Engineering Identity and Project-Based Learning: How Does Active Learning Develop Student Engineering Identity?

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Abstract

This purpose of this research paper is to understand how the use of evidence-based pedagogical methods, such as active learning, for teaching engineering design concepts, influence students' engineering identity growth and increase retention in engineering programs. Students in a statics course (n=333) with active learning, used the entirety of the design process during a balsa bridge team project. Following testing of their bridges, students completed journal entries about their self-efficacy to design. Previous results suggest that students might better develop an engineering identity due to their participation in active learning. Newer results from an inductive qualitative content analysis on these journals (n=165) suggest active learning allows students to develop competence and individual interest, and further their engineering identity development, through increased and repeated exposure to opportunities of situational interest found in active learning. These results continue to support use of active learning as an effective teaching tool in engineering education, and as a potential method of increasing retention in engineering.

Introduction

Active learning methods[1] have proven to be an effective way to increase engineering self-efficacy[2], academic performance[3], feelings of responsibility to complete future tasks[4], and recently retention in science, technology, engineering and math (STEM)[5]. While the list of positive effects of active learning use continue to emerge in the literature, its use is still minimal due to the resources required of practicitioners[1,3]. Research on the effects of active learning should continue to be researched and published until it is clear to researchers and practitioners that the benefits outweigh the cost.

Of the various calls within STEM education, the most noted is the need to increase the amount of students entering and graduating from engineering programs to develop a workforce for the future[6]. This includes finding innovative ways to "patch the leaky pipeline" and increase program retention[7]. To do so, innovative solutions should seek to develop students feelings of belonging in engineering, as it has been found to be essential to increasing student retention in engineering programs[6,7]. Students' feelings of how well they fit or belong to a group is often called identity[8] and more specifically when discussed in the context of engineering, is called engineering identity[9].

While there exists a large body of research on active learning, there is limited engineering identity research in non-traditional teaching environments, such as active learning[5]. It is wondered then how an active environment might affect engineering identity development. Project-based learning, one method of active learning, uses cooperative projects to link learning to real-life application and increase motivation[10]. Previous work on self-efficacy development suggested that students might develop an engineering identity as a result of their participation[11]. However, further work was considered necessary to understand how project-based learning might foster such identity formation. Active learning methods such as project-based learning may prove to be beneficial for academic performance (grades), but also for increasing students' desires to be identified as an engineer.

In continuation of our previous work, we seek to understand how active learning affects student engineering identity development through the following research question: *How do students develop an engineering identity in active learning environments?*

Background

Original conceptualizations of design self-efficacy (students feelings in their ability to complete design tasks now and in the future) included students' confidence to complete design tasks, students' motivation to complete design tasks, students' perceived success completing design tasks, and students' anxiety to complete design tasks[12]. Quantitative work by Major & Kirn[11] in a project-based learning setting found that students perceive confidence to complete design tasks and perceived success completing design tasks to be the same. Additionally, it was found that students had a significant increase in their development of this combined confidence-success factor over the course of a semester (p-value = .002). Based on extensive research by Godwin et al.[13], measures of self-efficacy (presented as performance-competence), alongside subject interest and recognition by others, have shown to be an important factor to students' development of engineering identity. It is suggested then that active learning may allow students to develop an engineering identity[11].

Initial qualitative work from Major & Kirn[11] found five emerging themes: 1) students discovered design tasks they were competent in or not competent in, which lead to motivation to complete or not complete specific design tasks, 2) students linked class content to real-world design opportunities, 3) students linked experience success and failure of the project to their future goals, 4) students felt they could have had succeeded more if they had the opportunity to complete the design process and redesign, and 5) students mention team members as resources for content and skill competence. This work seeks to present completed qualitative analysis to answer how students develop an engineering identity in active learning environments.

Methods

This qualitative population for this study was a large Engineering Statics course (n=333) that utilized problem- and project-based learning. During the last three weeks of the course, students were required to complete a group bridge-building project in which they utilized the entirety of the engineering design process to design, analyze, build, and test a balsa bridge, given material and size limitations.

