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Developing Engineering Proficiency and Self-Efficacy Through a Middle School Engineering Course (Fundamental)

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Developing Engineering Proficiency and Self-Efficacy through a Middle School Engineering Course (Fundamental)

Introduction

In recent years, engineering has become a new priority in elementary and secondary science classrooms across the United States. Numerous states have adopted engineering standards [1], [2], [3] and at the national level, the *Next Generation Science Standards* [4], [5] call, for the first time, for the meaningful integration of science and engineering. With this emergence of engineering within the K-12 educational arena comes a new imperative for education research exploring the outcomes of efforts to engage pre-college students in engineering. A systematic review of P-12 engineering education studies from 2000-2015 [6] describes a sharp increase in P-12 engineering education and highlights student perceptions, attitudes, motivations, beliefs, and knowledge; teacher professional development; and outcomes of engineering curricula as major themes within the extant literature. Descriptions of students' experiences with engineering have also occasionally appeared within the science education literature; however, because engineering has only recently begun to take hold as a discipline in K-12 schools, much of the science education literature featuring engineering focuses on informal settings. For example, Barton, Birmingham, Sato, Tan & Barton [7] provide accounts of identity development among middle school students whose interest in engineering is fueled by their experience in an afterschool program focused on Green Energy Technology.

In spite of this recent expansion of the P-12 engineering education literature, relatively few researchers have investigated the development of engineering proficiency longitudinally. Existing longitudinal work tends to focus on undergraduate students or how pre-college experiences influence students' attitudes, interest, motivation and persistence as undergraduate engineering students. For example, Zarske, Yowell, Ringer, Sullivan, and Quinones [8] examined outcomes of a pre-college engineering model implemented in a 9-school feeder system and found positive impacts on perceptions, preparedness, and persistence in engineering among participating high school students. Fantz, Siller, and Demiranda [9] used retrospective surveys to examine the long-term effects of pre-college engineering experiences on first-year undergraduate students' self-efficacy related to their engineering studies. Other researchers have looked at developments in students' engineering experiences cross-sectionally. Capobianco, Ji, and French [10] compared variations in the development of engineering identity across a sample of preadolescent students in first through fifth grade. While there are compelling qualitative studies describing the nature of P-12 students' engagement with specific aspects or stages of the Engineering Design Process (EDP) [11], [12], research exploring the development of students' understanding of and engagement with the EDP during the critical middle school years remains scarce. This scarcity contrasts with the relatively rich literature on students' learning progressions and the mastery of practices within the science education literature [13], [14]. Further, while research documenting learning outcomes of curricular interventions is becoming more commonplace, this work most often reports pre/post results of relatively short-term programs. We know relatively little about how students' understanding of the EDP develops over successive experiences with vertically-aligned curricula intended to increase students' engineering proficiency over the course of several grades.

Decades of research has documented that the beliefs students hold about their academic capabilities – their self-efficacy beliefs- can have a powerful influence on academic performance [15], [16]. Students with strong self-efficacy beliefs tend to work harder, engage in more self-regulatory strategies, evaluate their progress more frequently, solve problems more efficiently, and show greater levels of persistence than equally capable peers with lower self-efficacy [17], [18]. As self-efficacy beliefs are thought to be context-specific [17], researchers examining students' self-efficacy beliefs have often focused student beliefs within specific subject areas including mathematics [19], [20] and science [21].

While self-efficacy is well established as a powerful predictor of academic performance, less is known about how self-efficacy beliefs within specific domains develop over time. As described further below, Bandura [15] hypothesized that students interpret information from different types of experiences (e.g mastery experiences, vicarious experiences, social persuasions, and physiological/affective states) to form self-efficacy beliefs. Although engineering education researchers have begun to explore students' engineering self-efficacy [22], [23] much of this work has focused on adults or undergraduate students [24], [25]. Research examining the factors influencing the early development of students engineering self-efficacy at the P-12 levels remains relatively scarce.

This study builds on previous work [26] to explore the development of proficiency with the EDP and engineering self-efficacy among a sample of students (N=6) who participated in two semester-long engineering courses over a two-year period. Using a case study approach, the study triangulates interview and student artifact data to trace the development of students' understanding and application of the engineering design process. Drawing on social cognitive theory [1997], the study also explores whether students' descriptions of their course experiences indicate possible changes in engineering self-efficacy.

Research questions

The study addresses the following research questions:

- To what extent and in what ways do students' descriptions of the engineering design process change over multiple experiences with the engineering course?
- What do students' descriptions of their experiences in the engineering course reveal about changes in their engineering self-efficacy and the sources of their engineering self-efficacy?

Frameworks

Two frameworks were instrumental for the study: the Engineering Design Process (EDP) and Social Cognitive theory. Each of these frameworks are described below.

Engineering Design Process

Although conceptual models describing the engineering design process vary in terms of specific terminology and the sequence of activities [24], such models commonly describe the iterative process by which engineers develop design solutions. The Engineering Design Process (EDP) (Figure 1) served as the overall conceptual framework guiding the development and implementation of the curriculum. Specifically, the curriculum was designed to utilize the EDP within a problem-based learning context, combined with an emphasis on science and mathematics practices defined by the Next Generation Science Standards [5]and the Standards of Mathematical Practice [27]. As such, this particular EDP model was utilized by teachers as they guided students through the curriculum. It also served as the basis for the engineering design log (described below), and informed the development of protocols and coding schemes utilized to analyze student interview data.

