Students' Perceptions of a Middle School STEM Innovation and Design Course

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Introduction

A growing number of researchers seek to understand whether and to what extent the development of engineering "habits of mind and action" in middle school STEM (science, technology, engineering, and math) courses leads to improvements in problem solving abilities, integration of STEM content, and increased interest in engineering. The Next Generation Science Standards (NGSS; NGSS Lead States, 2013) call for "raising engineering design to the same level as scientific inquiry in science classroom instruction at all levels" (p. 1). Reflecting this emphasis on engineering as a core idea, recent reforms include proficiency in engineering design as a key component of college and career readiness (Auyang, 2004; Carr, Bennett, & Strobel, 2012; Duderstadt, 2008; Kelly, 2014).

In 2011 the National Research Council (NRC) released *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Based on research about teaching and learning over the last 20 years, the framework details the practices most central to conducting science and, therefore, most essential for students to learn. It also describes disciplinary core ideas and crosscutting concepts that unify science and engineering. These themes and constructivist approaches to learning are in alignment with the Common Core Standards in mathematics (The National Research Council Report, 2012).

Engineering education in the middle school is an important, emerging field of research. It focuses on fostering students' understanding of engineering fields and how engineering utilizes mathematics and science (Dawes & Rassmussen, 2007). The middle school years have been identified as a crucial period for getting students engaged in mathematics and science and subsequently increasing student interest in engineering as a profession (Tafoya, Nguyen, Skokan, & Moskal, 2005).

In particular, the Science, Technology, Engineering, and Mathematics Innovation and Design (STEM-ID) curriculum is grounded in a problem-based learning (PBL) model of instruction. PBL is a cognitive-apprenticeship approach with roots in medical school training (Barrows, 1985; Collins, Brown, & Newman, 1989) in which students work collaboratively to solve problems—thereby learning individually and in group settings. Students identify what they know and what they need to learn, plan how they will learn more, conduct research, and deliberate over the findings together in an attempt to structure and solve a challenge or problem. This study explores students' perspectives on the STEM-ID curriculum regarding what they have found challenging, engaging, and academically useful, specifically related to their core mathematics and science courses. This study is guided by the following evaluation questions:

1) What are students' perceptions of the STEM-ID curriculum?
2) What are students' perceptions of key components of the curriculum such as collaboration?
3) To what extent do STEM-ID students make connections between the STEM-ID curriculum and core science and mathematics courses?

Theoretical Framework

The overall framework for the STEM-ID curriculum is the Engineering Design Process (EDP), which is a conceptual model that describes the iterative process by which engineers address design challenges. In order to guide instruction and assessment related to engineering design, a variety of EDP models have been implemented as guiding frameworks for engineering education; these models vary in terms of specific terminology and sequences (Carberry, Lee, & Ohland, 2010). Figure 1(see Appendices) shows the specific EDP model that guided the development of the STEM-ID curriculum and related assessments.

STEM-ID Curriculum

The 18-week STEM-ID engineering courses present students with a series of challenges, culminating in a design challenge, all set within a particular context. The challenges are designed to build specific skills needed to address the final design challenge, but many of them also contain smaller, more scaffolded design challenges within them. The challenges focus broadly on themes such as data, visualization, and systems, but also include reinforcement of appropriate math and science skills. The activities are hands-on, and any worksheets are delivered in an electronic format whenever possible (e.g. calculations are done in a spreadsheet, both with and without the use of built-in formulae.) The STEM-ID courses have been iteratively designed based on feedback from teachers and observations of the course in action.

For example, in the 6th grade course, students explore the engineering design process and entrepreneurial thinking in the context of a carnival. The course begins with students making a sales pitch for a new carnival food stand based on market research. Students then run experiments using a pneumatic catapult, and they must design a new carnival game board with appropriate odds of winning. Then, after some skills development in engineering drawing, they re-design the catapult cradle to change the performance characteristics of their carnival game. Students incorporate math and science content including data representation, probability, experimental procedures, profit calculations, drawing, and measurement. The table below depicts the skills tapped in each sequential challenge, with the culminating final Design Challenge, which requires all of the skills developed in the previous challenges. This is a crucial element of the course design. After teachers learn how the course flows, they develop appreciation for each of the challenges and recognize how they build upon each other within a grade level, even though the context evolves between them.

