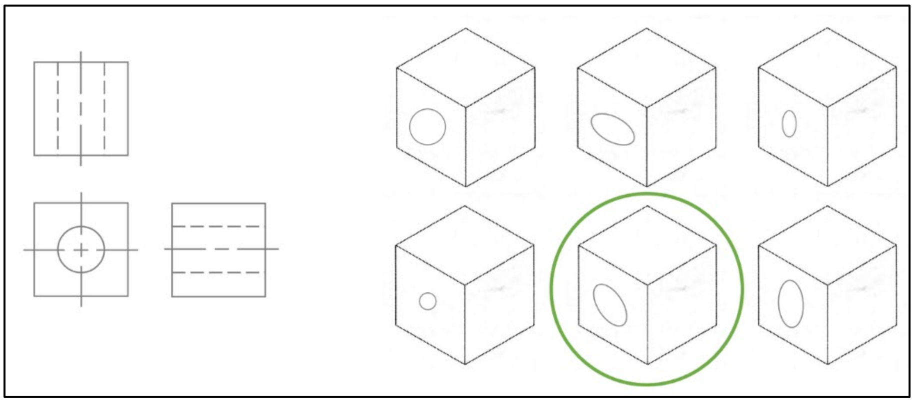
The *position* is determined by identifying which plane the circle is on in the multiview (front, top or right side plane) and then measuring dimensions (height, width, or depth) to the centerpoint of the circle in the two-dimensional view. The centerpoint is then located and marked on the corresponding plane in the isometric drawing. The *size* is determined by measuring the circle diameter in the 2D multiview drawing. Then the corresponding ellipse is identified on the student's isometric ellipse template to use as a stencil. They *position* the ellipse template over the centerpoint in the isometric view and need to rotate the template to the correct orientation. The *orientation* of the ellipse template depends on which plane they are drawing the ellipse on (i.e. a vertical ellipse is rotated 30° to the left for the front plane, 30° to the right for the right side plane and 90° for the top plane).

Exploration Activity

Students worked in groups of 4-5 on a two-part activity. In Part 1, students were shown a two-dimensional multiview and six isometric views of the same object (see Figure 1). Five of the isometric views depicted an incorrect drawing of the hole on the object while the remaining correct isometric view was circled. In groups, students were directed to discuss *why* the circled isometric depiction was correct. In this activity, students are effectively identifying the problem features.

Figure 1

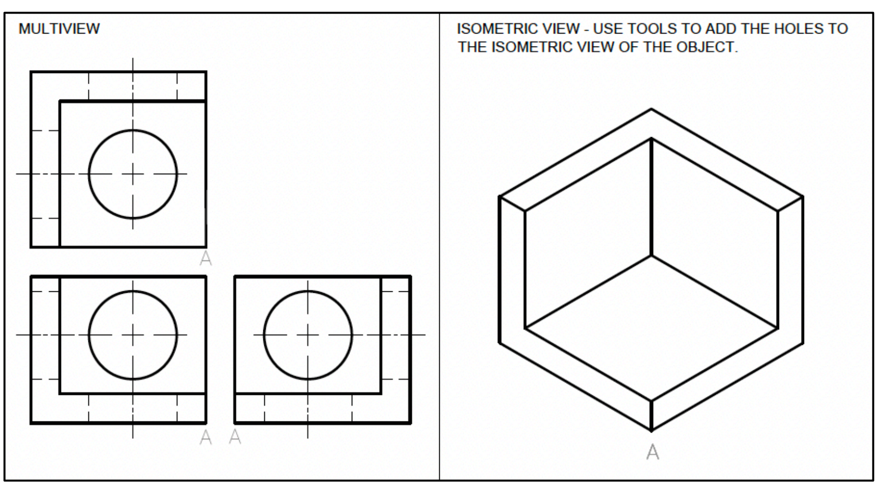
Activity Part 1. Students were asked to discuss why the circled isometric view is correct.



In Part 2, students were given a handout with a two-dimensional multiview of a different object and were instructed to draw the holes in the isometric view (see Figure 2). Students were provided multiple (identical) isometric views to explore various techniques for drawing the holes depicted in the two-dimensional multiview.

