The Tiny House Project: Building Engineering Proficiency and Self-Efficacy through Applied Engineering at the High School Level (Evaluation)

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Introduction

One of the commonly cited benefits of engaging K-12 students in engineering is the potential for students to identify and work to solve authentic real-world problems [1], [2], [3]. In their recent elucidation of a set of epistemic practices of engineering, Cunningham & Kelly highlight the importance of contextualizing engineering problems, arguing that “engineering problems, and respective relevant knowledge, emerge out of social needs and are typically resolved and completed through social processes” [1, p. 492] and that “engineering lessons should engage students in real-world experiences” [1, p. 500]. Similarly, the *Next Generation Science Standards* challenge students to consider ‘‘potential impacts on people and the natural environment that may limit possible solutions’’ and to take “a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts’’ [2, p.86] into account when evaluating potential solutions to a design problem. Penuel challenges education researchers to go beyond studying science and engineering for our own purposes, such as preparing students to participate in disciplinary science and engineering, to “focus also on participants’ own changing purpose for involvement and on their contributions to activities that are focused on transforming communities” [3, p. 13].

Although inviting students to utilize the engineering design process to solve problems that matter to them is an important goal implied in engineering education policy documents, we currently know far too little about how teachers and students can apply the knowledge and practices specific to engineering to make real change in their lives and communities. This case study aims to contribute to this area of research by exploring the outcomes of a year-long project implemented in an Engineering Applications course at one purposively selected public K-12 school. Inspired by student interest in addressing scarcity in local affordable housing, the course devoted an entire school year to the collaborative design and construction of a tiny house. This study examines how that experience fostered students’ proficiency in the engineering design process and students’ engineering self-efficacy. The study addresses the following research questions:

1. To what extent and in what ways did participating in the tiny house project foster proficiency with the engineering design process?
2. To what extent did participating in the tiny house project foster students’ self-efficacy for engineering?

Frameworks

The study was guided by two frameworks, each aligned to one of the study’s research questions. The collection and analysis of data pertaining to student proficiency with the engineering design process (Research Question 1) was guided by a conceptual framework used by the school’s design program, consisting of six stages: 1. Brief, 2. Research, 3. Idea development, 4. Prototyping, 5. Testing, and 6. Production. Working with the participating teacher, the general definitions for each phase were refined to create a rubric describing expectations and levels of performance specific to the tiny house project.

The study's investigation of student self-efficacy was guided by Bandura's social cognitive theory. Social cognitive theory posits self-efficacy, defined as "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments [4]", as an important factor influencing motivation. Scholars have emphasized that self-efficacy tends to be context-specific [5]. As such, research has often investigated teacher and student self-efficacy within specific subject-areas, with strong traditions of self-efficacy research in science and mathematics education [6], [7], [8], [9]. Although some engineering education researchers have investigated students' engineering self-efficacy [10], [11], [12] much of the research in this area has focused on adults or undergraduate students [13]. Research on the development of students' engineering self-efficacy at the P-12 levels remains relatively scarce.

In addition to exploring self-efficacy within specific disciplines or domains, self-efficacy researchers and theorists have investigated the sources of self-efficacy beliefs [8], [14], [15]. Self-efficacy theory describes four sources of self-efficacy beliefs: 1) *mastery experiences*, an individual's previous performance of relevant tasks; 2) *vicarious experiences*, which occur through observation of other's performance of a task, or through comparing one's own performance to that of someone else; 3) *social persuasions*, consisting of feedback from others; 4) *physiological and affective states*, which tend to influence how an individual assesses their capabilities or performance [4]. These definitions of the potential sources of self-efficacy provide a useful lens for interpreting the development of engineering students' self-efficacy beliefs. Of particular relevance for the current study is Bandura's assertion that self-efficacy may be influenced by the quality (e.g. positive or negative) and the quantity (e.g. the frequency with which an individual has an experience) of experiences. Thus, this study is concerned with both the nature of students' isolated engineering experiences as they participate in the tiny house project but also how repeated exposure to and practice with the engineering design process over the course of a long-term project may influence students' self-efficacy development.

Method

Study Context

The study takes place in the context of a year-long high school Engineering Applications course taught at STEAM Charter School (a pseudonym), a public charter school located in a major city in the Southeastern United States. STEAM Charter School serves over 1800 students in Pre-K through 12th grade. Although significant community revitalization has occurred in recent years, the school community remains predominantly low-income and the majority of students qualify for free or reduced-price lunch. Over the previous two decades, STEAM Charter School's academic program has developed a strong reputation and the school is currently recognized as one of the highest performing schools in its district and a top charter school in the State. For the previous seven academic years, the school has transitioned to an instructional model focusing on project-based learning (PBL) integrating STEAM (Science, Technology, Engineering Arts, Mathematics) disciplines. Recently, the school has utilized funding from major grants to expand project-based learning through makerspace resources. In addition to classroom instruction in core disciplines, students participate in a rotating schedule of enrichment courses in a variety of STEAM disciplines including: engineering design, robotics, technology, visual and performing arts, and environmental science. Since opening in 2011 as an addition to the school's K-8 program, the Senior Academy (9-12th grade) has garnered attention for innovative project-based learning, particularly in engineering, and impressive academic outcomes. For example, the school's inaugural graduating class had a 100% graduation and college acceptance rate.

