# Middle School Students' Engineering Discussions: What Initiates Evidence-Based Reasoning? (Fundamental)

**Emilie A Siverling, Purdue University, West Lafayette (College of Engineering)**

Emilie A. Siverling is a Ph.D. Student in Engineering Education at Purdue University. She received a B.S. in Materials Science and Engineering from the University of Wisconsin-Madison, and she is a former high school chemistry and physics teacher. Her research interests are in K-12 STEM integration, primarily using engineering design to support secondary science curricula and instruction.

**Elizabeth Suazo-Flores, Purdue University**

Elizabeth Suazo-Flores is a Ph.D. candidate in Mathematics Education at Purdue University. She is a former secondary mathematics teacher graduated from a Chilean university. Elizabeth's research is centered on mathematics teachers' knowledge. Currently, she is exploring a middle school mathematics teacher's practical knowledge using personal experiential research methods.

**Corey A Mathis, California State University, Bakersfield**

Corey Mathis is currently an instructor at California State University, Bakersfield for Teacher Education and is completing her tenure as a Ph.D. candidate in Engineering Education at Purdue University. She received her B.S. in biology and her M.E.D. in secondary education from Northern Arizona University and is a former high school science and technology teacher. Her research interest includes improving students learning of science and engineering through integrated STEM curricula.

**Prof. Tamara J Moore, Purdue University, West Lafayette (College of Engineering)**

Tamara J. Moore, Ph.D., is an Associate Professor in the School of Engineering Education and Director of STEM Integration in the INSPIRE Institute at Purdue University. Dr. Moore's research is centered on the integration of STEM concepts in K-12 and postsecondary classrooms in order to help students make connections among the STEM disciplines and achieve deep understanding. Her work focuses on defining STEM integration and investigating its power for student learning. Tamara Moore received an NSF Early CAREER award in 2010 and a Presidential Early Career Award for Scientists and Engineers (PECASE) in 2012.

**Siddika Selcen Guzey, Purdue University, West Lafayette (College of Engineering)**

Dr. Guzey is an assistant professor of science education at Purdue University. Her research and teaching focus on integrated STEM Education.

**Mr. Kyle Stephen Whipple, University of Minnesota**

# Middle School Students' Engineering Discussions: What Initiates Evidence-Based Reasoning? (Fundamental)

## Introduction and literature review

As part of an effort to remain internationally competitive, the United States has endeavored to produce more students who are prepared for careers in science, technology, engineering, and mathematics (STEM)[1,2]. In addition to this goal, improving STEM education has the potential to increase the STEM literacy of all precollege students[3]. Part of this focus on STEM is the emergence of engineering as a subject in precollege settings[4, 5]. Over the past decade, engineering has been incorporated into many states' science standards[6], as well as the national *Next Generation Science Standards*[7].

In addition to promoting STEM content knowledge, there has also been an increased focus on equipping precollege students with 21st century skills[8]. One of these skills is the professional practice commonly called argumentation. Argumentation has been deemed a practice important for many disciplines, such as history, English language arts, and STEM[9]. Arguments occur in our daily lives, within and outside of school and work[10]. Children develop basic argumentation skills early, and these skills can be improved with practice and age[11].

In the scientific process, argumentation is critical and has been substantially used and researched in P-12 science education[12]. It is essential to scientific discourse because it provides a framework for students to justify their claims with evidence and reasoning related to theories and laws of science[13,14]. This allows students to act like practicing science professionals, discussing and writing about research in order to persuade others of the significance of their findings[11,15]. In P-12 schools, argumentation can also support students' ability to perform other skills, such as critical thinking and problem solving[9,11,16]. Teachers have an important role encouraging students' use of argumentation. Schwarz[9] suggested assisting students in learning how to use argumentation in verbal and written communication. This can be done through student-centered pedagogies that allow students to engage in and construct an understanding of argumentation through observation and practice[17].

In terms of standards, NGSS contains eight scientific and engineering practices, one of which is *engaging in argument from evidence*[5,7]. This practice has been more robustly used and researched in precollege science education settings, sometimes referred to as *scientific argumentation* but often simply called *argumentation*[12]. Several models of *scientific argumentation* exist, but they share three common components: a *claim* related to a conclusion about natural phenomena; support with *data* or *evidence*; and reasoning that links the *claim* and *evidence*, called *justification*[14] or *explanation*[16]. This exact model of *argumentation* does not quite fit for engineering, however, because the goals and practices of engineering and science are fundamentally different, as outlined in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*[5] and other documents. As a generality, engineers make decisions based on evidence; whereas scientists make arguments to defend their positions. Thus, we have introduced the term *evidence-based reasoning* (EBR) to describe the practice of *engaging in argument from evidence* in engineering[18]. In engineering, a *claim* is related to a design idea or solution, and *justifications* may be about science and mathematics but may also involve the context, criteria, and constraints of the engineering problem. While researchers have an idea of what *scientific argumentation* looks and sounds like in a precollege science classroom, the exploration of EBR in engineering design-based learning environments is just beginning.