Table 1: *Skills in 6th Grade STEM-ID Course*

6th Grade STEM-ID Course- Carnival Tycoon					
	Engineering and Problem Solving	**Skill Building**	**Science Practices (NGSS)**	**Foundational Math**	**Communication**
Data Challenge	Decision-making using data	Data Collection & Analysis	Analyzing & Interpreting Data Engaging in Argument from Evidence	Fractions, Arithmetic, Calculating Profit	Sales Pitch
Systems Challenge	Engineering Design Process	Probability Validation	Analyzing & Interpreting Data	Probability, Profit	Presentation of a Design
Visualization Challenge	3D Drawing	Spatial Reasoning	Developing & Using Models	Geometry, Surface Area, Volume, Rotation	Using visuals and drawings to convey an idea
Design Challenge	All of the above	All of the above	All of the above	All of the above	All of the above

The 7th and 8th grade STEM-ID courses follow a similar trajectory to the 6th grade course and incorporate many of the same skills, but in different contexts and with increasingly technologically challenging manipulatives. In 7th grade, the focus is on aerospace engineering, where students re-design an interior cabin and airplane shape to make more fuel-efficient, comfortable, and profitable airplanes. Instead of the hand drawings that they did in 6th grade, the students are introduced to CAD software, which is more technologically advanced than paper and pencil. In 8th grade, the course is grounded in robotics and biomechanics. Students design "feet" for a walking insect-bot, render them in 3D modeling software, 3D-print the prototypes, and test the robot's performance with respect to speed, traction, and ability to overcome obstacles. All three courses require students to collect data, analyze data, visualize data, follow an engineering design process, communicate and justify their ideas, use foundational mathematics in context, and follow relevant science practices. They also all require some spatial reasoning, a skill that has been linked to success in mathematics, computer programming, and engineering (Sorby, & Baartmans, 200).

Methods

A qualitative research approach for this study was chosen because qualitative methods are especially useful in discovering the meaning that people give to events that they experience (Merriam, 1998), which is necessary to understand the students' perceptions of the curriculum and its connection to the math and science courses as described in the evaluation questions

Participants and Data Collection

This study is being conducted in a public school district in the Southeastern United States. Interviews were conducted with students from 6th-8th grade at four middle schools during the final two weeks of the school year. Approximately 67% of the students qualify for free/reduced lunch, and the race/ethnicity subgroups are White (45%), Black (44%), Hispanic (7%), and Other (5%). Participants in the study included 92 students who were enrolled in the semester-long STEM-ID courses during the 2015-2016 school year. Males represented 51% of the interview participants while females represented 49% of the participants. The demographics of this sample are also representative of the school district as a whole.

Data Sources

Interviews

For this study, qualitative interviews were the primary method of data collection. Interviewing is the best technique to use "to find out those things we cannot directly observe…feelings, thoughts, and intentions" (Merriam, 1998, p. 72). Qualitative interviews result in thick descriptions of the subject being studied.

All interviews were conducted face-to-face and were audio-recorded to ensure a complete transcript. All interviewers used the same protocol with follow up questions to elicit rich data that could be used in qualitative analysis. Each 20-minute interview began by having students describe how they used the Engineering Design Process to solve a design challenge. The interview protocol was designed around five themes: student understanding of the engineering design process, math and science connection/integration, collaboration, perception of the curriculum and the curriculum relevance outside of the classroom. For the purpose of this study, only the results of three themes are presented: math and science connection/integration, perception of the curriculum, and collaboration. Specifically, students were asked to discuss positive and negative perceptions of the course, whether or not they see any connections between the math and science skills they use in the STEM-ID course and those they use in their core math and science classes, and their impressions of collaborative activities.

Data Analysis

Following transcription, the NVIVO software program was used to code and analyze all student interviews. The interview coding process proceeded in three phases. In the first phase, descriptive codes were used by a single coder to categorize student responses according to the major topic areas included in the interview protocol. These categories were largely mutually exclusive due to the structure of the interview protocol; however, responses were coded into multiple categories as necessary. In the next phase of coding, a group of four coders applied a provisional list of sub-codes to a cross-sectional sample of six interview transcripts (two interviews from each grade level). These sub-codes included process codes aligned to individual phases of the Engineering Design Process (e.g. Problem Identification, Prototyping and Testing Solutions) and magnitude codes indicating positive and negative examples (e.g. Positive/ Negative Perceptions). Code definitions and illustrative examples are presented in Table 2 (See Appendices) .