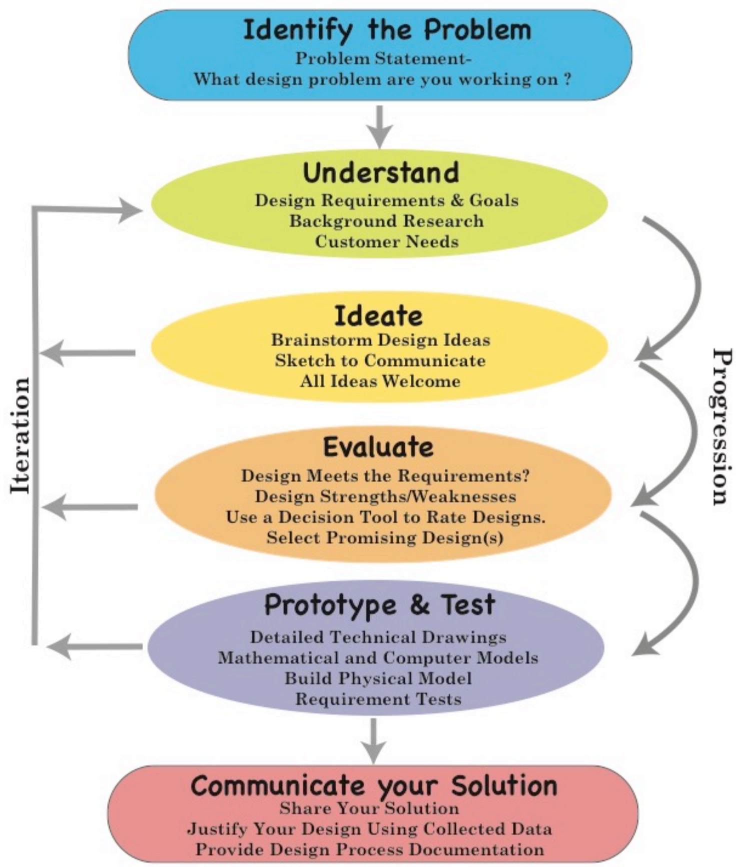


Figure 1. Engineering Design Process

Social Cognitive Theory

Social Cognitive theory was employed primarily as a lens for data analysis. As the initial purpose of the study was to investigate students' engineering experiences and their understanding of the engineering design process, as defined by the framework described above, interview protocols and coding schemes were not developed with the explicit intention of gathering data related to students' self-efficacy. However, as efficacy-relevant data emerged from students' broader descriptions of their engineering experiences, social cognitive theory provided a useful tool for making sense of this emergent data.

Bandura's social cognitive theory argues that self-efficacy, defined as "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments [15]", is a critical factor motivating human behavior.

In addition to defining self-efficacy as it relates to various outcomes of interest, researchers and self-efficacy theorists have explored the sources or antecedents of self-efficacy in order to further understand the genesis of self-efficacy beliefs [20], [28, [29]. Self-efficacy theory suggests a framework identifying four main sources of self-efficacy beliefs: 1) *mastery experiences*, which are experiences from an individual's previous performance of relevant tasks; 2) *vicarious experiences*, which occur through an observation of someone else performing the task, or comparing one's own performance of a task with that of someone else; 3) *social persuasions*, which consist of feedback from others, and are differentially impactful on self-efficacy based on the contents of the feedback and the perceived standing of the person providing the feedback; 4) *physiological and affective states*, which exert an impact on an individual's assessment of their capabilities within the current setting [15]. This conceptualization of the potential sources of self-efficacy provides a useful framework for interpreting and exploring the origins and development of engineering students' self-efficacy beliefs. Of particular relevance for the current study is Bandura's argument that self-efficacy can be influenced both by the quality of experiences (e.g. positive or negative) and the quantity of experiences (e.g. the frequency with which an individual has an experience). As such, we are interested not only in the nature of students' isolated engineering experiences and what these experiences may indicate about students' self-efficacy, but also in how the sources of self-efficacy manifest with repeated exposure to and practice with the engineering design process over multiple years taking middle-school engineering courses.

Methods

The study utilizes a descriptive case study design [30]. The primary motivation for selecting a case study approach is the study's goal of developing a contextualized understanding of project-based engineering as it unfolds in particular classrooms and communities. Merriam notes that descriptive case studies, in particular, are "useful in presenting information about areas of education where little research has been conducted [30]."

Curriculum Context

As part of a National Science Foundation Math-Science Partnership program, semester-long engineering courses were developed to engage 6^{th} through 8^{th} grade students in engineering design challenges intended to foster understanding of the engineering design process while reinforcing mathematics and science content. In sixth grade, students explore data collection, experimental design, sketching, prototyping, statistical analysis, and communication for a challenge in which they design and test a new carnival game. In seventh grade, students complete a project with an aerospace engineering focus that involves re-designing the interior cabin and airplane shape in order to maximize the fuel-efficiency, comfort, and profitability of an airplane. In eighth grade, students complete two design challenges. In the first challenge, they use 3D modeling software to design and prototype a cell phone holder for another student serving as their client. In the second challenge, which focuses on robotics, students again use 3D modeling software as they design, prototype, and test "feet" for a walking insect-bot. For additional details on the curriculum, see (curriculum website).

Data for this case study were drawn from a larger research agenda examining the implementation and outcomes of the engineering course over a 3-year implementation period in four middle schools within the partnering school district. The district is in an urban fringe area outside a major city in the Southeastern United States. The district's student population is relatively low-income and diverse, with approximately 67% of the students qualifying for free/reduced lunch, and the race/ethnicity subgroups including White (45%), Black (44%), Hispanic (7%), and Other (5%).