Studies of EBR to this point have been exploratory. In Mathis, Siverling, Glancy, and Moore[19], researchers analyzed P-12 STEM integration curricular documents. They found that there were three main curricular activities within engineering that had the potential to encourage EBR in the classroom: the report to the client at the end of the unit, the types of questions the teacher asked of the students (i.e., asking students to further explain the "why" or "how" of their answers), and student discussions. However, this research did not address actual implementation of the curricula. Mathis et al.[18] explored students' use of EBR during solution generation of an engineering design challenge in a seventh-grade classroom. The study found that students used EBR most while planning a design idea and evaluating the tested design solution; also, instances of EBR were found in student worksheets and group discussions. Both the curriculum and implementation of EBR provided evidence that EBR has the potential to integrate science and engineering learning in P-12 classrooms, but more research is still needed.

The purpose of our research on EBR is to understand and eventually cultivate EBR in precollege settings in order to help students learn and make connections in integrated settings. Studies have shown that in precollege STEM integration units, the science content is not always necessary in order to solve the engineering challenge[20]. Students may learn science content but ignore it during solution generation of the engineering problem. We predict that using EBR will help students tie the science and mathematics content knowledge to engineering by using this science and mathematics as part of the evidence and justification of their design ideas and solutions. In this paper, the focus is on the contexts that seem to prompt students to state instances of EBR. In knowing this, we will have a better idea of scaffolds for EBR that can be explicitly integrated into curricula and what situations teachers can observe for EBR. Thus, this study proposes the research question: *What initiates the need for middle school students to use evidence-based reasoning while they are generating a solution to an engineering design problem in a STEM integration unit*?

## Conceptual framework

The STEM integration framework[21] is the conceptual framework underlying the larger project of which this EBR study is part. According to this model of STEM integration, problem-based engineering design is the central component to which the disciplines of science and mathematics are applied. Engineering design challenges are situated within motivating and engaging contexts, and the process includes having the student learn from failure and redesign. Other key components of the STEM integration framework are that lessons are primarily student-centered, mathematics and science lessons are focused on standards, and students develop teamwork and communication skills. Technology is prevalent throughout STEM integration, but in particular, the outputs of engineering design challenges are technologies. Using this model of STEM integration, the disciplines of STEM are merged cohesively in order to deepen students' understanding of each discipline[22]. Thus, the design and implementation of the curriculum used in this study is supported by the STEM integration framework.

**Theoretical frameworks**

This research was guided by two theoretical frameworks: Toulmin's Argument Pattern (TAP) and The Framework for Quality K-12 Engineering Education. Our research question requires that we understand when an instance of EBR is occurring within the solution generation phases of the students' design processes. Therefore, we have selected these two theoretical frameworks to define EBR and the stages of the engineering design process in which students engage in order to answer our research question.

TAP[23] is a classic theory of how arguments develop and the elements of an argument. The main premise of the TAP theoretical framework is that the validity of an argument depends on its logical structure, and the process for constructing these arguments is *argumentation*[23]. The TAP model is a general model that can be applied to many disciplines, including philosophy, law, and mathematics, among others. Per Toulmin's definition, a rational argument contains some, though not necessarily all, of six main elements: *claim, data, warrant, backing, modal qualifiers,* and *rebuttals* (See Figure 1). More complex arguments will include more elements. For the purposes of this research, we chose to define an instance of EBR using a limited version of Toulmin's six elements in order to explore a greater variety of EBR. This simpler version of "instance of EBR" included a *claim* about a design that was supported by anything else, whether that support was a piece of *evidence* or a *warrant.*

