



## **Teachers' Use of Argumentation in the Development of Integrated STEM Curricula (Fundamental)**

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## Teachers' Use of Argumentation in the Development of Integrated STEM Curricula (Fundamental)

Over the past several years, there has been a growing concern that the United States is not producing enough students who are prepared for careers in science, technology, engineering, and mathematics (STEM), which is needed if the U.S. is to continue to be internationally competitive<sup>1,2</sup>. Efforts placed on improving STEM education have the potential to not only meet these demands but also to improve STEM literacy of all citizens<sup>3</sup>.

Recent national policy documents have focused their attention on STEM for primary and secondary education<sup>4-6</sup>. The *Next Generation Science Standards* (NGSS), which include engineering design as well as science, were recently developed and have begun to be adopted by various states<sup>7</sup>. Other states are developing their own STEM-focused standards, usually by including engineering concepts in their science standards (e.g., Massachusetts<sup>8</sup>, Minnesota<sup>9</sup>).

While policy and standards that focus on STEM may help increase the number of students interested in STEM careers, they do not ensure that the students will have the skills employers in industry desire. Employers want people who can solve problems, think critically, communicate, work in teams, collaborate effectively, and have technical skills<sup>10</sup>. This means that future employees will need both technical and professional skills regardless of which STEM career is chosen. Therefore, teachers need to not only teach standards that support STEM content knowledge, they must also help students build professional skills.

One of these professional skills that has been gaining more attention in K-12 education is argumentation<sup>11</sup>. Learning the process of argumentation helps the development of reasoning, critical thinking, communication, social behaviors, and information gathering skills. These skills are necessary for daily life, professional activities, and all facets of education, which makes argumentation an important competency for students to engage in. Incorporating argumentation skills into curricula encourages students to become independent thinkers and problem solvers while also gaining content knowledge<sup>12,13</sup>.

For students to engage in argumentation, teachers must provide a curriculum that incorporates such skills using hands-on, student-centered pedagogies that allow students to experience and construct an understanding of argumentation<sup>14</sup>. People learn through experiences and social interactions<sup>15</sup>. Therefore, providing students with opportunities to observe and practice argumentation may help students develop skills that are needed to become capable STEM professionals.

The goal of this paper is to gain insight for teachers and researchers who are interested in exploring how argumentation can be used to support STEM content. This paper explores how teachers incorporate argumentation into their lessons when they are asked to develop integrated STEM curricula. We focused our attention on understanding how argumentation was used in science and mathematics lessons to support engineering. Additionally, we explored how argumentation manifests in K-12 engineering within integrated STEM units. The following research questions guided this study:

- How do teachers incorporate argumentation into teacher-developed integrated STEM curricula?
- How does argumentation used in the curricula support the learning of engineering concepts?

## Theoretical Framework

The research in this study was guided by a STEM integration framework<sup>16</sup>. According to Moore et al., problem-based engineering design challenges that require the use and development of science and mathematics content can serve as models for integrated STEM activities. STEM integration means that the disciplines of science, technology, engineering, and mathematics are meaningfully combined to create cohesive units to deepen students' understanding of each discipline<sup>17</sup>. STEM integration is an interdisciplinary curriculum approach allowing for the marriage of the four disciplines<sup>18</sup>.

## Argumentation in Education

Arguments are an integral part of being human and are found within our daily lives<sup>19</sup>. While children do have basic argumentation skills, they can be improved with age and practice<sup>12</sup>. As such, it becomes the responsibility of teachers to offer activities that allow students to engage in argumentation<sup>11</sup>. Schwarz<sup>11</sup> also noted that educational systems emphasize the development of critical thinking, which depends on the use of argumentation.

Arguments come in an array of forms and can lead to new understandings. Though argumentation may occur as a solitary activity, it is more often done in social situations through verbal or written communications. In education, this may occur during discussions, sharing opinions, or writing persuasive text. Educators can then gauge students' progress by assessing these argumentation interactions.

Though argumentation can be used in all academic domains, it is a critical component of the scientific process and is an essential part of scientific discourse. As a general definition, argumentation provides a framework that allows students to make claims based on evidence and convince others that the argument is sound<sup>20,21</sup>. In addition, using argumentation emulates the process professional scientists go through. Scientists, along with professionals in many other disciplines, often find themselves practicing argumentation, whether it be deep discussions interpreting the results of an experiment or writing research papers to convince the scientific community to consider publishing their work<sup>12,22</sup>.