Journal Development and Administration

After bridge testing, students were offered five points of extra credit on a 1000-point scale to complete a 15 to 30-minute short-answer journal entry, found in Appendix A, regarding their experience of designing, building, and testing the bridge project. Use of student reflections, such as journals, have been shown to allow students to find better meaning in the work they have done, and to be beneficial towards students experience of completing design projects[14].

Online Learning Management Software was used to collect responses. Available for review in Appendix A, the structured journal protocol consisted of questions from a previously developed Design Self-Efficacy Instrument[12] modified for short-answer use in previous work[11]. Modification was done by converting questions from the quantitative Design Self-Efficacy Instrument to questions that qualitatively asked how the hands-on activity presented in the course developed students' self-efficacy. Specifically, short-answer questions asked students about their confidence (feelings in their own abilities to complete design tasks), motivation (willingness to complete design tasks), feelings of their ability to succeed at a task, and anxiety (unease or worry about ability to complete a task) towards the bridge project and other tasks in the future. Additionally, students were questioned about the reasons they choose to design and why they might ever fail at completing design tasks. To aid all responses, students were given a list of design tasks developed in prior work[12]; shown in Figure 1.

Design Self-Efficacy Engineering Design Tasks
1) Identifying a design need
2) Developing design solutions
3) Selecting the best possible design
4) Constructing a prototype
5) Evaluating and testing a design
6) Communicating a design
7) Redesigning

Figure 1: Design tasks from previous design self-efficacy work[11,12] given to aid student responses related to their competence, motivation, and anxiety to complete engineering design tasks.

The study was institutional review board (IRB) approved and provided an opt-out clause to participating students.

Analysis

To answer the research question, inductive qualitative content analysis (IQCA) was used[15]. This method, used previously in engineering education research[16], involves three phases for analysis (I. Preparation, II. Organization, and III. Reporting) and is used to manipulate large volumes of text-based data to more manageable themes that can be collected, separated, or managed in ways the researcher sees fit. The inductive aspect of IQCA allows for creation of categories during data analysis based on previous theoretical background[15]. In the preparation phase, data is collected and a unit of analysis is chosen. The unit of analysis is considered to be the smallest single unit of data within the content analysis. In the organization phase, abstract theoretical categories that represent the data are chosen to be the start of analysis. Additionally, definitions of these categories are developed. Then, the researcher analyzes half of the qualitative data while adding, removing, organizing, and condensing categories as well as their associated definitions. When the initial half of the data has been completely analyzed and categories cannot be condensed further, the researcher analyzes remaining data (without changing categories) to ensure data fits the remaining categories. Finally, in the reporting phase, the researchers use of content analysis is presented as well as the resulting categories and definitions.

Phase I: Preparation

In this analysis' preparation phase, journal entry responses (n=165; 49.5% response) were collected and the unit of analysis was chosen to be a single journal entry due to their size. Individual journal entries averaged approximately a page in length.

Phase II: Organization
In the beginning of the organization phase, broad, abstract theoretical categories were made to represent the qualitative data being analyzed. Confidence, motivation, success, and anxiety; aspects of design self-efficacy framework [11,12], were used as beginning theoretical categories as they were used to develop journal questions and represented each unit of analysis. Then, half of the collected qualitative data was read several times while the researcher concurrently commented and organized data into themes, and smaller themes into larger categories. When the first half of the data had been completely analyzed and final definitions had been created for each of the categories, the researcher then analyzed the remaining half of the data, making only minimal changes to the categories, to ensure remaining data fit the created categories.

Phase III: Reporting
The entirety of this paper represents the reporting phase in which the researchers use of qualitative content analysis were previously described. Additionally, resulting categories and definitions of those categories will be presented.

Results and Discussion
IQCA of journals led to three resulting categories: discovery of competences or lack thereof, perceived instrumentality, and development of interest.

Competency – Project or design tasks students felt competent at or not competent undertaking as they completed design activities.