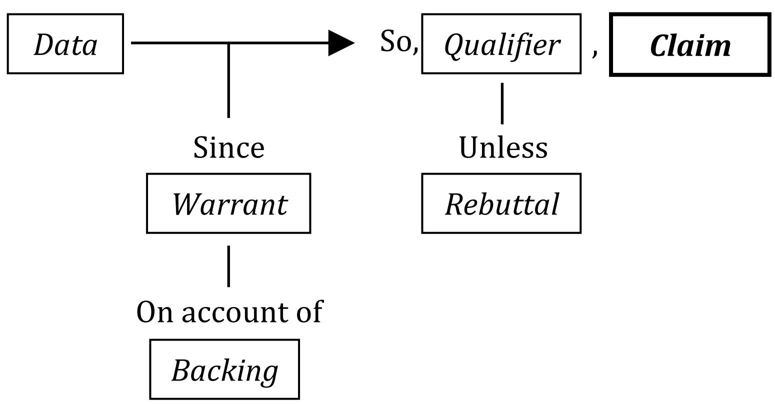


*Figure 1*. Toulmin's Argument Pattern[23]. Adapted from *The Uses of Argument* (p. 97), by S. E. Toulmin.

The *Framework for Quality K-12 Engineering Education* was designed to inform the development and evaluation of curricula, standards, and other education initiatives related to K-12 engineering education[24]. The framework is made up of nine indicators that define key characteristics of quality K-12 engineering education. Figure 2 shows the full list of key indicators, as well as a short description of each. The engineering portion of the curriculum used in this study was designed using the Framework for Quality K-12 Engineering Education. As such, the main outline of the curriculum can be mapped to the first indicator – *Process of Design (POD)*, which is subdivided into six engineering "phases": *problem, background, plan, implement, test,* and *evaluate*.

| Key Indicator | | Description |
|---|---|---|
| **Complete Processes of Design (POD)** | | Design processes are at the center of engineering practice. Solving engineering problems is an iterative process involving preparing, planning and evaluating the solution. Students should understand design by participating in each of the sub-indicators (POD-PB, POD-PI, POD-TE) below. |
| **Sub-indicators of POD** | **Problem and Background (POD – PB)** | Identification or formulation of engineering problems and research and learning activities necessary to gain background knowledge. |
| | **Plan and Implement (POD – PI)** | Brainstorming, developing multiple solutions, judging the relative importance of constraints and the creation of a prototype, model or other product. |
| | **Test and Evaluate (POD – TE)** | Generating testable hypotheses and designing experiments to gather data that should be used to evaluate the prototype or solution, and to use this feedback in redesign. |
| **Apply Science, Engineering, Mathematics Knowledge (SEM)** | | The practice of engineering requires the application of science, mathematics, and engineering knowledge and engineering education at the K-12 level should emphasize this interdisciplinary nature. |
| **Engineering Thinking (EThink)** | | Students should be independent and reflective thinkers capable of seeking out new knowledge and learning from failure when problems arise. |
| **Conceptions of Engineers and Engineering (CEE)** | | K-12 students not only need to participate in an engineering process, but understand what an engineer does. |
| **Engineering Tools, Techniques, and Processes (ETool)** | | Students studying engineering need to become familiar and proficient in the processes, techniques, skills, and tools engineers use in their work. |
| **Issues, Solutions, and Impacts (ISI)** | | To solve complex and multidisciplinary problems, students need to be able to understand the impact of their solutions on current issues and vice versa. |
| **Ethics (Ethics)** | | Students should consider ethical situations inherent in the practice of engineering. |
| **Teamwork (Team)** | | In K-12 engineering education, it is important to develop students' abilities to participate as a contributing team member. |
| **Communication Related to Engineering (Comm-Engr)** | | Communication is the ability of a student to effectively take in information and to relay understandings to others in an engineering context. |

*Figure 2*. Truncated version of the *Framework for a Quality K-12 Engineering Education*[24] (reprinted)[6].

The *Process of Design* could also be broken up into two main categories, problem scoping and solution generation. The problem scoping requires students to define the problem (POD – Problem) and learn about the problem and the background information (POD – Background) that would be helpful in solving the problem. Through problem scoping, students gather knowledge about the problem and content that will help them to be more intentional with making decisions about their designs. Solution generation within engineering design is also multifaceted. The first facet of solution generation asks students to develop a plan (POD – Plan) for their design solution which includes brainstorming, proposing multiple potential solutions, and evaluating the pros and cons of competing solutions. Students then use the developed plan to try out their design (POD – Implement) through the creation of a prototype, model, or other product. After a model or prototype is created, it must be tested (POD – Test) to determine if the designs are meeting the stated criteria and constraints determined during problem scoping. Finally, students evaluate (POD – Evaluate) their prototype or solution based on strengths and weaknesses and decide whether their solution is good enough to meet the criteria and stay within the constraints or if they need to use the feedback to redesign their solution.