This case study is part of a larger, multi-year evaluation project focused on investigating the outcomes of project-based learning within the school. As preliminary data collected for this larger project suggested the Engineering Applications course as a context where students were engaging in particularly ambitious project-based engineering, the decision was made to conduct a year-long case study within the course.

The Tiny House Project

The tiny house project originated at the end of the previous school year, as the Senior Academy engineering teacher, Ms. Green (a pseudonym) worked with students to identify the problem they would address in the Engineering Applications course the following year. During this problem identification phase, Ms. Green had the idea of building a tiny house in mind and was working on a proposal for the grant that would ultimately support the project. However, she intentionally did not propose the specific idea to students. Instead, she led students through a series of exercises in which they identified and researched various problems within their community, including housing scarcity. Observing students' genuine interest in the problem of housing scarcity, Ms. Green arranged for the class to meet with a potential "client", an Americorps member who worked at the school as part of the MakerVista program. This visitor shared the challenges she experienced securing safe, affordable housing, with her relatively low income and rising rents in the surrounding area. It is at this point that students independently generated the idea to build a tiny house as a solution to the problem of housing scarcity. With guidance from Ms. Green, grant funding, and additional support from various community partners, the students devoted the following school year to researching and designing all systems within the house, using CAD software to iteratively develop floor plans and models of their designs, sourcing building materials, and completing initial construction of the tiny house.

Participants

Participants in the case study included the students enrolled in the Engineering Applications course and their teacher, Ms. Green. All of the students were either Juniors (n=8) or Seniors (n=2) and all had completed pre-requisite engineering coursework with Ms. Green the previous year. Student responses to a career interest item on the survey taken at the beginning of the school year indicate that the students began the course with a strong interest in engineering. All the students who completed the survey listed an engineering field among their career interests, with students expressing specific interests in civil, mechanical, geospatial, aerospace, and chemical engineering. Several students listed multiple engineering fields among their interests and five students listing engineering as their top career choice. Six students reported that they plan to major in engineering in college. Note that although a total of ten students initially enrolled in the course, one student withdrew early in the first semester, leaving nine enrolled students (two female students and seven male students) for the majority of the academic year. These nine remaining students were included in data collection for the case study.

Ms. Green was in her fifth year teaching engineering at the school. As all students had participated in pre-requisite engineering coursework prior to the Engineering Applications course, Ms. Green had worked with each of the students in the class in at least one additional year-long course. Although she is a relatively new teacher, with a background in civil engineering, Ms. Green brings a wealth of knowledge and expertise to her engineering instruction. She has been actively involved in a number of the school's recent professional development initiatives focused on enhancing project-based learning in STEAM disciplines. As the Senior Academy's only engineering teacher, Ms. Green has implemented a vertically aligned engineering design program in which students are challenged to complete increasingly sophisticated engineering projects as they progress through the high school engineering course sequence. Although certain projects are pre-determined and repeated each year, Ms. Green emphasizes student agency, often encouraging students to take the lead on the conceptualization and implementation of major engineering projects.

Data Sources

Using a case study approach [16] the study triangulates observation, interview, and survey data to explore student engagement in the engineering design process and the development of students' engineering self-efficacy over the course of the year-long project.

Observations

Classroom observations were conducted over the course of the project, with a minimum of two observations conducted each month. Observations typically lasted the duration of the class period (approximately 60 minutes). Observation data were collected using a rubric-based protocol (Appendix A) to document the overall progress of the project along with evidence of individual student engagement with various stages of the engineering design process. The tiny house Engineering Design Process rubric (Appendix B) was adapted from the Engineering Design Process Portfolio Scoring Rubric (EDPPSR) [17] to align with the six-stage engineering design process utilized in the course and the particular objectives of the tiny house project.

Interviews

Observations also included informal interviews in the form of short discussions in which students were asked to describe the activity they were currently engaged in (e.g. "Tell me about what you are doing?") These short discussions typically lasted 1-2 minutes and were intended to provide additional information about specific engineering design tasks and to gather students' perspectives as they completed various tasks. Similarly, short discussions with the teacher, which typically took place at the beginning or end of the class, provided additional context for the engineering design activities students engaged in as part of the project. Whenever possible, these short interviews were audio recorded and transcribed for analysis. When discussions were not recorded, relevant comments were captured in field notes.