Participants

Following a unique case sampling strategy [30], six students (identified in this paper using pseudonyms) were selected for this case study based primarily on their experience with the engineering course. According to Merriam [30], a unique sample is based on "unique, atypical, perhaps rare attributes or occurrences of the phenomenon of interest". Within this case study, the students were selected because, within their school context, they were relatively unique for having participated in the semester-long engineering course for at least two consecutive years during their middle school tenure. Five of the six students had participated in the engineering course at the same school with the same teacher each year. The sixth student, Steven, had changed schools several times, starting at the same school as the other students and subsequently participating in the engineering course offered at two other schools in the district. Participant information is presented in Table 1 below.

Table 1. Case Study Participants

	Gender	Grade		Number of Years in Engineering Courses
Student (Pseudonym)		Year 1	Year 2	
Marissa	F	6	7	2
Alicia	F	7	8	3
Steven	M	7	8	3
Bethany	F	7	8	3
Oscar	M	7	8	3
Evan	M	7	8	3

Data Sources

Interview data served as the primary data source for the study with student artifact data utilized as secondary data sources to confirm and extend findings. Each of these data sources are described below.

Student Interviews

Semi-structured interviews were conducted in order to explore students' experiences with the engineering design process and any related changes in engineering self-efficacy. Interviews followed a semi-structured protocol in which students were asked to describe their engagement in the course activities. Specifically, the protocol included a series of questions intended to elicit students' reflections on their experience with the engineering design process along with additional questions related to various other aspects of the course including collaboration, the integration of math and science, and students' overall perceptions of the course. A total of twelve interviews were conducted with the six students in the case study sample, one interviews with each student at the end of two of the semesters in which they were enrolled in the engineering courses. Interviews were conducted during the final week of the academic year in which students were enrolled in the engineering course. Interviews lasted 20-30 minutes and were conducted by one of four researchers in a quiet area of the school. All interviews were audio recorded and transcribed for analysis.

Interview data were analyzed using an eclectic coding process [31] in which a combination of holistic, descriptive, and magnitude codes were iteratively applied in order to reveal patterns in the interview data. In the first round of coding, holistic codes were used to identify general topics areas within the interviews, including both topics aligned to the interview protocol (e.g. engineering design process) and instances in which students' responses to protocol questions pertained to their self-efficacy. The second round of coding focused on identifying instances of descriptive sub-codes, such as student discussion of particular stages within the engineering design process or sources of self-efficacy, and magnitude codes, such as student responses indicative of various levels of understanding. Following coding, interview data were then described using conceptually clustered matrices [32] in order to illustrate variations in patterns between students and across the two years for each student. These patterns were then triangulated with students' engineering design logs and results from an engineering design process assessment and a measure of academic self-efficacy (described below) to confirm within- and between-case patterns.

Engineering Design Process Logs

Engineering Design Process (EDP) Logs for two focal students, Alicia and Bethany, were reviewed in order to provide additional illustrative examples of changes in students' understanding of engineering design. These two students were selected based on the availability of longitudinal data for the two years in which interviews were conducted. The EDP Log was developed as part of the overall engineering course as an instructional resource to provide scaffolding to guide students to provide clear evidence of their engineering design process. The EDP log is implemented using notebook computers and Google Sheets within the version of Google classroom used in our partnering district. The EDP log includes multiple tabs, each focusing on one or two steps of the EDP (Figure 1) along with instructions guiding student entries. EDP Logs were rated by one of the curriculum developers using rubrics specifying expectations for the EDP logs at various levels of proficiency. This rubric was adapted from the Engineering Design Process Portfolio Scoring Rubric (EDPPSR), developed as part of a National Science Foundation (NSF) grant whose purpose was to develop a scoring system that could be used to distinguish among student performance levels on engineering design projects [34]. The adapted rubric for the EDP log includes six elements that correspond to the stages of the EDP: Identify the Problem; Understand; Ideate; Evaluate; Prototype and Test; Communicate your Solution. A seventh Progression rubric was utilized to rate the degree to which students' EDP logs documented the systematic progression of the engineering design process. Each element was scored using a rating scale with four categories (3 = Advanced; 2 = Proficient; 1 = Developing; 0 = No evidence). See [33] for a detailed description of the EDP Logs and their development.

Findings

Taken together, student interview data and EDP logs suggest variations in students' understanding of the engineering design process and their self-efficacy. Findings pertaining to each of these areas are described below.

Engineering design process

Interview data indicate that, to varying degrees, all six students were able to provide descriptions of how they utilized the engineering design process in their engineering course across years. Students' descriptions were coded to identify instances when they described each stage of the engineering design process as well as the level of students' descriptions. These levels approximated those used to score students' engineering design logs. Responses were coded at Level 0 when students either did not describe a particular stage or clearly mischaracterized a stage of the EDP. Level 1 responses included those where students gave a partial response or a response that suggested novice or developing understanding and Level 2 responses included those that suggested a proficient or advanced understanding of the EDP.

As illustrated in Figure 2, interview data suggest that students were both more likely to reference each of the stages of the EDP and more likely to do so at a higher level following their second year participating in the engineering course. All six students increased the level at which they described at least one stage of the EDP following successive experiences in the course, with several students' responses demonstrating increased understanding of multiple stages. Notably, students were least likely to provide Level 2 responses when describing the Identify the Problem and Communicate the Solution stages of the EDP. As several students pointed out, the Identify the Problem stage, while included in the EDP Log, was not emphasized within the curriculum as the overall design challenges were typically presented to students, usually in the form of a request for proposal (RFP), rather than having students identify the initial problem their design would address. Increases in the level at which students described the Understand the Problem, Ideate, Evaluate, and Prototype phases were somewhat more apparent. Illustrative examples of student descriptions of the EDP at the various levels are presented in Table 2 below.