In previous work[11], it was seen that students found what aspects of completing design tasks they were competent or not competent doing. These examples continued to be found and can be seen in Mickey's journal:

> Our group was most confident about designing and calculating necessary dimensions on the bridge. More difficult, and with lesser associated confidence were the cutting and gluing which took precision – we were extremely unsure about the mechanical strength of our materials. - Mickey

Because of his participation in active learning activities, Mickey has identified what parts of designing and building a balsa bridge he and his team are competent at and not competent at. He perceived his group as competent designing and calculating dimensions, topics taught in the statics course, but not good at aspects, such as mechanical strength, that would not have otherwise been taught in his course without access to active learning activities. We see this again in Wendy's journal:

> It was nerve-wracking to choose the best design and hope that it would hold the minimum weight requirement. [Now, after completing the project], I feel more confident about choosing the best design. We were able to exceed our expectations because we used the knowledge from our class. - Wendy

Like Mickey, Wendy expressed what she was competent at and not competent at while building the bridge. Later, we see that she felt more competent about her abilities to do tasks she previously felt less competent in because of her participation in active learning activities. This suggests that the active learning environment allowed her to build competence in completing specific engineering design tasks.

Previous work by Major & Kirn[11] quantitatively expressed similar results. Students who participated in the courses' active learning activities averaged an increase in competence from 6.8 to 8.1 on a scale of 0 to 10, with 10 being the highest. Thus, not only does qualitative work support such an increase, but it also directly links increases to the participation in active components of the course.

Perceived Instrumentality – Identification of knowledge needed to develop students' emerging engineering identities.

While students found what parts of engineering they were competent at or not competent at, some students went further to identify what aspects of design they needed to learn more about for their future careers. We can first see this in Marcus' journal when he is asked about the aspects of design he felt he is better or worse able to complete in the future (Appendix A – Q7):

> I know that I have adequate communication skills for the design process. I know that I need to hone my analytical skills to be able to attack problems with more opportunities… [Also], I think my analytical/creative skills are lacking. I need to be able to think of a problem, come up with an accurate solution, and then be able to explain/communicate how it will work. – Marcus

Marcus discussed the overall difficulty with this project and his need to continue to develop his skills. He understood and described, some of the things he is competent at and some of the things he is not as competent at. Additionally, from reflecting on his experience, Marcus derived from this challenge a better sense of what he needs to learn in the future to reach his goals.

Matusovich, Streveler, and Miller linked attainment value[17], an aspect of task-value[18], to engineering identity and persistence in engineering[19]. They suggest that by changing classroom practices to increase students' feelings of attainment value that practitioners can also increase student persistence in engineering. Additionally, Matusovich, Streveler, Miller, and Olds[20] express the hand-in-hand relationship that exists between competence and value. In other words, as students develop attainment value, they also develop feelings of competence. The expressed experiences of students in this work provides a level of validation that the use of active learning develops students' engineering identity through the development of attainment value and competence.

Interest Development – Generation of feelings of interest.

During analysis, it was found students often used words such as "interest", "disinterest" "excitement", "enjoyment", "like", and "dislike" in responses to questions about motivation

(Appendix A – Q4, Q5). Additionally, students linked attainment of enjoyment and interest to their participation in active learning activities:

> I am interested in prototyping more and learning more about manufacturing. Although I had some experience previously, I would like to learn how to implement the theory that is presented in class. – James

Patrice has a similar response:

> The bridge project helped me to realize how much I like bridges. I have always had a fascination with them, but never knew much about how they work… Now that my knowledge is increasing, I am continually impressed with bridges and am reassured of my thoughts on emphasizing in structural engineering. In the future, I would be very confident and motivated to design bridges. I am even more interested in them now than I was before the project. – Patrice

Both James and Patrice have identified development of an interest to be a result of participating in the bridge project. James discussed a developed interest in learning new engineering topics while Patrice discussed her deeper interest in bridges that she connects to further development of a future goal. Both of these students claimed their participation in active learning to have been an important part of this discovery.

Previous results highlight the importance of interest in engineering identity and motivation development[13,19,20]. Neither of these models of student attitudes serves to connect the three themes that have emerged in this work: competence, perceived instrumentality, and interest.