Overall agreement (kappa) among the four coders for this round of coding was 0.7. Coder comparisons revealed that variation in coding was due primarily to differences in how much text coders selected rather than differences in how coders were defining or interpreting the coding scheme. Minor changes to codes and any disagreements regarding code definition or interpretation were discussed and resolved among coders. The full sample of student interviews (n=92) were then divided and coded by the four coders over a six-week period. To facilitate analyses, a final set of classification codes assigning attributes to individual students (e.g. gender, grade level, school) were then applied to the dataset. Coded data were then assembled into matrices to identify potential patterns and themes.

Findings

STEM-ID Student Perceptions

Across grade levels and schools, students tended to express positive attitudes toward the STEM-ID course. Students commonly discussed their engagement in the engineering design process as a highlight of the course. Specifically, as illustrated by the following comments from two 6^{th} graders, students' discussions of what they liked most about the course often centered on the challenges inherent in iteratively prototyping and testing their designs, and the feelings of accomplishment associated with meeting those challenges.

> There's some things that were challenging, but once you get past the challenge and you're like 'I finally got it to work. That is awesome.' It's an amazing feeling. The challenge is actually really good.

> It was challenging trying to come up with all the designs and test them out, and you would sit there and get frustrated when it wouldn't work, so we had to come up with another design. When you finally get the design and you finally get something right, you would feel like that accomplishment, and it would be a happy moment.

Similarly, when asked whether they would consider taking the course again, several students expressed interest in the specific engineering design challenges they look forward to completing. For example, one 7th grade student explained why she would like to take the course again by referencing the design challenge offered in the 8th grade course:

> Because I feel like it challenges me. I like stuff that challenges me. They make the cell phone holders, and they print it out on 3D printers, and I would love to do that. I love the 3D printer.

In addition to highlighting their experiences with the engineering design process, many students drew comparisons between the "hands-on" approach of the STEM-ID course and more traditional modes of instruction they had experienced in other classes. For instance, in describing his experience with one of the course's design challenges, one 6th grade student remarked:

> It was fun that we got the chance to actually think of something. They didn't give us the design, we actually go to think of the design and make our own. I liked that part… we actually got to do stuff. We didn't just have a piece of paper and a workbook.

Similarly, another 6th grade student at the same school described his favorite part of the course by drawing a direct comparison with "ordinary classes," stating:

> Being able to design the models and being an entrepreneur and being able to sell my product. Probably just like the hands-on stuff, I would have to say. That was pretty cool because it's not like one of your ordinary classes where you're just like, 'book work. Here you go. Write it down.' This actually revved up my mind and made me want to work harder in math and science to make sure it all works.

One 8th grade student described how the hands-on STEM-ID course aligned particularly well with her learning style:

> It's hands on and you don't have to sit at a desk all day and do computer work. It actually gives you a chance to experience things. You get to learn up close. I'm a visual learner. I learn from what I see and what I can touch and play around with and it helps me function very well to know that I can do my hands-on work.

Finally, as detailed further below, in describing their favorite aspects of the course, many students referred to opportunities to work in collaborative groups.

When students shared negative perceptions, they generally referred to specific aspects of the engineering design challenges that they found frustrating rather than more globally negative views of the course. Several students cited issues with time constraints or pacing. For example, one 6th grade student described the time constraints placed on the design process as her least favorite part of the course:

> I didn't really like the fact that we had a time limit, which was a couple days, maybe a week. I don't really like time limits. If you keep on putting it in my ear that there's a time limit, it's going to make me feel rushed. It's going to not make my ideas come out.

Interestingly, one of her classmates also referred to pacing as an issue, but shared the opposite view that the pacing could be too slow, particularly when working at their own pace on design challenges resulted in boredom for groups who completed design challenges earlier than others.

In addition to frustrations related to pacing, some students shared examples of activities that they found exceedingly difficult and were not able to master. Several 6th grade students shared negative attitudes toward the 3-D figure drawing exercises in the 6th grade curriculum, referring to their belief that they "can't draw". For example, one 6th grade student noted, "I'm not a person that likes to draw, so when it was 'you've got to do this specific step', it frustrated me. I stressed out that whole week." Other students described using the IronCAD program to create design renderings and presenting their work to their class during the "Communicate your Solution" phase of the engineering design process as somewhat frustrating or stressful experiences.