Figure 2

Activity Part 2. Students were instructed to use their graphics tools to draw holes in the isometric view, based on the Multiview.



Assessment

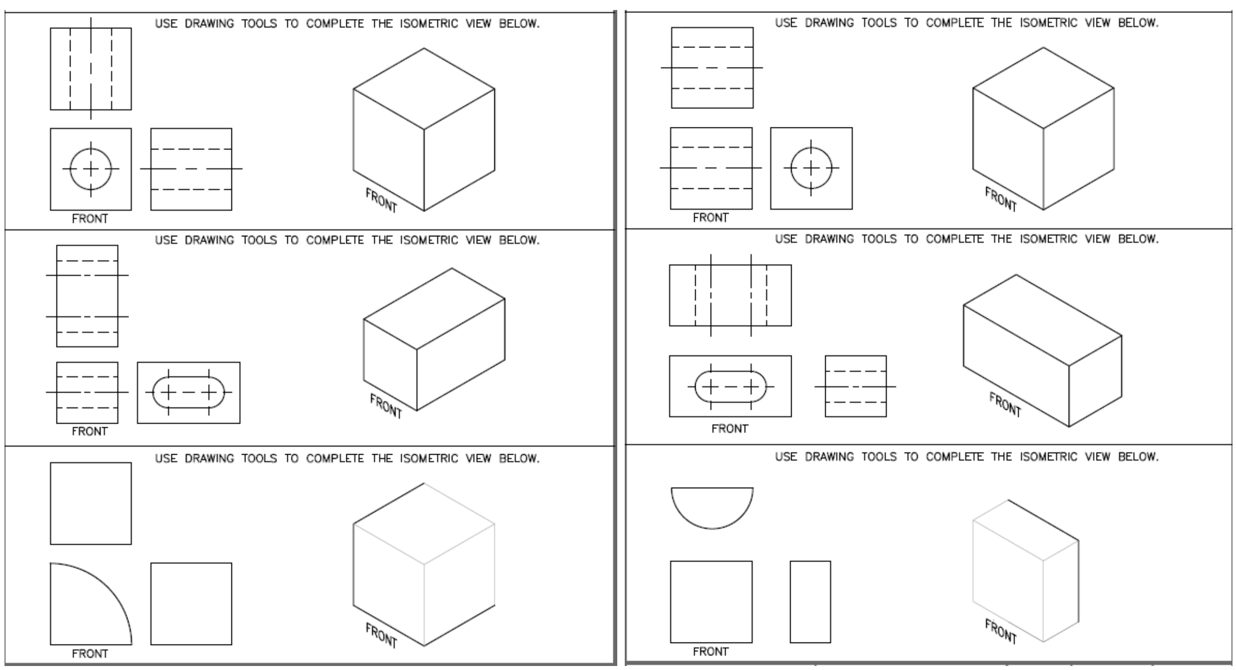
The assessment (Figure 3) included 3 drawing problems of various difficulty, to assess students' learning. The assessment included both procedural knowledge and transfer. Students were asked to translate a hole or circular feature depicted in the two-dimensional multiview drawings into the isometric views. Each of the 3 problems was evaluated on the 4 key problem features (for a total of 12 possible points):

1. Shape (whether the feature was correctly drawn as an ellipse instead of a circle)
2. Position (whether the ellipse was correctly positioned on the isometric view)
3. Size (whether the ellipse was correctly sized)
4. Orientation (how the ellipse was rotated on the isometric plane)

Two forms of the assessment were administered to deter students from copying off their neighbor. The problems were of similar difficulty, but the holes/circular features were on different planes of the object.

Figure 3

Drawing assessment version A (left) and B (right).



As illustrated in Figure 3, the first question of both assessment versions was a cube with a circular hole in one plane, similar to one shown in the instruction. The second and third questions were transfer items to different shapes. Question 2 required drawing two ellipses, and Question 3 required relating the drawing of isometric holes to rounded external surfaces of objects.

Analysis

We assessed learning by conducting an analysis of covariance (ANCOVA) on overall assessment score (percent correct) with independent factors of *order* (explore-first, instruct-first) and *instructor* (1, 2) with a covariate of course performance (end of semester weighted average). This covariate was included to consider any individual performance differences across sections. Exploratory analyses were also conducted without instructor as a factor, and results were similar.