There is far less research about argumentation in engineering education. The *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* has identified the need for students to engage in arguments based on evidence for both science and engineering<sup>6</sup>. However, not much has been said about the differences in arguments between the two domains. One of the differences that has been explored is the purpose of argumentation in each of these fields; whereas scientists use arguments for evaluating and explaining natural phenomena, engineers use arguments for finding the best solution for a problem with a given set of constraints. One of the few examples of research in engineering education was a study of college students who engaged in realistic ethical problems in engineering; the researchers found that

these students were able to generate better arguments than those who did not participate in the intervention<sup>23</sup>. Others have suggested that engineering students who participate in problem-based learning (PBL) improve their problem solving abilities, critical evaluation, and argumentation skills, which are used by practicing engineers<sup>24</sup>. While these research studies and reports have identified that argumentation is important, little is known about how it is used in K-12 engineering education.

Though argumentation has been studied in individual disciplines, there is little insight into how teachers develop curricula that use argumentation during integrated STEM lessons or how it is used to support engineering concepts in K-12 education. With new pressures for teachers to integrate STEM subjects in their classrooms, we hope to gain an understanding of how teachers are attempting to include argumentation within integrated STEM units as well as how argumentation can support engineering learning.

## Methodology

An exploratory multiple-case study design was selected to investigate how elementary and middle school teachers use argumentation within integrated STEM curricular units. Case studies are an in-depth investigation used to understand the complexities of a system<sup>25</sup>. This methodology also allows for a holistic view of a real situation<sup>26</sup>. In this case, the real situation was the use of argumentation in teacher-generated STEM curricula. By using case study, we gained a unique and in-depth understanding<sup>27</sup> of how teachers used argumentation in the construction of curricula. Each of the cases was embedded within a bound system<sup>28</sup> that included teachers who participated in a STEM integration professional development workshop during the summer of 2013.

The holistic approach was established because this study involved four bounded cases, was exploratory, and attempted to understand the use of argumentation as a phenomenon. This case study included four integrated STEM curricular units, or cases, that were developed by teachers during a summer professional development institute. This approach allowed for within case analysis as well as cross-case analysis.

**Teacher Professional Development Institute.** The units included in this study were developed as part of a teacher professional development institute about elementary and middle school STEM integration in science classrooms. The goal of the institute was to support 4<sup>th</sup> – 8<sup>th</sup> grade teachers in the development and implementation of an integrated STEM unit centered around an engineering design challenge situated in a rich, realistic context. The professional development institute occurred during the summer over a three week period. The focus of the three weeks included (a) understanding engineering design, data analysis, and measurement as well as associated pedagogies; (b) gaining a deeper understanding of science content; and (c) developing curricular units.

Teachers developed integrated STEM units using an iterative process. Following the professional development institute, teacher participants piloted selected lessons from their curriculum with students attending a voluntary summer camp. Teacher participants and coaches revised the curricula based on their experiences during the pilot prior to classroom implementation. Teachers

and coaches made additional revisions to their curricula after classroom implementation. During this first year of the larger project, a total of 22 curricula were developed. The four curricula that had completed their final iteration were selected for this analysis.

Nine teachers worked either individually or in teams of two or four to develop the four units which made up the cases for this study. All of these teachers are elementary or middle school science or STEM teachers, and the content areas for the units were either earth science or physical science. The teachers in this study represented eight different schools within two urban districts with high diversity in the Midwestern region of the U.S. Teacher grade levels ranged from 4th grade to 7th grade.

**Data Sources & Analysis.** The data used for this study consisted of written curricular documents generated by the teachers for the four units. These documents included lesson plans, worksheets, rubrics, and other supplemental artifacts such as PowerPoint slides and readings.

Content analysis methods were used to examine the documents. This analytical method was selected because it is a systematic way of analyzing a body of text, which may include written texts, picture, symbols, or other forms of communication<sup>29</sup>. Using content analysis allowed us to take a few readings from four units, and look at them carefully for the purpose of understanding how teachers used argumentation to support the learning of content knowledge.