Our research looks at the intersections of solution generation and argumentation (i.e., EBR). With the above frameworks in mind, we undertook our research on the question: *What initiates the need for middle school students to use evidence-based reasoning while they are generating a solution to an engineering design problem in a STEM integration unit*?

## Methodology

This research follows the naturalistic inquiry methodology[25,26] with lenses of *STEM integration framework*[21], *A Framework for Quality K-12 Engineering*[24], and *Toulmin's Argument Pattern*[23]. The research question and theoretical frameworks used to guide the inquiry are described above. The remainder of this section will address the data sources, use of the theoretical frameworks in our research, and data analysis.

## Data sources

### *Project*

This study takes place within the context of a federally funded curriculum development project. The curricular unit included in this research was developed as part of a teacher professional development institute for upper elementary and middle school teachers of science. The goal was to support these teachers in the development and implementation of curricular units which were guided by the STEM integration framework[21]. The curriculum used in this study was developed by three middle school teachers who participated in the project.

### *Curriculum*

The *Loon Nesting Platforms* STEM integration curriculum was designed for a middle school life science course. The context of the unit was a real local problem that the Department of Natural Resources was trying to solve. Due to increased development of lake shorelines, loons were losing places to build nests. Thus, the underlying engineering design challenge had two components: design a prototype floating platform on which loons could build a nest and be protected from predators, and choose a local lake on which to test the platform. The broad science focus of this integrated STEM unit was ecology, with specific learning objectives related to human impact on the environment, levels within an ecosystem, food webs and the relationships within (e.g., producer, consumer, decomposer), and biotic and abiotic factors. For each of these science objectives, students learned about them in a general sense and also in a context specific to the loon. Students also used concepts related to area and proportion in order to scale down the base of their prototype platforms in comparison to a platform's real size. The unit was designed such that the students were introduced to the engineering problem, then learned the science and mathematics content, and finally tied it all together to generate solutions for the engineering design challenge.

An important note is that the curricular unit did not explicitly teach the practices of scientific argumentation or evidence-based reasoning. There were prompts within the curriculum, both on student worksheets and suggested questions for teachers to ask, that asked students to further explain their answers. However, these requests were an attempt to encourage students to articulate their thinking, not purposeful scaffolds for eliciting EBR or scientific argumentation.

### *Setting and participants*

While three teachers contributed to the development of the *Loon Nesting Platforms* curricular unit, we only used data from one of their classrooms for the purposes of this study. This was a seventh-grade classroom in an urban, inner-ring suburban district with 11,000 students grades K-12, 41% of students of color, 42% students receive free or reduced-price lunch, and 35 different languages are spoken by the students and their families. Within this classroom, we collected audio data of one student team's discussions. This student team was made up of four seventh-grade girls and was chosen based on the recommendation of the teacher as to which group might provide the best audio data.

## Data analysis

The first phase of data analysis was to limit our analysis to those transcripts which would be most useful for studying evidence-based reasoning. This meant that we only analyzed transcripts from the solution generation portion of the process of design, as defined by the *Framework for Quality K-12 Engineering Education*[24]. This included the *plan*, *implement*, *test*, and *evaluate* portions of initial design and redesign. By limiting our analysis to these transcripts, we were able to focus on students' discussions about their design ideas and solutions, which are one of the two main pieces of EBR. This narrowing of the data yielded six class periods of audio transcripts.

The second phase of data analysis was to identify instances of EBR within the transcripts. This was based on our altered version of Toulmin's Argument Pattern[23] as described above. For our purposes, a *claim* was defined as a statement related to a design idea or solution. However, a claim alone did not count as an instance of EBR. The design idea or solution statement also needed to have another statement of support, though this support could come in many forms. For example, types of support could be evidence or justifications from previous science lessons, or explanations related to the design challenge's context, criteria, or constraints. In sum, each instance of EBR was one claim (i.e., design idea or solution) plus one supporting statement; these instances of EBR were the chunks which were further analyzed.

The third phase of data analysis is represented in Figure 3. In order to develop a coding scheme, we did open coding on a different, but highly related, data set on the instances of EBR in order to determine why students used EBR. As a result of this open coding, we divided our codes into two overall categories: what initiated the need for students to use EBR and the action students were doing when the instance of EBR occurred. The latter category is not explored in this study. For this study, using the sub-categories within the former category, we used *a priori* coding on the instances of EBR in the data set previously described. Two researchers coded to consensus, meeting routinely to discuss discrepancies and refine the codebook so that we were better able to distinguish between them. This analysis process brought us to identify seven categories that instigated students' use of EBR: *clarifying with team, responding to adult, negotiating, correcting, validating, documenting*, and *sharing.* These categories are described in more detail in the results and discussion section.