Engineering Design Self-Efficacy Instrument
Self-efficacy was measured using the engineering design self-efficacy instrument [18] which was administered online at the beginning and end of the course. This instrument is designed to measure students' self-efficacy as it relates to engineering design generally and to each of the stages of the engineering design process. The full instrument includes a total of thirty-six items, with the same nine items aligned to the engineering design process repeated across four sub-scales measuring the related constructs of Self-Efficacy, Motivation, Outcome Expectancy, and Anxiety. For this study, only data gathered from the 9-item self-efficacy sub-scale were analyzed. The scale asked students to "rate your degree of confidence (i.e. belief in your current ability) to perform the following tasks by recording a number from 0 to 100. (0 – cannot do at all; 50=moderately certain can do; 100=highly certain can do). The nine task items include the general engineering design item (conduct engineering design) along with eight items aligned with the stages of the engineering design process (identify a design need, research a design need, develop design solutions, select the best possible design, construct a prototype, evaluate and test a design, communicate a design, and redesign). Note that although the wording of these engineering design process stages was not identical to the six-step engineering design process model used in the course, the steps were well aligned conceptually.

In addition to the self-efficacy items, the survey asked students to indicate their career interests ("please list your top three career choices below"). As this study does not investigate students' interest in engineering careers as an outcome, this item was included primarily in order to provide a more complete description of the student participants in the study. The post-survey asked students to respond to the following open-ended item: "What is the most important thing you've learned over the course of the tiny house project? Please share any specific examples of skills or knowledge you have gained through the project." This item was intended to gain insight into particular project experiences that may have fostered engineering proficiency or engineering design self-efficacy.

Data Analysis

Rubric ratings assigned based on observation sessions were compiled as matrices to illustrate student mastery of the engineering design process as it developed over the course of the project. Scoring guidelines provided by Carberry and colleagues [18] were followed to calculate average engineering design (ED) scores based on student responses to the first self-efficacy item (conducting engineering design) and an engineering design process score (EDP Score) by averaging the eight items aligned to each step in the engineering design process. Although we could not make inferences to a larger population and findings should be interpreted with caution given the small sample size, we did compute descriptive statistics and conduct paired-samples t tests comparing pre-post responses on self-efficacy subscale items in order to identify potential patterns or changes in students' self-efficacy over the course of the project.

Interview data, observation field notes, and responses to the open-ended survey item were subjected to sequential qualitative analysis [19] to identify salient themes related to students experience with the project and their engineering design self-efficacy. This process involved two rounds of coding, which was conducted using the NVIVO qualitative analysis software program. In the first round of coding, we focused on applying a provisional start-list of codes aligned to each of the stages in the EDP model. The second round of coding focused on identifying additional patterns and themes related to students' self-efficacy and engagement in the EDP.

Findings

Proficiency with the Engineering Design Process

Taken together, observation, interview, and survey data provide clear evidence that students' proficiency with the EDP developed over the course of the project. Figure 1 below illustrates rubric ratings for each stage of the engineering design process by student at the end of the first (T1) and second (T2) semesters of the project. The cells of the matrix are shaded to correspond with levels of mastery evidenced by observation data, with the darkest shade representing the Advanced level on the rubric and the lightest shade representing the Novice level.

EDP Stage												
	1 - Brief		2 - Research		3 – Idea Development		4 - 3D Prototyping		5 - Evaluation and Testing		6 - Production	
Student	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
1												
2												
3												
4												
5												
6												
7												
8												
9												
% Proficient or Advanced	89	89	89	89	67	89	56	89	0	67	0	100

EDP Rubric Level	Advanced	Proficient	Developing	Novice

T1 = End of first semester. T2 = End of School Year

Figure 1. Matrix Illustrating Mid- and End-of-Year Rubric Ratings by Student

The class devoted the first three months of the project to developing an in-depth understanding of tiny houses and how they are built, conducting in-depth research on the various components and systems within the tiny house (e.g. electrical, plumbing, framing), and engaging in an iterative design process in which they created and presented floorplan options to the Americorps member designated as the client. This research process included both independent investigation and consulting with experts. For example, students devoted a Saturday to attending a local Tiny House Festival where they could explore various designs first-hand and ask tiny house owners and builders about specific tiny house features. By the end of the first semester, all but one student had demonstrated proficiency with the first three stages of the engineering design process (brief, research, and idea development).