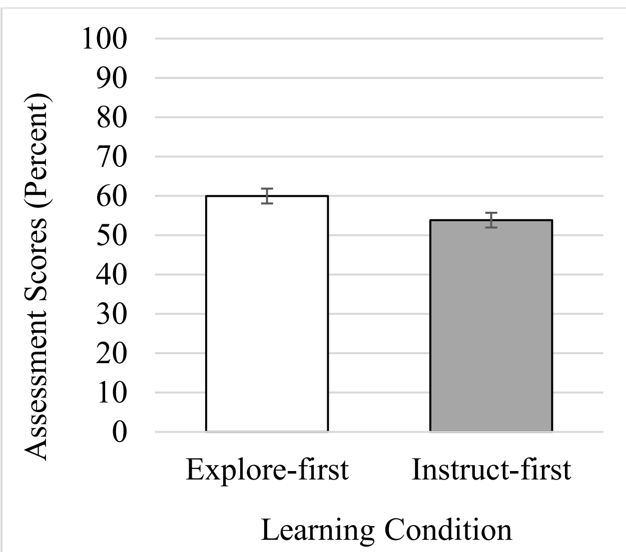
Results

Preliminary analyses determined that assessment scores did not differ as a function of the assessment form given to students, $F<1$.

To determine the effects of learning condition on drawing isometric holes, and to ensure the results were consistent across instructors, an analysis of covariance was conducted on assessment scores (percent correct). There was a main effect of condition, $F(1, 430) = 5.26$, $p = .022$, $\eta_p^2 = .01$. Students in the explore-first condition ($M = 59.97\%$, $SE = 1.89$, 95% CI [56.26—63.68]) scored at a higher level on the assessment than students in the instruct-first condition ($M = 53.84\%$, $SE = 1.89$, 95% CI [50.15–57.53]; Figure 4).

Figure 4

Assessment scores (percent) as a function of learning condition. Error bars represent standard error of the mean (SEM).



There were no main effects of course grades, $F(1, 430) = 2.48$, $p = .116$, $\eta_p^2 = .01$, or instructor, $F(1, 430) = 3.30$, $p = .070$, $\eta_p^2 = .01$, and condition did not interact with instructor, $F < 1$, demonstrating that the effects of condition occurred similarly across both instructors' sections.

Discussion

Students completing an exploration activity prior to instruction (explore-first condition) scored higher on a learning assessment than those who completed the activity after instruction (instruct-first condition). All class activities were similar between the two conditions, and the differences were significant across multiple sections taught by two instructors. Thus, this difference was due to the change in order of the instruction and activity. Consistent with previous exploratory learning studies ([2], [15]–[17], [20]), we suspect that presenting the activity as novel exploration allowed students to identify problem features and knowledge gaps that made the instruction more relevant once they received it. Additionally, students had the opportunity to experiment with their graphics tools prior to instruction, so that they had a greater context for the information being presented.

As this study was done using a difficult concept in the graphics unit of a first-year engineering course, we expect that exploratory learning could be useful in other places in the curriculum. Next steps include testing it in other course topics like programming, replicating our effects, and extending the work to other classrooms.

Limitations

The study groups were not entirely random, and although the section assignment was random, it is possible that group differences between sections may have affected results. However, the purpose of including the covariate was to eliminate any group effects, so we believe we achieved a well-controlled study. In addition, the unequal distribution of conditions to instructors (one instructor had two sections of instruct-first and vice versa) makes the study slightly imbalanced. However, instructors worked closely together, using the same slides and the same protocol, which included specified timing for the activity and the instruction. Instead of considering this a limitation, we believe our results highlight a strength of exploratory learning: the results were not limited to one instructor and their teaching approach, but instead generalized across two different instructors.

Conclusion

Exploratory learning, i.e., an activity followed by instruction, was more beneficial to engineering student learning in a first-semester course than the traditional tell-than-practice order. This successful application of exploratory learning in graphical drawing indicates that the practice may be useful in a wide variety of disciplines, and certainly in engineering education.

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