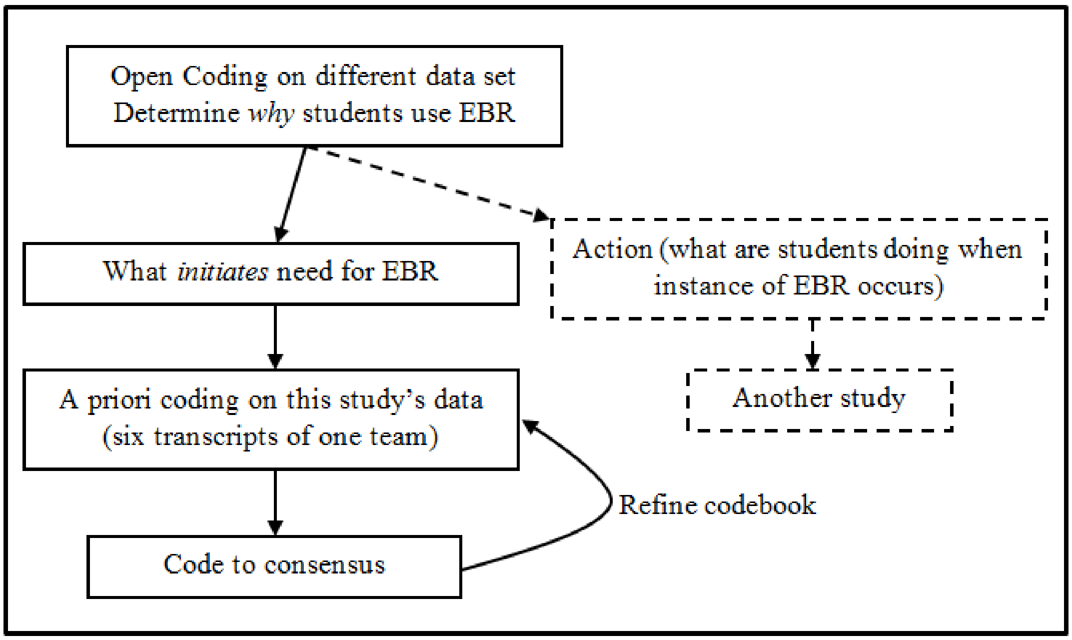


*Figure 3.* Third phase of data analysis.

**Results and discussion**

In the following paragraphs, we describe the seven categories of situations that prompted students to use EBR. Each of these explanations will include a brief description of the category and example from the student audio transcripts that highlights the category. Within the examples, instances of EBR related to the category are noted by the use of *italic* font. Additional statements beyond these instances of EBR are included to give context for the example and better demonstrate why each instance of EBR falls into each category. Note that some of these additional statements were also identified as instances of EBR; however, in order to demonstrate the category description, only the instances that fall into that category are *italicized.*

***Clarifying with team***

In the category of *clarifying with team,* students articulated an instance of EBR to respond to a teammate who asked a question to either understand an idea or position, or gain reassurance because he or she was unsure about an idea discussed within the group. In other words, *clarifying with team* was used when a team member was confused or unsure about something and asked the team for clarification, prompting the teammates to use EBR in response.

Student 1: And then, what else? So what are these made out of? Like the X and the top.

Student 3: Those are made out of *wooden sticks, I was trying to find something that would be cheap enough and it's three wooden sticks for a dollar*, but we'd need like, I don't know how high we have to have it.

Prior to this example, the team had already decided to design an above-nest structural piece for the platform that would protect the eggs from predators, specifically eagles. During this example, the team was discussing the specifics of the structure, including its shape and the materials it would be made out of. This excerpt exemplifies the category *clarifying with team* because Student 1 wanted to know what type of material would be used to construct this overhanging part of the structure (i.e., the X and top part). This prompted Student 3 to answer and provide a rationale for why she selected wooden sticks: wooden sticks were cheap enough. While Student 3 could have simply answered "wooden sticks," she chose to add a further justification to her design idea, making this an instance of EBR.

***Responding to adult***

An instance of EBR was classified as *responding to adult* whenever students justified their design ideas when prompted to do so by an adult in the classroom: a teacher, an aide, or a coach. The questions posed by the adult were often used to check students' understanding of the activity and formatively assess their work. *Responding to adult* usually happened when the adult approached the team as they were working and posed a question or prompting statement; on occasion, the teacher made an announcement to the whole class that prompted the students to use EBR when considering something they had not thought of until the teacher pointed it out. The following is an example of the former version.