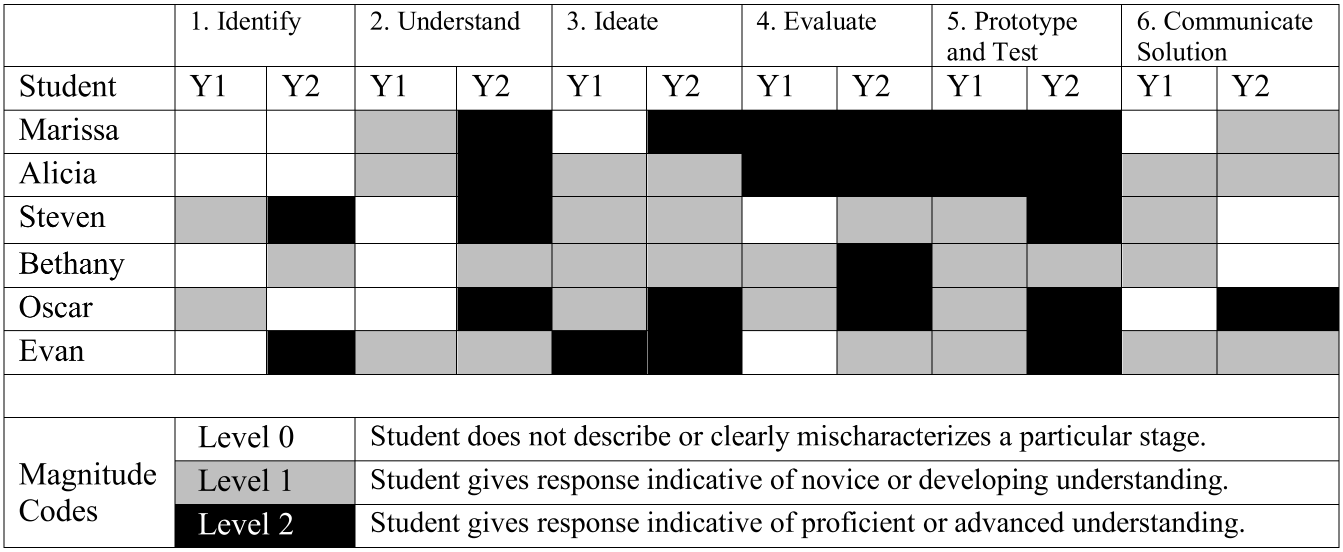


Figure 2. Matrix Illustrating Understanding of the Engineering Design Process by Student in Year 1 (Y1) and Year 2 (2)

Table 2. Engineering Design Process Illustrative Quotations

	Proficiency Level	
EDP Stage	Level 1 Responses	Level 2 Responses
Identify	“First we identified a problem, which we had to fly farther than 17.1.” Steven (Year 1)	“So we had to identify our problem. I said that the plane wasn't carrying enough passengers or they weren't making enough money by carrying higher, like standards! Where they have to have either more room and less seats with higher ticket costs, or they had more seats, less room, and lower ticket cost. I said, "Less seats and more ticket costs." So I had to find the problem with that and that's what I chose. Evan (Year 2)
Understand	“We had to understand the problem and then we basically had to use all of the requirements and build or draw a cradle.” Marissa (Year 1)	Most of the time we'll break down the problem into certain pieces or what can we answer now without any background knowledge versus what are more important things that have to be done….Sometimes it's easier to break apart the question and answer one part at a time. Marissa (Year 2)
Ideate	“We just thought of our designs and stuff and made them.” Alicia (Year 1)	Most of the time, me and my friend we'll talk about it and we'll give each other ideas back and forth. Sometimes we'll be like, oh, I like that idea, so we'll use it for our own. In exchange, we'll help the other friend out just so they won't necessarily think ‘y'all have used all the ideas, I have nothing left to do’. Marissa (Year 2)
Evaluate	I was just thinking of shapes. I was thinking in my head, would these shapes fly or would they not? Some shapes, it depends on the length and the width and how big it is and stuff. Some of them will fly and some of them won't. Bethany (Year 1)	We had certain requirements that we thought of that we think that the plane needed and stuff. We set it up with those and we figured out which ones best fit the requirements. Alicia (Year 2)
Prototype and Test	Researcher: What was your role in the group? Oscar: I had to test it, test the plane. Oscar (Year 1)	When you make a prototype and if it doesn't work you just redesign it and then make it better….I know I was a lot less lost in IronCAD because we had done stuff with it last year. Alicia (Year 2)
Communicate Solution	Then we evaluate how far, we evaluate which wing looks better, and then we tested it on the gliders or the planes. Then we communicated our solution. Steven (Year 1)	We usually have to do a recommendation and something after it. For example, with the holder. We had to write, after we finished and everything, we had to write the requirements and all that, and then which one we think would be the best one for them. And then they just chose. Oscar (Year 2)

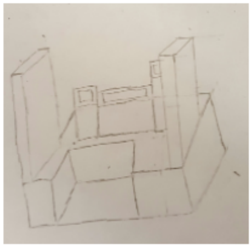
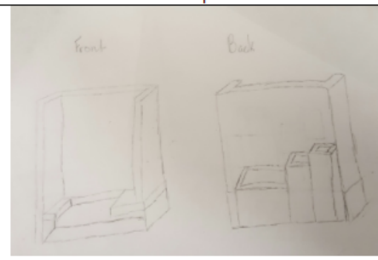
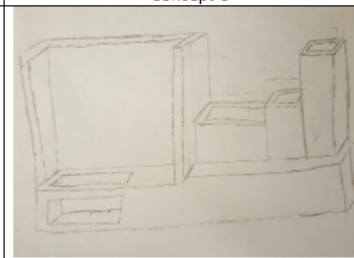
In addition to revealing the level at which students describe the engineering design process, interview data suggest *how* students understood and engaged with the EDP over the course of multiple design challenges. For example, students were more likely to describe the Evaluate stage as an important part of the EDP following an additional year of exposure to the engineering course. Indeed, in their first interviews, several students noted that either they or other students in their class tended to skip this stage when completing design challenges. Additionally, in their first-year interviews, two students, Steven and Evan, mischaracterized the Evaluate stage, confusing the evaluation of potential designs with the testing of prototypes in the Prototype and Test stage of the EDP. This misconception had resolved for both students after an additional year in the class, with both students providing more accurate descriptions of the Evaluate stage following their 8th grade engineering course.