As they started working with CAD software to create models at the end of the fall semester, students began to develop proficiency in this area as well. Note that, in the context of this project and the particular engineering design process model used by the school, 3D prototyping is understood to include the creation of simulated 3D models created using CAD software versus being limited to the creation of physical 3D models. Students' prototyping began with the translation of their detailed floorplans into CAD renderings using Google Sketchup. While she initially offered guided instruction on the use of the software, as students' proficiency with the software increased, Ms. Green challenged them work more independently to develop the 3D CAD model of the final tiny house design.

Evaluation and testing was an area where opportunities to develop proficiency were somewhat limited. Due to major revisions to the project timeline, discussed below, students did not have the opportunity to install and test systems within the tiny house. Some evaluation occurred as students considered their options for various materials (e.g. roofing materials, appliances); however, students were typically not observed systematically collecting and analyzing test data.

Student proficiency with production began developing in the first semester with the procurement of materials for the tiny house build. In the second semester, once the design for the tiny house had been finalized, all students actively engaged in the construction of the tiny house structure. This work included using an array of tools and techniques to build the major structural elements of the tiny house (sub-floor, walls, roof). Observation and interview data revealed that students began the build phase with a wide range of previous construction experience, from students whose experience was limited to using tools for previous engineering projects to a student who worked in his family's construction business (often referring to his family as a "construction family"). Not surprisingly, more experienced students often took the lead during the construction phase. For example, during one observation visit, the student from the "construction family", who was generally one of the quieter students in the class, self-identifies as the construction "foreman" and confidently gives direction to his classmates as they work together to assemble the final wall of the house. At one point he jokingly reprimands his friend who was reading him measurements from a laptop, "get back to the computer or you're fired!" In this particular building episode, the students' leadership enabled the two students to efficiently complete the wall, with Ms. Green offering encouragement when she returns to the classroom: "You guys are awesome. I can't believe I can leave you in there to build a wall, and here it is!" The foreman responds that they aren't quite finished and have fourteen minutes until the class period ends, at which point Ms. Green and the two students work together to complete the wall.

Interview data provided additional evidence of developing EDP proficiency. When asked to describe the engineering tasks they were working on, students frequently provided detailed descriptions that not only explained the particular activity but also drew connections to an iterative design process, sometimes referencing a particular stage of the engineering design process explicitly. For example, as he begins working on a revised floorplan, one student describes the class's iterative design process:

> *After we talked to (client) and I saw some other designs, I thought of some new ideas to incorporate, so I'm doing another one. We're each designing multiple floorplans, as many as it takes, to figure out which one is going to be best for all her requirements. That's kinda' how this process, the design process, works. You really got to spend so much time thinking through your ideas and trying them out, running them by people, taking them to the next level, before you just go build something. You can't just go building a house without knowing what you are doing.*

Illustrative examples of student proficiency at each stage of the engineering design process are presented in Table 1 below.

Table 1
Illustrative Examples of Tiny House Project Engineering Activities by EDP Stage

EDP Stage	Illustrative Examples
1. Brief	Students have met with the "client" several times in order to identify requirements for the tiny house. Students actively engage in decision-making around project management and the resources that will be utilized to carry out the project. For example, in one class discussion, a student serving in the Project Manager role prompts classmates to consider whether they should use Google Sketchup vs. drafting their floorplans with paper and pencil. (9/25 Observation)
2. Research	Students worked in teams to research options for various systems for the tiny house (i.e. framing, plumbing, HVAC, electrical.) With few exceptions, students actively engage in an iterative research process in which they present options for systems to the client and other experts in the community and go on to refine their recommendations. As new design elements are considered, students apply STEAM concepts and skills to further refine their plans. For example, having discovered the need to utilize flashing material for water-proofing, one student calculated how many rolls of a specific material they would need to purchase. (9/19 and 11/30 Observations)
3. Idea Development	Over several weeks, students iteratively develop floorplans for the tiny house. The floorplans are detailed, drawn to-scale, and take into consideration the dimensions of the chosen trailer and all systems and design elements for the tiny house. Following a vetting process in which floorplans are presented to the client, the class works together to combine elements of the client's top two floor plan choices to create their final design. (10/5, 10/26, 11/7 Observations)
4. Prototyping	Students convened for a Saturday work session to continue working on their CAD renderings of the tiny house design. The week following this session, the teacher reports that "they are all really, really good at CAD now." All students have worked for several weeks, devoting considerable time to using Google Sketch-Up. With the exception of one student still developing basic proficiency with CAD software, students' models accurately depict major elements of the trailer and tiny house design (including windows, doors, framing and roofing). During one observation period, two students demonstrate advanced proficiency, helping others use the CAD software to refine or troubleshoot aspects of their models. (1/22 Observation).
5. Evaluation and Testing	Students engaged in numerous discussions evaluating the merits of various options for the systems within the tiny house (9/19 Observation) and they have discussed the advantages and disadvantages of various floorplans. (10/5 Observations).
6. Production	Students independently utilize tools to cut lumber and assemble the framing for the tiny house walls within the classroom. Subsequently, students assemble the walls on the floor joist structure they have assembled on the tiny house trailer. Students take an active role in troubleshooting throughout the construction process. For example, when students discover that one of the walls did not fit as expected, they referenced their CAD models, identified an issue with one of the measurements, and adjusted the height of the wall accordingly. (5/8 Observation).