Teacher: So you guys have your things you can improve. You can improve the stability.

Student 1: We're going to *add like another sheet of cardboard so then it can hold more weight so then it's like double and the bottom it will make it heavier*.

In this excerpt, students had just finished testing and evaluating their initial platform prototype. During the test, their floating prototype platform had begun to sink after the model loon was placed on it and additional waves were applied to the testing pool. The team was now beginning to plan their redesign. To fix this problem, Student 1 suggested adding another sheet of cardboard to the base of the platform (i.e., double it) so that the platform could hold more weight and make it heavier. While it is clear that Student 1 had thought through this idea to improve the initial design, the prompt from the teacher is what caused her to verbalize it. In this example, the teacher was able to elicit EBR from a student by inquiring about the design.

***Negotiating***

Students' instances of EBR were identified as *negotiating* when one or more teammates used an EBR statement to challenge or defend a design idea. A clarification for this category is that in order to be considered *negotiating*, the challenge had to be to the design idea itself, not the underlying reasoning. (Challenges to underlying reasoning fall under a different category, *correcting*.) *Negotiating* usually occurred when the team was debating between two options, though sometimes a teammate would contest a design idea without providing an alternative. The following is an example of the two-option version, with both Student 2 and Student 3 providing instances of EBR that were classified as *negotiating*.

Student 1: Do you think the moss would hide it better?

Student 2: *But how easier would that be to hang on there compared to the grass? Like when she pulled it out, it was a big chunk, you know?*

Student 3: *But we could separate [the moss] easier, and it's thicker than [the grass] except for that.*

In the broader discussion that this excerpt was pulled from, the student team had agreed that they wanted to drape some plant-like material from the platform's overhanging structure, but they were trying to decide whether to use moss or grass for this task. Student 1 started the discussion by posing a possible advantage of the moss. This prompted Student 2 to challenge the design idea of using moss by pointing out that because it comes in a big chunk, it might be more difficult to hang from the structure than grass would be. Student 3 then spoke up to defend moss as a design choice, pointing out that it would be easier to separate and is thicker than the grass. In this back-and-forth discussion about moss versus grass, the students weighed the options based on different justifications: how well the material would hide the nest (i.e., thickness), how easy it would be to hang on the structure, and how easy it would be to separate (i.e., work with). Because the students needed to decide between two alternatives, they needed to provide evidence and reasoning for their design ideas in order to convince their teammates of the validity of their ideas.

***Correcting***

The *correcting* category is similar to *negotiating* in that there is a challenge to the idea. However, in order for an instance of EBR to be considered *correcting*, the challenge must be applied to another classmate's incorrect understanding or application of reasoning to a design idea. In other words, the design idea may or may not be valid, but the larger problem is that the underlying reasoning is problematic. This usually occurred when students used science or mathematics concepts inaccurately or when they misunderstood the context, criteria, or constraints of the engineering design challenge.

Student 3: Well like, we'd have to make it higher up so that the loons they can go in it too.

Student 1: *This isn't for a real loon though; that loon will fit in there just fine.*

Student 3: Oh yeah, I mean, I keep thinking we have a real loon here.

Student 1: *Yeah, it's not a real loon. So this will work, this will work*. (Pause) So do you still want to do the twelve then?

Student 3: No. We'd need eight I think.

Immediately prior to this example, everyone on the team except Student 3 had agreed on the height of the overhanging structure part of the platform and that this would require eight straws to assemble. Here, Student 3 suggested having a higher structure on the platform so that a real loon could fit under the overhang structure. However, Student 1 reminded her that the platform prototype needed to only fit a model of a loon, which is smaller than a real one. In correcting Student 3's misunderstanding about the criteria of the engineering challenge, Student 1 chose to use EBR to make her point: because the model of the loon is smaller than a real loon, "this will work" (i.e., eight sticks will be enough). The final statements were also included to show that Student 1 successfully corrected Student 3's misunderstanding.

### *Validating*

In the category of *validating*, an instance of EBR was used to support another student's design idea and provide additional evidence and/or explanation. A key point to make here is that repeating verbatim another student's statement of EBR, which did happen occasionally in student conversations, was not only not classified as *validating*, it was not even counted as an instance of EBR. This was because it was clear that the student repeating the statement was not expressing an original thought, but rather just agreeing with and restating the original statement. Thus, in order for an instance of EBR to be counted as *validating*, the student needed to express support of another student's design idea *and* justify it with unique reasoning. This can be seen in the example provided.