Examining EDP logs for two focal students provide additional illustrative examples of students' understanding of the engineering design process. Figure 2 below illustrates rubric ratings for each student for the 7th grade engineering design challenge (Year 1) and the two engineering design challenges completed in 8th grade. Alicia is an example of a student whose EDP log suggests mastery of each stage of the engineering design process early in her experience with the courses and sustained proficient performance across most stages at each time-point. In contrast, Bethany is an example of a student with more inconsistent scores for the Identify, Understand, and Ideate stage and an incomplete EDP log for the Prototype and Test stage. See Figures 4 and 5 below for examples of Alicia and Bethany's EDP log entries.

	Alicia			Bethany		
EDP Stage	Year 1	Year 2: Challenge 1	Year 2: Challenge 2	Year 1	Year 2: Challenge 1	Year 2: Challenge 2
1. Identify						
2. Understand						
3. Ideate						
4. Evaluate						
5. Prototype and Test						
EDP Progression						

EDP Rubric Levels		
	0	No Evidence or Incomplete EDP Log
	1	Developing
	2	Proficient
	3	Advanced

Figure 3. Matrix Illustrating EDP Log Rubric Scores for Two Focal Students

	Concept A	Concept B	Concept C
Picture or Sketch			
Concept Description	The phone is against the chapstick, earbud, and pen/pencil holder. There is space for the earbuds and charger to be plugged in under the phone, but there is not enough space for it to fall through. There are sides, but they are low enough that you can use the volume and power button.	The phone is held in the front, and the back has the chapstick, earbud, and pen/pencil holders. The phone is held, but it's low enough to use the power and volume buttons, and there is space to have your charger and headphones in.	The phone is held beside where the other holders are. There is room below to have your earbuds and charger in your phone while it is in the holder. The phone is held on all sides except the front, but it is low enough that you can use the camera and buttons.

+ ≣ EDP | Identify & Understand | Ideate | Evaluate | Prototype & Test | Additional Data & Procedures

Figure 4. EDP Log Example – Alicia's Ideate Section Scored at Advanced Level

	Concept A	Concept B	Concept C	
Picture or Sketch				
Concept Description	My first picture is a nike phone case because i like nike and i can add a kickstand on the back of the phone case because it will look cool with some nike check arms	My second case is like paint dripping down the phone case and with two different the reason I chose this is because i like the way it look and we can put a stand on the back so you can lean you phone on it and it will look good and u will have a stand to hold your phone up on.	My third case is a minnie mouse case because I like the theme of minnie mouse and the case is going to be red and black and her feet are a kickstand so you can stand it while you watching a movie.	

+ ≣ EDP | Identify & Understand | Ideate | Evaluate | Prototype & Test | Additional Data & Procedures

Figure 5. EDP Log Example – Bethany's Ideate Section Scored at Developing Level

Engineering self-efficacy

Interviews focused primarily on gathering student perspectives on the engineering course and the engineering design process rather than asking questions explicitly about self-efficacy. Nonetheless, students' descriptions of their experiences provide insight into their developing engineering self-efficacy. Several students discussed how their confidence in using the engineering design process increased as a result of taking the class multiple times. For example, in comparing his previous experiences in the courses (in 6th and 7th grade), Evan affirmed that taking the sixth grade course prepared him for the subsequent course saying "I knew a little more. I wasn't fresh. I knew somewhat what to do and somewhat how to do it. It was pretty much easier."

Possible progressions in students' self-efficacy were also evident in their discussions of how challenging they found their engineering classes. Students tended to affirm that the course was sufficiently challenging and several discussed how the engineering course sequence becomes more challenging as they progress through middle school. For example, in the following excerpt from his interview conducted at the end of the eighth grade, Evan reflects on the progressive difficulty of the engineering courses:

> *It was much harder this year than last year because this year we had more projects, more complicated work put on us because we're transitioning to the next grade. Then after that it's going to be high school, so I'm pretty sure they want us to learn what we can now, that way we have all the knowledge within eighth grade and transitioning over the summer. That way, when we come back we know what to do, how to do it, our mindset's right.*

Evan's speculation that "they want us to learn what we can now" in order to "have all the knowledge within eighth grade" and his statement that, following the summer, he and his classmates will "know what to do, how to do it" and that their "mindset" will be "right" suggest increased self-efficacy as he participated in progressively difficult design challenges within the engineering course sequence.

Similarly, students' self-efficacy for engineering was occasionally revealed through their discussions of particularly challenging aspects of the course. This was perhaps most evident in students' discussions of their experience learning how to use the CAD software (IronCAD). Within the engineering curriculum, 7th grade students complete a tutorial in which they learn how to use IronCAD to create designs as part of an aeronautics design challenge. Students apply their IronCAD skills again in the 8th grade design challenges. According to both student and teacher interviews conducted over the course of the project, developing a working understanding of IronCAD is one of the most challenging objectives of the course sequence. Indeed, within the case study sample, four students (Marissa, Alicia, Bethany, and Steven) described how they overcame challenges learning IronCAD. Marissa shared that working with technology is generally difficult for her, stating "the computer has not really been my friend" and notes the difficulty of the IronCAD tutorial, "some of the directions are very confusing for me because I've never done it before." However, she comments on her increased understanding following the 7th grade course stating, "now I'm towards the end, I fully understand." Similarly, in her interview at the end of 8th grade, Alicia notes "I know I was a lot less lost in IronCAD because we had done stuff with it last year." Thus, in their discussions about the overall challenge level of the course and particular activities they considered challenging, students highlighted numerous examples of mastery experiences that are likely to have positively influenced their engineering self-efficacy.

