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Supporting Student Persistence in Engineering Graphics through Active Learning Modules

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Supporting Student Persistence in Engineering Graphics Through Active Learning Modules

Abstract:

Self-efficacy and academic success, including mental rotation, are positively associated with student persistence, and retention in engineering and engineering technology degree programs and engineering graphics courses play a vital role in students' success in engineering education. This paper details the investigation of active learning modules applied through a facilitative instructor model at two institutions in the United States and how the modules encourage the development of students' knowledge and skills as well as the self-efficacy levels and mental rotation abilities of students enrolled in introductory engineering graphics courses.

Students access the active learning modules through an online learning management system. Modules consist of ten units that engage students through relatable examples and practices of foundational principles and applications of engineering graphics. The team took self-efficacy and academic success measurements, which were then analyzed using paired t-tests.

Results support previous findings that there are significant differences in self-efficacy and academic success, including students' mental rotation abilities, when instructors provide supplemental materials. The data also supports that students at risk of non-matriculation benefit from the combination of active learning modules and additional video tutorials in the realms of self-efficacy, final exam scores, and course grades. Students not at risk of non-matriculation show higher self-efficacy and mental rotation ability levels when using the active learning modules. With this information, engineering and engineering technology degree programs can incorporate elements of active learning modules through a facilitative instructor model to promote student success in both subgroups, possibly increasing persistence and retention rates in engineering degree programs. Furthermore, the IUSE team provides the active learning module material through open access for educators and students to utilize.

Introduction

Enhancing student learning experiences within engineering design graphics involves exposing students to opportunities for enhancing self-efficacy of 3D modeling skills and academic success, including students' mental rotation abilities. This paper describes the Improving Undergraduate STEM Education (IUSE) project's use of active learning modules through a facilitative instructor model within an introductory engineering graphics course and how it affects students' self-efficacy of engineering graphic skills and academic success, which are predictors of success in engineering degree programs. This information is pertinent to future engineering design graphic programs and other engineering programs due to its ability to positively impact elements of success for students, including those who may be identified as at risk of non-matriculation. Through the utilization of an online learning management system (LMS), instructors can transition from traditional lecture-based use of course time and use that instructional period as an in-person meeting to facilitate collaborative engagements of students.

Facilitative Instructor Model with Active Learning Modules

A facilitative instructor model is a method of inverted classroom instruction where content and supplementary material appear in an accessible location for students, such as within an online LMS (1), and an instructor facilitates students learning through authentic learning experiences during course time (2). Students can utilize times and locations where they feel comfortable learning and practicing course content. During scheduled course time, students can collaboratively practice applying course content in a hands-on method where they can ask questions and demonstrate understanding (2). The facilitative instructor model of providing content and supplementary materials online reduces students' stress and encourages self-regulation (3).

While students engage with course content, such as engineering graphics, it is beneficial to do so in a problem-based active learning environment (4). Actively engaging learners in hands-on and real-world related activities that build off course content establishes an active learning environment as opposed to passively listening as in traditional instruction (5). As students apply their gained knowledge through active learning methods, they can increase their self-efficacy and academic success due to increased engagement (4). During their experience in applying course content in a real-world manner, learners can ask questions while enabling instructors to assess for understanding through performance-based assessment (2).

Support for Active Learning in Engineering Graphics

Incorporating active learning into an engineering design graphics course is important because it exposes students to tools and processes they can use while pursuing an engineering future. For this reason, many programs encourage early exposure of students to learning experiences involving the engineering-design process and how engineering graphics apply to different stages within a problem-solving approach (6, 7). Introductory engineering graphics communication, which can provide the above-mentioned experiences, is incorporated in the first two years of programs since most students who leave engineering programs do so during their third semester (8).

In an engaging environment where students are working with the content, students can fine-tune their visualization and mental rotation skills (9), as the ability to mentally rotate objects is foundational for persistence and success in engineering (10). Engineering program success can be defined as including multiple elements, such as self-efficacy and academic success. Self-efficacy is an individual’s confidence in their ability to complete a specific task (11). In engineering graphics design and other engineering programs, engineering self-efficacy is a significant predictor of a student’s GPA (12). Engineering design self-efficacy tends to be lower for female students than for male students (13). The second factor affecting the persistence of engineering students is academic success. While GPA is the typical measure of academic success (14, 15), three-dimensional spatial visualization ability is also a significant predictor of academic success in engineering (16). Mean mental rotation abilities tend to be lower for female engineering students than for male students (10).