Student 1: I can try it at home tonight, I can like put it, like I can fill my sink with water and take a piece of cardboard and lay it in there. I don't know if we need that thick of cardboard, except I'll use like a leftover cereal box cardboard or something.

Student 3: *Yeah, but that sounds, that sounds good though because it'll like have the ink on it so it's harder*.

In this discussion, the students were planning their initial platform design and were wondering about the sturdiness of corrugated cardboard after it gets wet. Student 1 proposed that she would test this at home that evening, though she might only have cereal box cardboard rather than the thicker corrugated cardboard. Student 3 supported, or validated, this idea of testing cardboard at home, using the rationale that the ink on the cereal box material would make it hard enough to be comparable to the thicker corrugated cardboard. This is an example of validating because the claim is a clear show of support for the idea, and the justification adds to this support without merely repeating what someone else has said.

### *Documenting*

In the category of *documenting*, students enunciate an instance of EBR to record design ideas or decisions or to write the answers for prompting questions. For this category, it is clear from other cues in the audio and transcripts that students have been prompted to use EBR because they need to write something down in an engineering notebook or on a worksheet. *Documenting* usually occurred when the team agreed about their design ideas; they had reached a decision and needed to write them down. However, *documenting* also sometimes occurred when questions on a worksheet prompted the students to start thinking about something new, as shown in the example.

Student 1: List two things that you could change to improve your design and score? I think that *we could add another piece of cardboard to the top or bottom of it to make it thicker cause* ...

Student 2: At the bottom, yeah.

Student 1: Okay, so add another sheet of cardboard...

Student 3: *And add more like ping pong balls and things to help it float*.

In this part of the transcript, students were filling out a required worksheet after they finished testing and evaluating their initial design. Student 1 read aloud a statement from the worksheet the team was required to fill out, prompting the team to think about what they would change about their initial design to improve it. In this excerpt, two different instances of EBR occurred in response to this prompt. Student 1 suggested adding another piece of cardboard to make it thicker, a suggestion Student 2 clearly agrees with. Student 3 also suggested adding ping pong balls to help the platform float better. Thus, being required to write something down motivated the students to use EBR as they considered how they would answer the prompt.

### *Sharing*

An instance of EBR was considering *sharing* if it was said without any explicit prompting or previous incentive. In essence, while the other seven categories are centered around a certain situation or context that seemed to prompt students to use EBR, *sharing* occurred when there was no context of initiation. The students weren't reacting to anything in the transcript; they just had an idea and shared it with the team.

Student 1: So this is my plan. I'm going to have, like, the platform and I don't know what it's made out of yet. And *then have, like, some of the grid sheets in the middle to kind of like let some water*. And then *right here would be bubble wrapped so they can have like a softer surface if they need to*. And *have like some plastic wraps and moss around it just to make it look kind of like a little island or something*.

Here, Student 1 shared her ideas for the platform prototype plan without any previous interaction with others, and she supported three of her four design ideas with additional justifications. For example, she proposed using bubble wrap so that the loons would have a softer surface if they needed it. The context of this statement indicates that she simply had ideas and needed to share them, thus making this excerpt an example of *sharing*.

## Conclusions and Implications

This study provides evidence of the students' use of EBR when working on *Loon Nesting Platforms*, a STEM integration unit that was not designed specifically to elicit EBR. Particularly, the data was extracted from the solution generation of the engineering problem (i.e., design a prototype floating platform on which loons could build a nest and be protected from predators, and choose a local lake on which to test the platform). We found seven categories that prompted the students to use of EBR: *clarifying with team, responding to adult, negotiating, correcting, validating, documenting,* and *sharing*.

These results have direct implications for P-12 educators in formal and informal settings. First, two of the categories can be directly implemented by teachers who want to encourage their students to use EBR. For example, *responding to adult* and *documenting* are categories that provoked instances of EBR from students. Asking students, in oral or written forms, about their design and decisions motivates them to generate EBR sentences. Questioning student teams directly and adding in prompts that require students to justify their decisions are both explicit strategies teachers can use to increase students' use of EBR. Second, an educator may not be able to directly cause the other five situations, but teachers should be on the lookout for conversations that include the other five categories. For example, if a team is debating between two competing design alternatives, it will likely include instances of EBR, since the conversation may involve *negotiating*, *validating*, *clarifying with team*, and/or *correcting*. The findings from the research presented in this paper can provide some structure to teachers as they enact the implication suggested by Schwartz[9] that teachers need to assist students in learning to use evidence-based reasoning. Thus, these seven categories that initiate instances of EBR can be useful to educators who want to directly plan for or indirectly explore EBR in their classrooms.