Engineering Design Self-Efficacy

Consistent with developments in student proficiency with the engineering design process described above, analysis of student responses on the Engineering Design Self-Efficacy Instrument suggest an increase in students' self-efficacy for each area of the engineering design process over the course of the project. The average Engineering Design (ED) score in which students rate their confidence in conducting engineering design, was relatively high at the beginning of the project, with a mean rating of 76.3 (*sd* = 25.8) but increased further to 93.5 (*sd* = 10.3) by the end of the project. Although the difference in this ED item was not significant, a paired samples *t* test comparing the average Engineering Design Process (EDP) score, calculated as the average rating across the eight engineering design process items, indicated a significant increase from 74.2 (*sd* = 18.9) to 92.1(*sd* = 9.9), ($t(8)=-3.8$, $p<.01$). Average scores on each of the items in the Engineering Design Process Self-Efficacy instrument are presented in Table 2 below. Additionally, an examination of student-level data confirms these consistent increases in self-efficacy across students and items. For each student who participated in the project, ratings for every self-efficacy item were either maintained or increased from pre to post.

Table 2
Average Pre-Post Scores on Engineering Design Self-Efficacy Items

	Pre		Post			
	M	SD	M	SD	Change	*t(8)*
Conducting Engineering Design	76.3	25.8	93.5	10.3	17.3	2.1
Identify a Design Need	78.8	12.8	94.9	7.4	16.1	3.8**
Research a Design Need	69.5	26.1	91.4	9.8	21.9	2.3
Develop Design Solutions	76.1	21.4	89.4	13.5	13.3	1.7
Select the Best Possible Design	79.8	19.8	91.0	10.1	11.3	1.9
Construct a Prototype	79.3	26.8	92.4	14.8	13.1	2.7*
Evaluate and Test a Design	65.9	22.6	91.9	11.0	26.0	3.3*
Communicate a Design	68.9	32.1	90.4	17.5	22.5	2.3
Redesign	76.6	25.1	94.5	12.0	17.9	3.4*
EDP Score	74.2	18.9	92.1	9.9	17.9	3.8**

Note: *p<.05, **p < .01

Students' open-ended survey responses highlighted specific activities that may have served as particularly powerful mastery experiences. Each student referenced a particular skill or areas of expertise they had developed through the project. For example, one student notes "I have become adept at constructing 3D models using CAD programs like sketch-up and I have become great with physical building." Additionally, many students mentioned collaboration and leadership, often in the context of overcoming a challenge the class encountered as they designed and built the tiny house. For example, one student discussed his leadership development, citing a particular instance when he worked with Ms. Green to address a construction challenge:

> *The most important thing I've learned was to be a better leader. Not only telling others what to do, but finding other tasks to work on so the project may continue. I recall on a Saturday, I came in by myself, and Ms. Green and I discussed how to attach the sub-floor. The problem was that both plywoods didn't line up to the support beam underneath, which would cause the plywood to sag. So Ms. Green and I made a plan to resolve the problem. That made me feel like the extra work was worth it, like even though this whole thing was new to me, I could figure it out so we could get this thing done.*

Similarly, another student described how they were able to work with their team-members to "use technology like computer-aided design and math topics such as Trigonometric functions to construct a very difficult, angled wall for the house."

The emphasis on leadership in students' survey responses is consistent with observation data documenting the significant responsibilities assumed by students over the course of the project. As evident in the episode involving the self-identified "foreman" describe earlier in the paper, although Ms. Green facilitated student work at each stage of the process, students were given significant agency when it came to project management. For example, Ms. Green often delegated important administrative tasks, such as writing reports for the grant that funded the project or making phone calls to negotiate pricing with vendors, to students. Similarly, during the spring semester, Ms. Green invited three students to join her to present the project at a national conference and, based on their impressive performance, these students were asked to give subsequent presentations to local stakeholders.

Challenges

Although case study findings clearly indicate positive effects of participating in this type of ambitious, applied engineering experience, both students and their teacher encountered a number of challenges over the course of the year-long project. Observation and interview data revealed unevenness in student engagement. While a number of students were engaged consistently, regardless of the engineering task, engagement was more task-dependent for other students. For example, during one observation visit conducted toward the end of the project, Ms. Green noted that one student seemed far more motivated to participate in the hands-on building of the tiny house than he had been in the research of the tiny house systems conducted earlier in the school year. The duration of the project meant that students typically devoted weeks or even months to each stage of the project, which could be difficult for students with focused interests. For instance, if a student was not particularly interested in designing systems or creating CAD models but enthusiastic about construction, they would have to wait until the final building phase of the project to participate in the activities that motivated their interest in the course.