The elements of self-efficacy and academic success, including mental rotation skills, are not enhanced by the traditional method of instructing introductory engineering classes, preventing an increase in persistence. The traditional instructional model, often a large class size or laboratory setting, involves lecture-based content instruction with students completing work outside of scheduled course time (6). This formal learning environment is ineffective for most learners (17). Students at risk of non-matriculation are especially disadvantaged with a traditional lecture-based content delivery format (18, 19, 20). Students at risk of non-matriculation in engineering degree programs include students whose GPA is less than 3.0 and includes individuals identifying as an underrepresented minority, or first-generation college students. (21).

As self-efficacy and academic success, including spatial visualization skills, play an essential role in engineering design graphics through active learning in a facilitative instructor model, it is vital to evaluate and analyze the effects and how they can impact students' performance in engineering degree programs. During the study, the IUSE team developed three research questions to evaluate the effects of a facilitative instructor model with active learning modules on elements related to student success.

1. How does the facilitative instructor model with active learning modules affect 3D modeling self-efficacy?
2. How does the facilitative instructor model with active learning modules affect mental rotation skills that are a predictor of academic success?
3. How do the sub-groups of students at risk and not at risk of non-matriculation differ regarding measures of self-efficacy, mental rotation, and academic success at the end of the course when exposed to a facilitative instructor model with active learning modules?

Method

A quasi-experimental design iterative study was conducted in an introductory engineering graphics course at two universities in the United States. Data on self-efficacy, mental rotation, ability, final project grade, final exam grade, and final course grade was collected from consenting participants in the study who were students enrolled in the course.

Self-efficacy was measured using a 3D Modeling Self-Efficacy instrument (22). Spatial visualization and mental rotation skills were measured using the Purdue Spatial Visualization Test: Rotations (PSVT:R), per the methods of Sorby and Baartmans (14). Researchers gathered measurements of academic success using a combination of the Purdue Spatial Visualization Test: Rotations Instrument, grades by the course's learning objectives, and final course grade (14, 23, 24, 16).

One of the institutions had course sections of up to 60 students per section. Enrolled students in these courses were in engineering degree programs, a technology and engineering education degree program, and science, math, or other STEM degree programs. Another institution had smaller course sizes consisting of up to 20 students enrolled in engineering technology and technology and engineering education degree program areas.

At the start of the semester, enrolled students were given pre-tests and then assigned the active learning modules to complete outside of regularly scheduled class time through a facilitative instructor model. The active learning modules were accessible in an online learning management system along with standard course content. Students received evidence of completion by obtaining a certificate of completion which was then submitted to the instructor for credit by the end of the semester. At the conclusion of the semester, researchers provided a post-test to students and recorded their final project grade, final exam grade, and final course grade scores from the semester.

Accompanying the active learning modules, the course LMS contained optional videos to supplement in-class lectures and demonstrations for students needing additional review. During this study, significant changes occurred in the software used in course instruction rendering the supplemental videos obsolete and no longer appropriate for continued use. This situation allowed investigators to examine the effect of active learning modules with and without supplemental videos.

Ten active learning modules that comprised one unit included: sketching, engineering geometry, orthographic and pictorial projections, working drawings, dimensioning standards and annotations, assemblies, section views, and auxiliary views. These modules comprise a single unit that aligns with an introductory engineering graphics course curriculum developed for engaging students through examples and reflection on how the content applies to real-world applications (21). Active learning modules contained course content information, video tutorials, sample exercises, and self-check features that enabled students to apply elements of self-regulated learning.

Technical content knowledge from the course was covered in the modules and reinforced through real-world examples, such as demonstrating how engineers use section views of models to show function (figure 1) and using everyday objects to help define technical terms, such as various section views cut out of vegetables (figure 2). Video tutorials guided students on how to apply content knowledge in software and technical practice, such as in a video demonstration of how to properly sketch lines or operate CAD software tools (figure 3). When students can control the pace at which they follow a demonstration, as with online video tutorials, they can remain engaged with the learning experience rather than becoming lost. Self-check sample exercises provided further interactions and clarification of understanding for students was present through the “click to reveal the correct result” sections. Pop-up reflection questions throughout the modules encourage student reflection in identifying real-world relations to content knowledge based on lived experiences (figure 4).