Finally, there was a subset of students who provided mixed reviews of the class. Often these students tended to express positive opinions about the class itself but share that it wasn't particularly interesting to them, personally. For example, when asked whether she would be interested in taking the class again, one 6th grade student stated: "it's a perfectly fine class. It's just not the class for me. There's nothing really you can change about it to make me want to be in the class. It's just not something I see myself doing." Other students' mixed views of the course centered on what they felt was a limited variety of activities offered by the curriculum. For instance, at one school, several students shared the opinion that the course required spending too much time on computers and one student noted the focus on robotics in the 8th grade curriculum: "I didn't think the course was bad. I just felt that maybe we should have did more than just robot stuff."

Collaboration

The majority of students across grade levels described collaborating with their classmates as a positive experience, with many students citing opportunities for group collaboration as a highlight of the STEM-ID course. Students noted a variety of reasons they enjoyed working in groups including social factors (e.g. spending time with friends, getting to select group mates), the ability to get help from classmates with different strengths/skillsets, being able to complete design challenges more efficiently, and being able to create prototypes that more successfully met design requirements.

In describing their experience working with groups, students generally reported that they felt comfortable sharing their ideas and many students were able to clearly describe their specific role within their group. When asked to describe whether their group ever disagreed and how disagreements were resolved, many students stated that their groups did not have any disagreements; however, there were students in each grade level who recounted how their group negotiated specific disagreements around design decisions. Consider, for example, the following exchange, in which one student describes a disagreement about the placement of the catapult in the 6th grade design challenge:

> R: Did you feel comfortable sharing your ideas with the others in your group?
> S: Yes ma'am.
> R: Why do you think that is?
> S: We was all buddies and stuff. She let us choose groups. We got to choose our buddies. I felt comfortable because, you know, there was really no target answers. It was just an idea.
> R: Was there a time when there was any kind of disagreement in your group?
> S: Yes. One time me and this kid, he tried to start an argument. Me and my buddy, we came up with this idea. If we put the catapult like a little angle up, it would help it go farther, which it did. He was saying if we just move it back some, kind of stand it up like this, they would go farther. I said, "No, that's just going to make it too less, too far. There ain't no guarantee it would get in the middle. Somebody might be too short, too tall. Everybody is different sizes." "No, no no. That will work." "No, it won't". We tried his idea. It just ... It's a little sketchy. Me and my buddy's idea, we did it and it hit it every time.
> S: Okay. So, how did you guys resolve that disagreement?
> R: We tested both ideas.

Although students didn't always provide such detailed accounts of their groups' disagreements, this pattern of students resolving conflicting ideas about specific elements of their designs through testing was recurrent within the dataset.

While relatively infrequent, there were students who reported negative experiences working in groups. Some students reported that they opted not to work in groups whenever possible because of a personal preference to work independently (e.g. "I just don't like working in groups"). However, students also cited issues with the motivation of their classmates and the division of labor among group members as concerns. For example, one 7th grade student provided the following account of their experience working in groups:

> A lot of times, because we did so much group work that it would kind of slow us down on what we were doing, because they would rather be playing and stuff and sometimes they will disagree on whatever they did because when I was deciding on who would do what in the group and we were all deciding our parts they would disagree on doing anything that involved work.

Connections to Math and Science

Across grade levels and schools, students commonly recognized connections between their work in the STEM-ID class and mathematics and science. Many students spontaneously identified specific and often multiple mathematics and science concepts that they applied when completing engineering design challenges. The discussion of these connections is exemplified by one 6th grade student's discussion of the Carnival Challenge. After describing how his group "had to measure how big the cart was and we had to measure how big our cradle was supposed to be so it will fit inside the car", the student discusses how the data analysis undertaken for the Carnival Challenge aligned with his work in this mathematics class:

> When we did the carnival game, we had to find the percentage of how many times it will make it into the big prize zone or the small prize zone, and I was having trouble with proportions, and we had to do proportions to find the percentage, and that helped me a lot 'cause I got proportions good in my math class after I did that.

This connection was echoed by a classmate who discussed how he realized the connections between his mathematics class and STEM-ID:

> When I was doing measurements in math and I figured out that we were doing measurements in engineering, that helped me because I figured out how to add, subtract, divide and multiply all the fractions. So after I did that and I brought the engineering over to math, it just kind of fused together and just helped me.