Two analytical frameworks were used to analyze the cases. The first was Toulmin's Argument Pattern (TAP)<sup>30</sup>. This model identifies six key elements of an argument: *claims*, *data*, *warrants*, *backing*, *modal qualifiers*, and *rebuttals*. According to Toulmin<sup>30</sup>, a *claim* is a statement or conclusion of a point that is trying to be established. *Data* refers to facts that support the *claim*, and *warrants* explain how data are connected to the claim. Toulmin stated that *claims*, *data*, and *warrants* provide a general skeleton of argumentation. More complex arguments may also include *backing*, *modal qualifiers*, and *rebuttal*. For this analysis, we only looked for the three elements found in the general argument because they are the minimum requirements needed for an argument. When we identified the presence of an argument or part of an argument, we recorded the context for which it was used.

While the ideas from TAP were used as the argumentation analysis framework, the language of the teacher-written curricula was not usually a clear match with *claims*, *data*, and *warrants*. We resolved this by using an altered coding scheme. We used *claims* in the same way that the term is used in TAP. However, we matched phrases in the curricula referring to *data* or *evidence* with TAP's *data*, and *warrants* included any reasoning beyond *data* (e.g., *explanation*, *justification*, *rationale*). The results section of this paper reflects both of these types of argumentation language, the terms of TAP and those used by the teachers.

Additionally, this work was guided by the *Framework for Implementing Quality K-12 Engineering Education*<sup>31</sup>. This framework identifies nine key indicators that define the characteristics of K-12 engineering. Figure 1 provides a list of the key indicators and a short description of each. When an element of argumentation was identified to be in an engineering context (as opposed to a scientific context), we used this framework to determine how this particular use of argumentation supported students in learning engineering concepts. These were

then used to identify patterns of how argumentation was being used to support engineering throughout the four units.

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 1. Truncated version of the *Framework for a Quality K-12 Engineering Education*<sup>31</sup> (reprinted)<sup>32</sup>.

## Case Descriptions

The research findings for the four curricular units, or cases, are presented here individually. The cases are presented in order by grade level, starting with the 4th grade *Thermal Energy: Engineering a Better Insulator* curriculum, then the two 5th grade units - *Rocking Good Times* and the *Human Impact on the Mississippi River Recreational Area Design*, and ending with the 6th/7th grade *Ecuadorian Fishermen* case. This order also roughly reflects how much argumentation was found in each curricular plan. In the first three units, we coded between 10 and 20 phrases as exhibiting evidence of claims, partial argumentation, or full argumentation. However, the *Ecuadorian Fishermen* unit, Case 4, contained approximately 75 coded phrases. This curriculum differed from the others in that it was written in such a way that it could be broken up into two units; thus, it was significantly longer than the first three curricula.

Each case description includes a summary of the unit, followed by a description and interpretation of how argumentation was incorporated into the STEM curriculum. All of the units have a similar structure, which follows the structure encouraged by the professional development institute in which the teachers participated. Each unit is centered on an engineering design challenge situated in a realistic context. In order to develop background knowledge and to test and evaluate their designs, students engaged in activities that developed science and mathematics content knowledge. Armed with their knowledge of science, mathematics, and engineering, the students designed a solution to the initial problem as the culminating activity for the unit. In three out of the four of the units analyzed here, the students were also asked to create either a letter or presentation (or both) to accompany their design in their final communication to the client.

After each unit summary, we give descriptions of argumentation found in the plans. In each case, these descriptions are organized from the clearest examples of elements of the argumentation process to the least clear. We acknowledge that by only using written curricular plans as data, the amount of possible argumentation found was limited; plans often do not reflect implementation exactly. However, the written plans were deemed suitable for this initial analysis. Following the descriptions of each of the units, argumentation within the units is compared and contrasted in cross-case analysis.

### Case 1: *Thermal Energy: Engineering a Better Insulator*

This unit was designed for a 4<sup>th</sup> grade physical science class. Students are introduced to the concept of heat transfer through several investigations and then complete an engineering design challenge in which they design a *cooler* to keep a soda can cold in the summer. Students first model how temperature affects the movement of molecules, discover that heat transfers from warm areas to cold areas, and test a variety of materials to identify which are good insulators and which are good conductors. After these investigations, students are then introduced to a client who would like them to design a can cooler that will keep cans of soda cold during hot summer camping trips. Students can use what they learned about the materials to inform their design decisions.