Figure 1: Real-World Use of Section Views

Figure 2: Example of Section Views Cut Out of Vegetables

Figure 3: Example of Guided Video Instruction

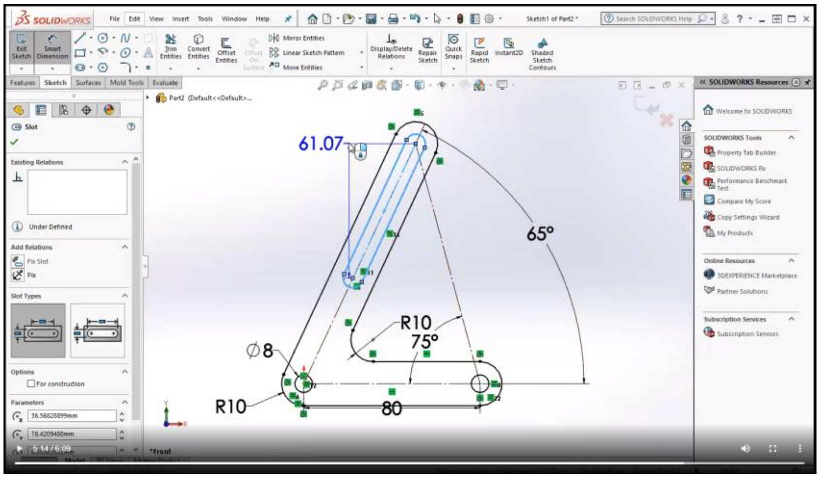

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Figure 4: Example of Self-Reflection Question from Active Learning Module

Have you ever researched an item online where you examined different views of the item? What was the item? How did seeing the different views influence your decision to buy (or not buy!) the item?

Results

Over three semesters between 2017 and 2019, pilot tests occurred at both institutions, with field tests during the 2019 and 2020 academic years. University one had a total of 904 students consent for their data to be used in this study. Participation from the three pilot and field tests semesters included 284, 318, and 302 students. University two involved 98 participants over two field tests, with 44 and 54 participants in two semesters.

Pilot and field test data were combined for analysis. Differences in academic and non-academic indicators were examined with students identified as at risk of non-matriculation and not at risk of non-matriculation subgroups. Academic and non-academic outcomes through pre-test/post-test progressions are in the analysis tables. The paired t-test results show a significant ($p < .05$, two-tailed) positive impact that active learning modules had on increasing self-efficacy and mental rotation abilities (table 1).

Table 1 Project Total

		Pre-Test		Post-Test					
	n	Mean	SD	Mean	SD	Diff.	t	df	p
Self-Efficacy	633	51.89	20.21	74.67	26.65	22.78	20.61	632	< .001
Mental Rotation	641	5.73	2.18	6.21	2.38	0.48	4.76	640	< .001

Along with the active learning modules, the course LMS contained additional tutorial videos to supplement lectures and demonstrations for further review as needed by students. During the study, significant changes occurred in the course instruction software rendering the supplemental videos obsolete and no longer appropriate for continued use. There was not enough time to recreate videos to match the updated software. This situation allowed for examining the effect of active learning modules with and without supplemental videos.

Subgroup analysis shows that students at risk of non-matriculation experienced a significant increase in final exam grades and self-efficacy along with an increase in final course grades when tutorial videos were available along with active learning modules than with only the modules (table 2). Students not at risk of non-matriculation experienced a significant increase in self-efficacy and mental rotation ability when only the active learning modules were available (table 3).