Just as some students described this "fusing together" of mathematics and engineering, with their work in STEM-ID serving as practice or reinforcement of what they were learning in the mathematics classroom, several students expressed differing attitudes toward their experience with mathematics in the two contexts. For example, asked to describe how he used math in the STEM-ID class, one student contrasted "engineering math" with his experiences in math class stating, "It wasn't the hard, nervous type of math. It was fun engineering type of math that would help you with your design and keep you on top of everything." The student continued, "engineering math is better than regular math class, sitting there and being bored in math class."

Although students' references to connections between engineering and science were somewhat less common, a number of students did draw parallels between the engineering design process and the scientific method. For example, one 6^{th} grade student drew an analogy between the engineering design process and hypothesis testing in science:

> The scientific method is kind of like the same thing. You have to find out what the problem is, then you have to brainstorm ideas, and then after you brainstorm, you have to make up different concepts and if those don't work,…no, you have to make a hypothesis before that. You have to make a hypothesis, you have to figure out what you think will work better, like we did in the engineering class, like the circle base or the square.

Additionally, some students identified specific science concepts related to STEM-ID challenges; however, students tended to describe these science connections as less central to the design challenges than they did mathematics concepts. For instance, in describing science connections to the 7^{th} grade glider challenge, one student stated:

> I guess we did some energy science, I guess. I think we were doing energy science, but we didn't really know it. Because we had to do the variable, how far we threw it and stuff…and the force. We learned about the force and friction, and you get the friction from the air and stuff to stop it…so yeah, we used a little bit of kinetic science and stuff.

Summary

Students across all grade levels and schools generally expressed positive attitudes toward the STEM-ID curriculum. Students enjoyed engineering design challenges and having opportunities to do hands-on activities. Further, students indicated that the STEM-ID curriculum seemed very different than their other classes. Even though students found the class enjoyable, they expressed some negative perceptions regarding some stages of the engineering design process, and the pacing of the course. Further, some 7th graders described the 3D CAD software as being hard to follow.

Additionally, students learned that collaboration is an important component of the STEM-ID curriculum. In real-life settings, engineers collaborate with their peers throughout the design process. It is important that students be able to collaborate because a critical stage of the process is the selection of the most promising solution among several competing ideas. Collaboration among classmates was perceived as a positive experience by STEM-ID students across all grade levels.

Finally, students viewed the STEM-ID courses as allowing them to put their science and mathematics knowledge into practice. They also identified multiple specific math and science concepts that they applied to the engineering design challenges.