Along with fluctuations in engagement, observations and interviews indicated a corresponding unevenness in students' skill development that wasn't necessarily evident from the EDP Rubric ratings. Students were assigned various specialized roles within the project and tended to develop somewhat stronger expertise when it came to particular tasks associated with these roles. For example, the student who served as the CAD Manager was typically the one called upon to troubleshoot issues with the 3D model of the tiny house. This experience afforded an opportunity for this student to practice and deepen his expertise with CAD software that was not necessarily available to all students. Similarly, if a student demonstrated a particular proficiency with a specific tool, as was the case when one of the girls in the class became known for her aptitude using the circular saw to cut lumber for the tiny house framing, they would often be tasked with that step of the construction. While this specialization certainly increased efficiency and allowed students to work on aspects of the project that aligned with their strengths and interests, it also limited the scope of expertise individual students could develop through the project.

As is the case with any major construction project, the students and Ms. Green came up against challenges related to time and material resources. Having never constructed a tiny house before, Ms. Green began the project with only an approximation of how long the various stages of the project would take and how the project timeline would coincide with the school calendar and students' daily schedules. Even with a full school year devoted to the project, early in the second semester, Ms. Green and the students came to terms with the reality that, given their school schedule and the time required to execute their design, it would be impossible to finish the tiny house by their original May deadline. In consultation with Ms. Green, the class decided to extend the project into a second year, setting the new goal of having the exterior structure of the house complete, while leaving the interior and installation of the tiny house systems to students in the next year's Engineering Applications course.

In addition to the constraints of their $10,000 budget, the unique school context of the tiny house build presented certain challenges related to materials management. Even with a large state-of-the art engineering classroom, the storage of lumber would become a challenge as the project progressed from design to construction. Ultimately, a large area in Ms. Green's classroom was devoted solely to the storage of lumber. Another large area of the classroom was used for arranging the lumber to create the walls of the tiny house, which would eventually be assembled on a large trailer located in a parking lot near the classroom. Because the classroom needed to be utilized by other students throughout the day, if a wall wasn't completed by the end of the class period, there was not space for students to leave building materials laid out on the floor. So, each of the individual pieces would be returned to the lumber area and students would resume construction the next class period. Other issues related to materials included the challenge of keeping tools organized when they may be used throughout the school day by other students, keeping power tools sufficiently charged, and the need for specialized construction resources (e.g. scaffolding) that aren't typically found in an engineering classroom.

The scale of the project posed certain challenges at the school level that don't typically exist for engineering class projects. For example, Ms. Green had to work closely with school leaders to allocate sufficient space on school property for the tiny house build. Follow-up conversations with Ms. Green indicate that, as the tiny house is nearing completion in the second year of the project, considerations regarding insurance, equipping the tiny house with utility services, and liability have emerged. Although the school has been supportive and has demonstrated its capacity to support students and teachers as they undertake such an ambitious engineering project, that capacity has limits. Strongly believing in the importance of authentic project-based learning experiences, Ms. Green envisioned students building a tiny house that could address housing scarcity by actually being inhabited by someone for at least one year. At this writing, as the house is being completed, the permanent site for the tiny house and whether and how the school will manage the process of finding an inhabitant remain unknown.

Discussion

This case study provides clear evidence that, through their participation in the tiny house project, students in the Engineering Applications course developed proficiency with the engineering design process along with increased engineering design self-efficacy. In many ways, attaining proficiency at each stage of the engineering design process was tied to the class's pursuit of the long-term engineering challenge of designing and building a tiny house. The early stages of the project afforded numerous opportunities for students to gain significant experience with engineering activities within the brief, research, and idea development stages of the process. As the project progressed, the course devoted significant time to the development of CAD models of students designs before beginning actual construction of the tiny house during the spring semester. Although the class generally progressed from the research to design to prototyping phases, their engineering design process was iterative, providing multiple opportunities for students to gain additional experience with each stage over the course of the project. Similarly, although the entire class was engaged in the overall design process for the tiny house, individual students and small groups of students progressed through the stages of the engineering design process many times as they made decisions about the individual systems or components of the tiny house.

Our data collection focused primarily on student experiences with the project. However, to the extent that observations and discussions with Ms. Green provide insight into her pedagogical approach, the case study provides some support for a mode of project-based learning that engages engineering students in ambitious long-term projects, prioritizes student-agency, and challenges traditional roles of teachers and students. Additional research that explores the attitudes, self-efficacy, and pedagogical approaches of engineering teachers engaged in this type of work would be instructive.