Consistent with the self-efficacy literature and Bandura's characterization of mastery experiences as the most "potent" sources of self-efficacy, mastery experiences like those described above tended to be the most common source of self-efficacy cited by students. However, in addition to these clear examples of mastery experiences, to varying degrees, interview data also provide examples of the ways in which social persuasions, vicarious experiences, and physiological or affective states may serve as powerful sources of engineering self-efficacy. Often students' descriptions of their most successful experiences in the engineering courses reflected the combined influence of more than one source of self-efficacy. For example, asked to describe his collaborative work on the 7th grade design challenge, Evan states:

> *Me and him work really good. We had to ask a lot of questions. We didn't understand. It was our first time doing the IronCAD. It was very complicated but we pulled through and it worked and I'm glad we did because that turned out really cool….We worked together so if I knew something and he didn't I'd go help him and explain it, but if he knew something and I didn't he'd come over here and explain it to me, show me how it worked. That's how we contributed to one another.*

Similarly, Marissa described her positive collaborative experience as follows:

> *I really like working with groups because it's an opportunity to find out the people who are best at something…and when you see what they make and how they do it, it helps you really understand, maybe I should do this differently from now on or maybe I should keep it the same way because I see how somebody else does it.*

Both these examples suggest mastery experiences and vicarious experiences as potential sources of students' self-efficacy. Evan provides a clear example of a mastery experience, describing how he and his partner "pulled through" their challenging IronCAD experience to create a design that "turned out really cool". At the same time, his description of this partner work portrays a collaboration in which he seems to attribute his ability to succeed at a "very complicated" task in part to observing and learning from his partner's mastery. Similarly, in describing her group work experience, Marissa reflects on how she improves upon her designs, considering doing something differently (or not) because she sees "how somebody else does it."

Although these examples of collaboration imply that students encouraged one another as they engaged in engineering design activities, to the extent that students suggest social persuasions as a potential source of self-efficacy, they tended to describe feedback from their teacher rather than classmates. Frequently, such references occurred in the context of students' describing how their teacher provided feedback on their EDP logs. For example, Bethany describes why she believes her teacher asks the class to complete the logs stating:

Say, when we get older and we want to be an engineer or something like that, we can be that because in middle school she helped us out a little bit of how to do it and what to do and stuff like that…Sometimes she says that I skipped a step or I need a little work on this. Sometimes she said I did good.

Again, although students did not necessarily draw a direct connection between receiving such feedback and their self-efficacy, such descriptions confirm that social persuasions that could influence students' self-efficacy occurred within the classroom.

Instances of physiological or affective states (e.g. stress) potentially influencing students' self-efficacy were relatively rare within the interview data. Two students (Bethany and Marissa) described the confusion they experienced when first learning IronCAD in terms that suggest significant frustration, possibly to the point of feeling stress. For example, Bethany who reported that she generally enjoyed her the engineering classes, noted that "when I get so confused, I'm like 'I didn't want to take this class.'" Conversely, in describing their experience with the design challenges, three students (Evan, Oscar, and Alicia) explicitly described positive emotions associated with the engineering design process. For example, in his 8th grade interview, Evan shared how he feels when building prototypes, his favorite part of the engineering design process:

I like creating things. I'm more of a hands-on person. I love working with my hands and finding new things out so when I figured out the plane project I was like, "This is pretty cool. I'm going to go ahead and get this done." We had to make three designs, made of how we wanted and it was perfect, just my favorite thing. Working and doing hands-on work, I could zone-out and do it any time. It wouldn't even bother me.

Although he doesn't explicitly draw a direct connection to his developing confidence with the engineering design process, Evan's description of the prototype and test phases suggests a definite feeling of excitement about building his designs. Further, his use of the phrase "zoning out" implies a relaxed physiological state, suggesting that, for him, these types of design experiences may foster confidence in this particular stage of the engineering design process.

A final area where we noted connections to students' engineering self-efficacy was in students' feedback on the course. Although students were not explicitly asked to discuss career connections, when asked about whether they would recommend the course to other students, all six students described ways in which the course provides valuable knowledge and experiences for students considering careers in engineering or related STEM fields (e.g. computer science, architecture). The four students in the sample who expressed interest in engineering as a career described, with varying levels of specificity, how they thought what they learned in the courses relates to their career interests and their preparation to pursue engineering in high school and beyond. For example, in the following excerpt from her 7th grade interview, Marissa describes why she is glad she took the engineering class for multiple years:

Marissa: I feel like engineering is a major part of my career that I want to have when I grow up…I feel like it's important to know everything I can possibly know. That way when I go into my field, I won't be confused.

Researcher: So you will take it next year, too? In eighth grade?
Marissa: Probably, just to advance my knowledge, even though sometimes I don't like it. I realize with every subject, you don't have to like it to understand it.

Interestingly, for Marissa, deepening her engineering knowledge takes precedence over "liking" a subject and, although she may not enjoy every aspect, she sees taking the engineering course sequence as a way to advance her knowledge of engineering. Similarly, Oscar affirmed that he would recommend the class to other students interested in STEM careers:

If they want to be an engineer or architect or anything that have to do with construction, anything that follows within the construction line and architect, I would recommend this. I would actually do it three years. I want to do in next year too since I want to be an engineer.