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APPENDICES

Figure 1. *Conceptual Model: Engineering Design Process*

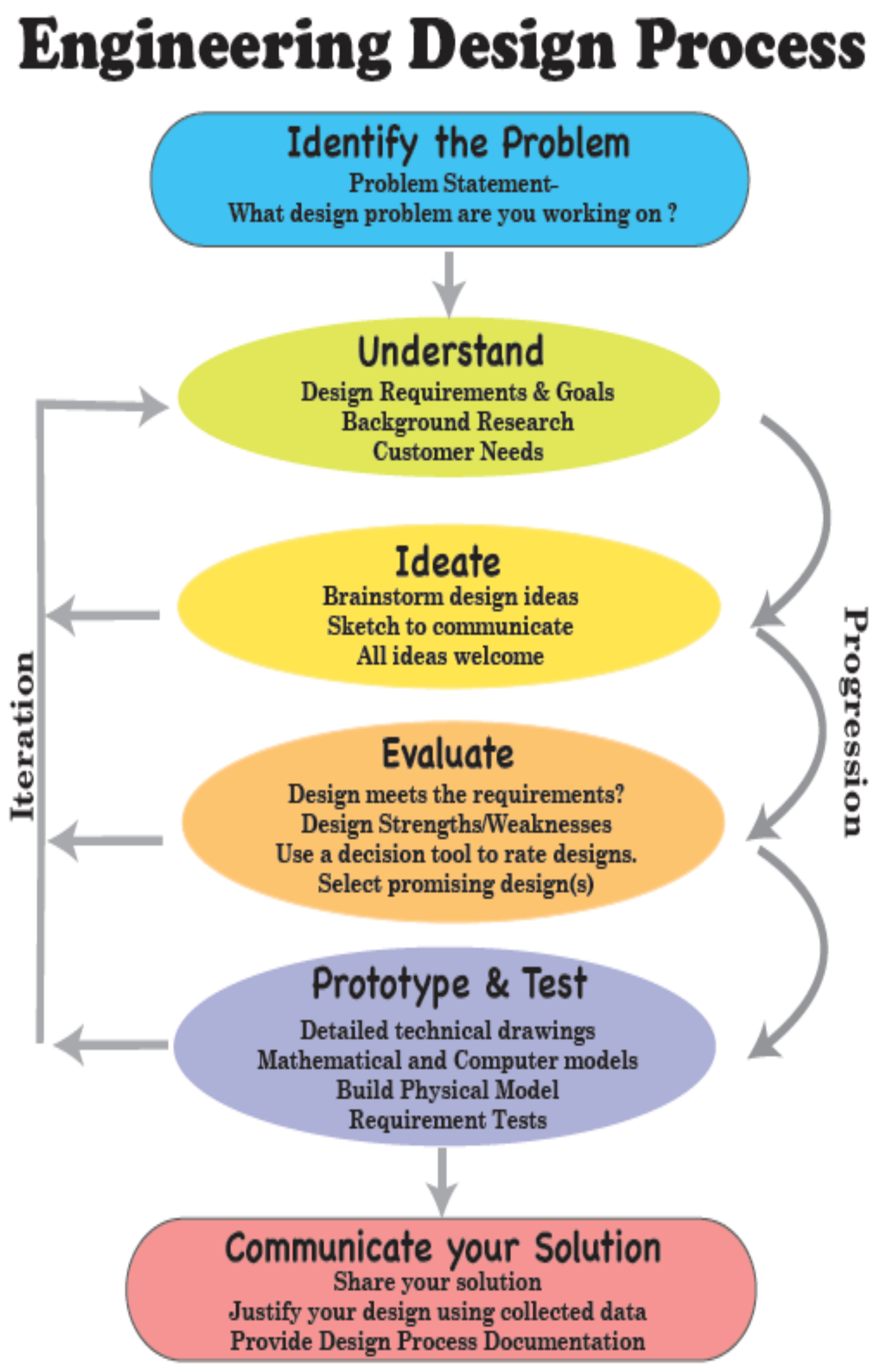

Table 2: *Sample of STEM-ID Student Interview Codebook*

Code	Definition	Example
Math Integration	Student affirms the integration of math in STEM-ID and/or describes integration of math in STEM-ID course (including practicing/applying math concepts)	Right now we're doing proportions and ratios and all that and we were doing measurements. When I was doing measurements in math and I figured out that we were doing measurements in engineering, that helped me because I figured out how to add, subtract, divide and multiply all the fractions. So after I did that and I brought the engineering over to math, it just kind of fused together and just helped me.
Science Integration	Student affirms the integration of science in STEM-ID and/or describes integration of science in STEM-ID course (including practicing/applying science concepts)	When I got into technology, for some reason, it would help me with the mathematics of how it all worked, how the speed worked. It helped me get advanced in science because of the technology that was put into it, the power source that was used.
Collaboration - Positive	Student describes group collaboration in STEM-ID as positive experience (any degree of positive experience including indicates preference for group/partner collaboration over working individually, describes examples of productive collaboration, group decision-making, engaging in group brainstorming, groups resolving disagreements).	Student: I honestly don't think I would have came up with the same designs if I were working by myself. Because as far as working by myself I would be like "alright I don't need to fix anything, I know it's alright". But since I had my partner he showed me that "no this is wrong you're going to have to change that" and I'm like "oh yeah I see it now". If I were to go with my original ideas working by myself I probably would have failed.
Collaboration - Negative	Student describes negative collaboration experiences in STEM-ID (e.g. students not working together well, students unable to resolve disagreements, one student doing all the work).	Interviewer: Do you like working in groups? Student: Sometimes but not most of the times because my groups get out of control.
Perceptions - Positive	Student comment indicates positive attitude toward STEM-ID;	It's unique. We have things in there that would help ... It teaches you life, engineering. How to build stuff. And it's very creative. Some stuff I didn't even know until I came to that class. I could have never told you how to build a plane. It shows you creating a business, your profit, what you would need to start it. It's a good class, I would recommend anybody take it.
Perceptions - Negative	Student comment indicates negative attitude toward STEM-ID	(Describing IronCAD) I did not like that because I did not know how to work that, I do not know how to build the stuff. The IronCAD book was challenging. I did not understand that book at all. And the steps were going way too fast.