The scope of a year-long project with such an ambitious goal may seem daunting or even unrealistic at the high school level. Indeed, as noted above, while the class had the original goal of designing and building a tiny house that would be ready for their client to inhabit by the following summer, early in the second semester it became apparent that this goal would not be within reach. Although some students were initially disappointed that they wouldn't see the completion of the tiny house, other than limiting opportunities to Evaluate and Test their design, this significant shift in the project goal did not seem to influence the degree to which students could demonstrate mastery of the engineering design process. While the time and resources required to complete a tiny house project may seem prohibitive, strong interest in expanding opportunities for project-based engineering at the K-12 level may bring new avenues for teachers and schools to pursue funding or partnerships that could make such projects more feasible.

Self-efficacy data suggest that, as students gained proficiency with the EDP through their work on the project, there was a parallel increase in their confidence with regard to engineering design, generally, and with the various stages of the engineering design process. In reflecting on their experience in the course, students often referenced specific mastery experiences, such as overcoming a particular construction challenge, learning how to use new tools, or applying specialized mathematics or science knowledge to the design and construction of the tiny house. Future research should continue to examine how engaging in challenging applied engineering projects such as this may influence the development of high school students' self-efficacy. Although this study describes changes in students' self-efficacy for engineering design over the course of the project and highlights potential mastery experiences cited by students, the data did not allow for a careful analysis of the sources of students' engineering self-efficacy. Much could be learned from additional qualitative research that explores whether and how the four sources of self-efficacy hypothesized by Bandura manifest in the context of applied engineering projects. Additionally, given observation data illustrating the ways in which students' prior experiences influenced the confidence with which they led particular activities, research that uses a sociocultural lens or explores how students' funds of knowledge effect engagement in applied engineering projects would be another fruitful avenue for future research.

Appendix A

Engineering Design Process Observation Guide

Observer____________________ Date_________________

	Engineering Design Process Stage									
Student	1	2	3	4	5	6	7	8	9	Notes
Student 1										
Student 2										
Student 3										
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N = Novice D = Developing P = Proficient A = Advanced										

Engineering Design Process Phase Definitions
1. Identify, define, and research a technological problem.
2. Utilize planning, time management, and leadership skills to organize an engineering project.
3. Research, select, and safely apply engineering concepts, machines, and tools for completion of the project.
4. Develop alternative solutions to a technological problem.
5. Select an appropriate solution that optimizes the outcome based on the specifications, constraints, and resources of the project.
6. Develop a 3D model of the solution using modeling software and/or physical materials.
7. Develop a working prototype of the solution
8. Test the prototype using engineering tools, concepts, and methods.
9. Analyze the results of the testing and modify the solution as needed.

Appendix B

Tiny House Project Engineering Design Process Rubric

Phase	No Evidence	Novice	Developing	Proficient	Advanced
1. Brief: Identify & define a problem any constraints/requirements **for the overall tiny house project or specific systems or design elements**; Utilize planning, time management, and leadership skills to organize an engineering project.	The identification and/or definition of the problem and constraints/requirements are **missing OR cannot be inferred from observation or project documents.**	The identification and/or definition of the problem and constraints/requirements **is unclear, is unelaborated**. Student **tends to play a passive role in project planning and organization**; may demonstrate challenges with planning and time-management related to project tasks.	The problem and constraints/requirements are identified only **somewhat clearly and defined in a manner that is somewhat superficial and/or minimally elaborated** with specific detail. Student **participates in project organization discussions but participation may be inconsistent .**	The problem and constraints/requirements are **clearly identified and defined with adequate depth,** elaborated with specific detail, although some information intended as elaboration may be imprecise or general. Student **takes an active role in goal setting, project organization, and monitoring team progress.**	The problem and constraints/requirements are **clearly identified and defined with considerable depth**, and it is well elaborated with specific detail. Student **takes a leadership in goal setting, project organization, and monitoring team progress.**
2. **Research:** Research the problem; apply STEAM concepts/skills to deepen problem understanding; identify and select appropriate resources (e.g. tools, materials, expertise) for completion of the project.	Documentation of research activities is **missing OR cannot be inferred from observation or project documents.**	Student **struggles to conduct research** related to the overall tiny house project or specific systems/design elements. The student **struggles to apply STEAM concepts and/or skills** or to identify resources that are logical and based on thorough market research.	Student **conducts research** related to the tiny house project or specific systems/design elements. but **generally does not engage in collaborative research activities** or share findings of research with team members. The student **may connect project work to STEAM concepts and/or skills** and identifies resources	Student **participates in collaborative research** activities related to tiny house project or specific systems/design elements. Student **provides clear documentation** of the findings of their research and shares these findings with teammates. The student **applies STEAM concepts and/or skills** and identifies resources	Student **leads project research efforts,** often supporting team members' research or leading collaborative research. Student **documentation of research is clear and detailed, and consistently communicated with team members.** The student **applies STEAM concepts and/or skills at a high level** and identifies