In other examples, students described how specific projects or stages of the engineering design process related to their ability to pursue particular career interests. Consider, for example, the following exchange in which Evan describes his longstanding interest in engineering roller-coasters:

Evan: I've always wanted to be a roller coaster builder, engineer. So with this class, with these steps, I could build a roller coaster and have it tested and hopefully be published somewhere.
Researcher: Yeah, so tell me more about that. What makes you want to be a roller coaster engineer?
Evan: Ever since I was probably about ten, they took me to Six Flags and Whitewater, so I was like, "What builds these?" So I've been doing studies on them. I've always wanted to build one. I want to build one now. I built one but just a little one with cars.
Researcher: What do you think you've learned in this class that's going to help you with that?
Evan: Probably the measurement, working and the engineering design process and evaluating.
Researcher: Okay, so tell me why evaluating in particular jumps out?
Evan: Because if I have to find the mass of something, of the material that I'm using, like the metal, then I'm going to have to find the calculations and evaluate the numbers and then find out my total.

Thus, regardless of the specific source of students' engineering self-efficacy, their reflections on their experiences in the courses suggest both that case study students have considered connections between their course activities and engineering careers and that taking engineering courses likely strengthens their confidence when it comes to pursuing such careers.

Discussion

This study highlights the possibility of fostering middle school students' proficiency with the engineering design process and engineering self-efficacy through an interdisciplinary engineering course sequence. Trends in the frequency and level with which students described each phase of the engineering design process indicate that students were able to provide richer accounts of their engineering activities following repeated exposure to the engineering courses. This trajectory provides preliminary support for student participation in such courses over multiple years and points to a need for additional longitudinal research tracing the development of students' understanding of the engineering design process as students progress within the K-12 educational pipeline. Students' descriptions of their experiences with the engineering design process also illustrate variations in the stages of the engineering design process students tended to focus on. At both time points, students emphasized the Prototype and Test stage of the engineering design process and devoted relatively little discussion to the Identify the Problem and Communicate Solution phases of the process. While this tendency certainly reflects students' conceptualization of of the engineering design process, it may also be related to the relative emphasis on the various stages within the curriculum and its implementation.

Additionally, interview data suggest potential developments in students' engineering self-efficacy over the course of their participation in the engineering courses. One limitation of the study is that students were not asked directly to describe their self-efficacy beliefs or to discuss the engineering activities that tended to make them feel more or less confident in using the engineering design process. Consequently, students did not tend to make explicit statements about their engineering self-efficacy or the sources of their self-efficacy. Indeed, in order to continue exploring students' engineering self-efficacy, the project is considering future research involving more self-efficacy focused interviews with an additional, larger sample of 8th grade students who completed all three courses. Although interview data do not conclusively trace the connections between experiences in the engineering courses and self-efficacy development, student interviews were laden with examples of potentially powerful mastery experiences and clear indications that students feel a sense of accomplishment as they tackle the design challenges within the curricula. The very fact that students so frequently and spontaneously discussed efficacy-relevant experiences suggests these types of engineering courses as a particularly interesting context for exploring middle school students' self-efficacy development.

Consistent with self-efficacy theory, interview data reveal instances in which students' confidence may have been influenced by a combination of vicarious experiences (e.g. observing a classmate), social persuasions (e.g. teacher feedback), or physiological/affective states (e.g. stress or excitement). In their critical review of research on the sources of self-efficacy, Morris, Usher, and Chen [28] suggest the possibility that there may be additional sources of self-efficacy beyond the four sources proposed by Bandura [15]. In this case study, students referenced the connection between taking engineering courses and pursuing engineering careers, often suggesting that confidence in their ability to pursue such careers increases with multiple years in the engineering course. In some cases, students seemed to have actually envisioned the specific career applications of their newfound understanding of the engineering design process (e.g. utilizing particular phases of the EDP when building a roller coaster). While perhaps similar to a mastery experience, this type of envisioning of a future engineering accomplishment does not fall neatly within Bandura's hypothesized sources of self-efficacy and may instead be reflective of students' outcome expectations (beliefs about what will happen if certain tasks are performed). Further, although data for this study were analyzed using Bandura's general formulation of the sources of self-efficacy [15], students' spontaneous connections between efficacy related experiences and career prospects suggest that derivatives of social cognitive theory focused on career development, such as social cognitive career theory [32], may provide another useful lens for analyzing variations and developments in students' engineering self-efficacy. Finally, this study did not directly explore the relationship between students' developing understanding of the engineering design process and their self-efficacy. Future research is needed to further investigate the interplay between students' understanding of the engineering design process, their self-efficacy beliefs related to the EDP, and related belief structures, such as their self-efficacy in related STEM subjects and their interest in pursuing engineering in college and beyond.

References

[1] J. Strobel, R.L. Carr, N.E. Martinez-Lopez, and J.D. Bravo, "National survey of states' P-12 engineering standards," Proceedings of the *2011 American Society for Engineering Education Annual Conference and Exposition.*

[2] G.H. Roehrig, T.J. Moore, H. Wang, M.S.Park, "Is adding E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration," *School Science and Mathematics*, vol. 112, no. 1, pp. 31-44. 2012.

[3] R.L. Carr, L.D. Bennett, J. Strobel, "Engineering in the K-12 STEM standards of the U.S. states: An analysis of presence and extent," *Journal of Engineering Education,* vol. 101, no.3, pp. 539-564, July 2012.

[4] National Research Council, *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press, 2012.

[5] NGSS Lead States, *Next generation science standards: For states, by states*. National Academies Press, 2013.