Table 2: Students At Risk of Non-Matriculation

	Videos and Modules			Modules Only						
	n	Mean	SD	n	Mean	SD	Diff.	t	df	p
Self-Efficacy	129	74.39	19.17	110	68.27	22.48	6.16	2.29	237	.023
Self-Regulation	129	4.16	0.70	110	4.29	0.72	0.13	1.47	237	.144
Mental Rotation	129	6.39	2.27	111	6.12	2.51	0.27	0.88	238	.382
Final Course Grade	207	88.83	10.64	193	86.44	14.66	2.39	1.88	398	0.062

Final Exam Grade	206	85.33	9.47	190	82.05	13.72	3.27	2.78	394	.006
Final Project Grade	207	89.83	17.15	193	87.00	21.48	2.83	1.46	398	.146

Table 3: Students Not At Risk of Non-Matriculation

	Videos and Modules			Modules Only						
	n	Mean	SD	n	Mean	SD	Diff	t	df	p
Self-Efficacy	162	72.80	19.70	144	79.08	18.50	6.27	2.86	304	.005
Self-Regulation	162	4.21	0.68	145	4.30	0.73	0.09	1.06	305	.291
Mental Rotation	162	6.26	2.29	146	6.87	2.22	0.61	2.37	306.00	.019
Final Course Grade	234	89.31	9.21	243	90.41	10.03	1.10	1.24	475	.215
Final Exam Grade	234	85.11	11.75	241	85.97	12.17	0.86	0.78	473	.434
Final Project Grade	234	90.32	12.07	243	90.77	15.93	0.46	0.35	475	.724

Discussion

Facilitative instructor modeling coupled with active learning modules demonstrated positive effects on self-efficacy and academic success including mental rotation ability within an introductory engineering graphics course. Subgroup analysis shows that students at risk of non-matriculation and those not at risk of non-matriculation progressed. This data demonstrates that active learning in a facilitative model can benefit both subgroups. Results of mental rotation scores support that spatial visualization, a pertinent skill in engineering design graphics, can be enhanced through active learning modules. When instructors provide supplemental materials that include real-world applications of classroom content and provide additional practice readily accessible to students outside of in-person course time, student 3D modeling self-efficacy increases, and engineering-related skills advance. The active learning modules are available through an online LMS, which offers flexible availability that encourages a mode of autonomy for students. The flexible availability of supplemental materials supports students' autonomy within self-regulation by reducing student stress and opening further engagement with course content. A primary goal of engineering graphics and engineering degree programs is to foster and enhance student success. Programs that model active learning modules through a facilitative instructor model and provide other supplemental materials in curriculum development and student support resources can promote students' success in engineering or other STEM fields. Supplemental materials developed as self-paced active learning modules can enhance student learning of how content from the classroom applies to real-world scenarios.

Incorporating a facilitative instructor model with active learning in an engineering graphics course improved student learning and performance. If positively impacting student success and self-efficacy occurs over the course of a semester, it begs the question of how such practice can impact student retention and persistence in engineering degree programs. It is possible that positive student experiences in a course using a facilitative instructor model with active learning can improve student retention in engineering degree programs and encourage students to persist through the successful completion of their pathway into an engineering career.

Encouraging student success through effective supplemental material can enhance students' technological and engineering literacy for effective function in an engineering future. Engineering degree program students at risk of non-matriculation are less likely to succeed and can flourish using supplemental learning materials. Increasing the accessibility of resources promotes elements of autonomy, an increase in self-efficacy, and an increase in academic success that can improve the success of students identified as at risk of non-matriculation. As students at risk of non-matriculation traditionally identify as underrepresented groups, improving performance through active learning modules and a facilitative instructor approach can increase diversity in engineering.

Conclusion

A facilitative instructor model with active learning modules in an engineering graphics course positively affects learners' self-efficacy and academic success, including mental rotation abilities. When an instructor provides course content flexibly, such as on an online LMS, students can experience less stress while learning and use course time to work on collaborative, hands-on content applications while the instructor facilitates learning. This practice is important because of engineering graphics' vital role within engineering degree programs. Increasing students' self-efficacy and academic success can lead to an increase in retention rates and persistence of students in engineering degree programs. As demonstrated in the study, both subgroups benefit from using a facilitative instructor model with active learning. With this information, developments can occur to incorporate increased active learning in programs to promote student success. Improving students' abilities in engineering graphics benefits the engineering field by establishing a larger prepared workforce. A limitation of this study is that not all metrics possess an equal number of responses which can enable a balanced comparison of results. Further limitations include the characteristics of the institutions at which the study applied. Engineering degree programs and communities vary across the nation. How students react at these two universities may vary from how students at other institutions react to the same model.

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