			that are logical and based on market research.	that are logical and based on thorough market research.	resources that are logical and based on thorough market research.
3 - Idea Development: Develop alternative solutions to design **problems related to the overall tiny house project or specific systems or design elements**; select an appropriate solution that optimizes the outcome based on the specifications, constraints, and resources of the project.	There is **no evidence of an attempt to arrive at a design solution through an iterative process based on design requirements**. **No sketches** for potential solutions were evident in observations or review of project documentation.	The student **occasionally participates** in generating design solutions but tends to play a more passive role and may be reluctant to engage in an iterative process. **The student occasionally contributes to sketches, models, or other representations for** potential solutions; however, these representations are not **thorough or sufficiently detailed** to communicate designs.	The student **participates** in a process for generating possible design solutions but, at times, may struggle to engage in a thorough, iterative process. **The student contributes to sketches, models, or other representations for** potential solutions; however, these representations may not be **thorough or sufficiently detailed** to communicate designs.	The student **actively participates** in a process for generating possible design solutions that is **thorough and iterative. In collaboration with teammates, the student creates sketches, models, or other representations for** potential solutions. These representations are **thorough and sufficiently detailed** to communicate each design.	The student **leads** a process for generating possible design solutions that is **thorough and iterative. In collaboration with teammates, the student creates sketches, models, or other representations for** potential solutions. These representations are **thorough and provide sufficient detail** to communicate each design.

4. **3D Prototyping:** Develop a 3D model of the tiny house and/or specific systems or design elements using modeling software and/or physical materials.	The student does not participate in prototyping a solution. Any attempt to explain the final prototype iteration is **unclear or is missing** altogether.	The student **does not participate in creating prototypes or takes a passive role in prototyping.** The student attempts but may struggle to provide clear explanations of prototypes.	The student **contributes to** iteratively creating prototype(s). The prototype is **explained;** however, the student may struggle to provide clear explanations and may lack enough detail to assure that **all or nearly all design requirements** could be tested.	The student **actively participates** the process for iteratively creating prototype(s). The prototype is **clearly and fully explained** and is constructed with enough detail to assure that **all or nearly all design requirements** could be tested.	The student **leads** the process of iteratively creating prototype(s). The prototype is **clearly and fully explained** and is constructed with enough detail to assure that **all or nearly all design requirements** could be tested.
5. Evaluation & Testing: Evaluate the degree to which prototypes of the overall tiny house design or specific systems/design elements meet requirements through iterative testing.	The student **does not participate** in evaluation or testing of tiny house design elements and does not engage in using test results to evaluate prototypes or design elements.	The **student does not participate or takes passive role in** testing and evaluating prototypes and tiny house design elements. The student attempts but may struggle to systematically use test results to evaluate prototypes or design elements.	The **student may contributes to** the process of iteratively testing and evaluating prototypes and tiny house design elements and the collection and analysis of test data; however, the student may struggle to systematically use test results to evaluate prototypes or design elements.	The **student actively participates** in the process of iteratively testing and evaluating prototypes and tiny house design elements including collecting and analyzing test data and systematically evaluating prototypes or design elements according to requirements.	The **student leads** the process of iteratively testing and evaluating prototypes and tiny house design elements including collecting and analyzing test data and systematically evaluating prototypes of design elements according to requirements.

6. Production: Construct a tiny house based on prototypes and testing using engineering tools, concepts, and methods; presentation of the final tiny house to client, potential users, and/or the public (written, oral, digital).	Student does not participate in the construction of the final product. Student does not participate in presentation, or presentation does not communicate the tiny house design and features.	Student **takes a passive role** in the construction of the final product and rarely applies knowledge of engineering tools, concepts, and methods. Presentation shows work and effort but is vague or missing key elements necessary to communicate the tiny house design and features.	Student **is somewhat engaged** in the construction of the final product, **exhibiting a developing understanding** of engineering tools, concepts, and methods. Presentation communicates topic in clear and compelling manner. Presentation exhibits basic grasp of tiny house design and features.	Student **actively participates** in the construction of major elements of final product, **exhibiting mastery** of engineering tools, concepts, and methods. Presentation communicates the topic in clear and compelling manner. Presentation exhibits an adequate grasp of tiny house design and features.	Student **leads** construction of major elements of final product, **exhibiting mastery** of engineering tools, concepts, and methods. Presentation communicates the topic in clear and compelling manner. Presentation exhibits expertise in the tiny house design and features.

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