[6] M.M. Hynes, C. Mathis, S. Purzer, A. Rynearson, and E. Siverling, "Systematic review of research in P-12 engineering education from 2000-2015," *International Journal of Engineering Education*, vol. *33*, no. pp. 453-462, 2017.

[7] A. Calabrese Barton, D. Birmingham, T. Sato, E. Tan, and S. Calabrese Barton, "Youth as community science experts in green energy technologies," *Afterschool Matters*, Fall, 2013.

[8] M.A. Zarske, J.L. Yowell,H.L. Ringer, J.F. Sullivan, and, P.A. Quiñones, "The skyline TEAMS model: A longitudinal look at the impacts of K-12 engineering on perception, preparation and persistence. *Advances in Engineering Education*, vol. *3*, no. 2, 2012.

[9] T.D. Fantz, T.J. Siller, and M.A. Demiranda, "Pre-Collegiate factors influencing the self-efficacy of engineering students," *Journal of Engineering Education*, vol. 100, no.3, pp. 604-623, 2011.

[10] B.M. Capobianco, H.Y. Ji, and B.F. French, "Effects of engineering design-based science on elementary school science students' engineering identity development across gender and grade," *Research in Science Education*, vol. 45, no. 2, pp. 275-292, 2015.

[11] M.E. Jordan and R.R. McDaniel, "Managing uncertainty during collaborative problem solving in elementary school teams: The role of peer influence in robotics engineering activity," *Journal of the Learning Sciences*, vol. 23, no. 4, pp. 490-536. 2014.

[12] K.B. Wendell, C.G. Wright, and P. Paugh, "Urban elementary school students' reflective decision-making during formal engineering learning experiences," Proceedings of the *2015 American Society for Engineering Education Annual Conference and Exposition.*

[13] National Research Council. (2001). *Knowing what students know: The science and design of educational assessment*, National Academies Press, 2001.

[14] A.C., Alonzo and J.T. Steedle, “Developing and assessing a force and motion learning progression,” *Science Education*, vol. 93, no. 3, pp. 389-421, 2009.

[15] A. Bandura, *Self-efficacy: The exercise of control*, Macmillan, 1997.

[16] P. R., Pintrich and D.H. Schunk, *Motivation in education: Theory. Research, and Applications, Second Edition,* Columbus, OH: Merrill Prentice Hall, 2002.

[17]F. Pajares, “Self-efficacy beliefs in academic settings,” *Review of Educational Research*, vol. 66, 543-578, 1996.

[18] F. Pajares, “Gender and perceived self-efficacy in self-regulated learning,” *Theory Into Practice*, vol. 41, pp. 116-225, 2002.

[19] F. Pajares, F. and L. Graham, “Self-efficacy, motivation constructs, and mathematics performance of entering middle school students,” *Contemporary educational psychology*, vol. 24, no. 2, 124-139, 1999.

[20] E. L. Usher, “Sources of middle school students’ self-efficacy in mathematics: A qualitative investigation, ”*American Educational Research Journal*, vol. 46, no. 1, pp. 275-314, 2009.

[21] S. L. Britner and F. Pajares, “Sources of science self-efficacy beliefs of middle school students,” *Journal of research in science teaching*, vol. 43, no.5, pp. 485-499, 2006.

[22] A. DeMiranda, K. Rambo-Hernandez, and P. Hernandez, “Measuring student content knowledge, iSTEM, self-efficacy, and engagement through a long-term engineering design intervention”. Proceedings of the *2016 ASEE Annual Conference and Exposition*.

[23] J. Major and A. Kirn, “Engineering design self-efficacy and project-based learning: How does active learning influence student attitudes and beliefs?” Proceedings of the *2016 ASEE Annual Conference and Exposition*.

[24] A. Carberry, M. Ohland, and H.S. Lee, “Developing an instrument to measure engineering design self-efficacy: A pilot study,” Proceedings of the 2009 *ASEE Annual Conference and Exposition.*

[25] T. D. Fantz, T. J. Siller, and M.A. Demiranda, “Pre-Collegiate factors influencing the self-efficacy of engineering students,” *Journal of Engineering Education*, vol. 100, no. 3, pp. 604-623, July, 2011.

[26] Authors, 2017.

[27] Illustrative Mathematics. *Standards for mathematical practice: Commentary and elaborations for K–5*. Tucson: AZ, 2014.

[28] D.B., Morris, E. L., Usher, and J.A. Chen, “Reconceptualizing the sources of teaching self-efficacy: A critical review of emerging literature,” *Educational Psychology Review*, vol. 29, no. 4, pp. 795-833, Dec, 2017.

[29] E.L. Usher and F. Pajares, “Sources of self-efficacy in school: Critical review of the literature and future directions,” *Review of Educational Research,* vol. 78, no. 4, pp. 751-796, 2008.

[30] S. B. Merriam, *Qualitative Research and Case Study Applications in Education. Revised and Expanded from"Case Study Research in Education,"* Jossey-Bass Publishers, San Francisco: CA, 1998.

[31] J. Saldaña, *The coding manual for qualitative researchers*, Sage, 2015.

[32] M.B. Miles, A.M., Huberman, and J. Saldana, *Qualitative data analysis: A methods sourcebook*. Sage, 2013.

[33] Authors, 2016.

[34] G. L. Goldberg, "Revising an engineering design rubric: A case study illustrating principles and practices to ensure technical quality of rubrics," *Practical Assessment, Research, & Evaluation,* vol. 19, pp. 1-12, 2014.

[35] R. W. Lent, R.W. Brown, and G. Hackett, "Social cognitive career theory," *Career choice and development*, vol. 4, 255- 311, 2002.