**Future work**

In this exploration of the initiation of EBR with students, we see that there are different types of situations that prompted students to provide evidence for their design ideas or decisions. The research data included transcripts from students that the teacher or aide in the classroom may not have heard during the activity. Furthermore, the quality of the EBR instances has not yet been analyzed. Many of the EBR instances seen in this research provided a claim and a "how" or "what" type of justification, but most did not have a "why" justification. Understanding when students actually use a "why their idea will work" type of justification is a needed next step. EBR has the potential to help students make the connections between science, mathematics, and engineering in a very meaningful way, and we need to understand how to elicit the ways students are thinking about the connections in order to help them learn more deeply.

**References**


1. National Academy of Sciences, National Academy of Engineering, & Institute of Medicine. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: The National Academies Press. http://doi.org/10.17226/11463

2. President's Council of Advisors on Science and Technology (PCAST). (2010). *Prepare and inspire: K-12 science, technology, engineering, and mathematics (STEM) education for America's future*. Washington, DC.

3. National Research Council. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: The National Academies Press. http://doi.org/10.17226/13158

4. National Academy of Engineering, & National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, D.C.: The National Academies Press.

5. National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press. http://doi.org/10.17266/13165

6. Moore, T. J., Tank, K. M., Glancy, A. W., & Kersten, J. A. (2015). NGSS and the landscape of engineering in K-12 state science standards. *Journal of Research in Science Teaching*, *52*(3), 296–318.

7. NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. book, Washington, D.C.: The National Academies Press.

8. Trilling, B., & Fadel, C. (2009). *21st century skills: Learning for life in our times*. San Francisco, CA: Jossey-Bass.

9. Schwarz, B. B. (2009). Argumentation and learning. In *Argumentation and education: Theoretical foundations and practices* (pp. 91–126). Boston, MA: Springer US.

10. Besnard, P., & Hunter, A. (2008). Nature of argumentation. In *Elements of argumentation* (pp. 1–20). Cambridge, MA: The MIT Press.

11. Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education*, *77*(3), 319–337.

12. Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*, 287–312.

13. Abi-El-Mona, I., & Abd-El-Khalick, F. (2006). Argumentative discourse in a high school chemistry classroom. *School Science and Mathematics*, *106*(8), 349–361.

14. Sampson, V., Enderle, P., & Grooms, J. (2013). Argumentation in science education. *Science Teacher*, *80*(5), 30–33.

15. Latour, B., & Woolgar, S. (1986). *Laboratory Life: The Construction of Scientific Facts*. Princeton University Press.

16. Llewellyn, D. (2014). *Inquire within: Implementing inquiry-based science standards in grades 3-8* (3rd ed.). Thousand Oaks, CA: Corwin Press.

17. Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation if the pedagogy of school science. *International Journal of Science Education1*, *21*(5), 553–576.

18. Mathis, C. A., Siverling, E. A., Glancy, A. W., Guzey, S. S., & Moore, T. J. (2016,

June). *Students' use of evidence-based reasoning in K-12 engineering: A case study (Fundamental)*. Paper presented at the 123rd ASEE Annual Conference & Exposition, New Orleans, LA.

19. Mathis, C. A., Siverling, E. A., Glancy, A. W., & Moore, T. J. (in press). Teacher's incorporation of argumentation to support engineering learning in STEM integration curricula. *Journal of Pre-College Engineering Education Research.*

20. Roehrig, G. H., Moore, T. J., Wang, H.-H., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics*, *112*(1), 31–44.

21. Moore, T. J., Stohlmann, M. S., Wang, H.-H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In Ş. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 35–59). West Lafayette, IN: Purdue University Press.

22. Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*(1), 3–11.

23. Toulmin, S. E. (1958). *The uses of argument*. New York, NY: Cambridge University Press.

24. Moore, T. J., Glancy, A. W., Tank, K. M., Kersten, J. A., Smith, K. A., & Stohlmann, M. S. (2014). A framework for quality K-12 engineering education: Research and development. *Journal of Pre-College Engineering Education Research*, *4*(1), 1–13.

25. Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage Publications, Inc.

26. Patton, M. Q. (2015). *Qualitative research & evaluation methods* (4th ed.). Thousand Oaks, CA: Sage Publications, Inc.