The relationship between competence, interest, and perceived instrumentality is found in academic interest research presented by Hidi & Renninger, and suggests interest is made of two components; feelings (enjoyment and excitement) and task-value (how valuable the task is to the future)[18]. Godwin et al contextualizes interest primarily as only emotional interest[13]. Hidi, Renninger, and Schiefele, among others, suggest that students develop an individual interest (personal developed interest in something) through repeated encounters with situational interests (momentary interests that pull them into the activity due to an emotional response or connection to future goals)[17–21]. Previous work utilizing engineering and active learning in K-12 has shown that students develop multiple dimensions of situational interest, including, but not limited, social involvement, novelty (the need to learn new information), and self-generation of interest (self-triggering of interest through use of resources to complete a task)[25]. The active environment may provide access to more engineering situational interests than a traditional lecture that might only focus on boosting student novelty.

Partnering ideas of Hidi & Renninger's interest theories[18] with results, it might be said that students' involvement with individual and collaborative experiential opportunities in active learning environments allow them to discover and develop competence in specific engineering tasks (thus building their self-efficacy) and while also allowing students increased opportunity to build interest through connections of present tasks to future goals and enjoyment, further developing their engineering identity.

Implications

As an evidence-based teaching method, not only can active learning be seen as a way to increase engineering self-efficacy[2], academic performance[3], feelings of personal responsibility[4], and student perceptions of competency as an engineer[11], but can now also be seen as a way to increase engineering interest; and further engineering identity, in post-secondary engineering courses.

Students discussed avoiding tasks they did not think they could do or were not interested in doing. To properly develop both student competence and interest in the completion of tasks in all aspects of the design process, and further, develop engineering identity, it is important that instructors develop varying active learning projects that attempt to trigger student situational interest in different ways. Doing so will allow students better opportunities to develop interest in engineering tasks and potentially an engineering identity. Student reflection might also be an important activity for practitioners to include within the design process as student gains, such as value of the activity, have been discovered from results of their use[14]. Collection of these reflections might also be useful to practitioners who wish to apply use of active learning to their design courses in ways that best develop student attitudes through the incorporation of varying situational interests.

Conclusion

Student journals show their development of engineering design competence and interest through participation in real hands-on engineering design experiences. By merging elements of design self-efficacy[11,12], interest development[18] and identity development models[13,19,20] we have developed further understanding of how active learning develops student engineering identity. Future studies will seek to validate these results in other project and problem-based learning classes as well as in classes utilizing other active learning methods[1]. Other work will also seek to study how situational interests differ between collegiate level design and K-12 setting and whether other situational interests exist. Identification of these important academic environmental factors will be useful for future active learning engineering education research.

The combination of multiple important aspects of student attitudinal development, presented here, in addition to a body of evidence supporting the value of active learning[1,3,5,6,11,26,27] implores practitioners to notice the immense need for teaching practices that move further from the use of traditional lectures to the use of any number of developed, research-based, active learning activities. Students not only appreciate the inclusion of enjoyment into their education, but also develop as engineers when they can make connections between what they and others believe about their individual accomplishments, their goals for the future, their feelings of enjoyment, and their feelings in knowing that their education provides to them access to each and every one of these opportunities.

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Appendix A

Design Self-Efficacy Journal Instrument
1) Please briefly describe the experiment you did in your engineering statics course. What was the goal of the experiment? What steps did you take to design a solution? 2) What parts of the experiment did you feel confident about designing? What parts of the experiment did you not feel confident about designing? What about the experiment made you feel this way? 3) After doing this experiment, what parts of engineering design do you feel more or less confident to be able to design in the future? Why? 4) What parts of the experiment did you feel you were motivated to design? What parts of the experiment did you not feel motivated to design? What about the experiment made you feel this way? 5) After doing this experiment, what parts of engineering design do you feel more motivated to do in the future? What parts of engineering design do you not feel more motivated to do in the future? Why? 6) What parts of the experiment did you feel you were successful in designing? What parts of the experiment did you feel you were not successful in designing? What about the experiment made you feel this way? 7) After doing this experiment, what parts of engineering design do you feel more or less able to succeed in doing in the future? Why? 8) What, if any, do you think would be reasons why you would not succeed in designing an engineering design task in the future? 9) What parts of the experiment did you feel comfortable designing? What parts of the experiment did you not feel comfortable designing? Why? 10) After doing this experiment, what parts of engineering design do you feel or not feel comfortable about doing in the future? Why? 11) Why do you solve engineering problems? 12) Do you have any more you'd like to say about the project, your ability to complete it, or your ability to design a solution in the future? If yes, please describe.