The *Thermal Energy* unit contained few elements of argumentation. In each of the units examined in this study, an opportunity to engage in argumentation exists when students are asked to argue the merits of their final designs, but in this unit that opportunity is implicit and not as fully developed as in some of the others. Students evaluate their designs in this unit using a scoring sheet that assigns points to measure the success of the cooler, and at the conclusion of the unit students do a gallery walk to view their classmates' designs and score sheets. According to the lesson plans, during this gallery walk "groups can discuss why they believe an insulator was successful or not." If students do engage in this discussion, asking *why* encourages students to support their claim about the success of the insulator with evidence, but students are not required individually or even in groups to document or formalize this. Unlike the other units examined here, this unit did not require students to create a presentation or write a letter to the client; thus, they were not explicitly asked to argue the merits of their design. Although the potential for argumentation is present in this lesson, it was difficult to determine how it would be implemented from the curricular plans alone.

Elements of argumentation were also identified in the use of questions throughout the unit. The unit frequently uses questions as prompts for class or group discussions, and these questions often require that students make a claim. Typically, however, these prompts do not require or encourage students to provide evidence or justification for those claims. In several of the lessons in the unit, these questions are used to introduce the day's lesson. For example, at the beginning of an activity investigating how quickly an ice cube melts when contacting different surfaces, the lesson plan provides the prompt, "Ask the students how they think heat moves" as the launch for a class discussion. This question asks students to make a claim, but this is before they engage in the activity so they are not asked to give evidence. Similarly, during the activities or investigations, the students are often asked to make claims about what they are seeing, but there is no indication that they should provide evidence or justification. For example, in order to investigate the insulating properties of different materials, students wrap their hands in the material and then place them in a bucket of ice water. The lesson plan indicates that as they do this, "Groups will discuss how that material is performing to insulate their hand from the ice water. One group member should record the group's observations." Asking the students to assess how well the materials are doing is prompting them to make a claim; however, it does not appear to go any further than that. In another instance of this, after collecting a set of data on the temperature changes over time of a set of liquids in different insulators, students are asked to "discuss and describe any patterns they see while recording the temperatures," but the curriculum makes no mention of supporting their claim with evidence or justification.

Additional places in the curriculum were identified as having the potential to provide students with the chance to develop arguments, but it was difficult to determine with confidence in these instances the intent of the curriculum writers. Specifically, this unit frequently describes discussions wrapping up investigations in the *Closure* section of the lesson plan. An example of this taken from the lesson on insulators and conductors is "Closure: Review insulators and conductors. Discuss which materials make up good insulators." It is not clear from this instruction whether the students are meant to engage in this discussion or if this is in fact meant to be a teacher-led review of the findings from the day's investigation. How a teacher chooses to implement this part of the lesson would greatly impact the nature of the argumentation present in the discussion.

### Case 2: *Rocking Good Times*

This unit was designed for 5<sup>th</sup> grade earth science. Students are presented with a client interested in building an amusement park near a city prone to earthquakes. Students must select the rides to include in the design, the type of soil that offers stability during an earthquake, and provide a mechanism for anchoring the rides securely during a simulated earthquake. Students use the iPad seismometer app to see how seismic waves are measured and graphed. Pictures of existing anchoring systems and websites posting earthquake activity as it happens reinforce the real-world context of the problem. Students need to choose a site based on the stability of the underlying earth materials, while also considering other areas of concern (e.g., distance of location from existing roads, housing). Once the site is chosen, students are asked to test, evaluate, and present their design.

The *Rocking Good Times* unit uses persuasive argumentation to communicate between the client and student engineering teams, which is developed throughout the unit. The initial letter from the client situates the project, emphasizes the “competitive bidding process,” and identifies the criteria for winning that bid. The competitive nature may support students’ development of an argument as they are expected to create a persuasive argument which will be assessed by the client. Additional clarification of the communication expectations are seen in the presentation to the clients. The curriculum states that students should be given

...a checklist or rubric showing expected elements for their presentation. These may include... graphs from the surveys taken, telling which earth material was chosen and why, showing sketch of the design, telling total score for design, amount of budget spent, and a unique feature which sets them apart from the other teams.

The rubric provided indicates that the qualities of the arguments presented are judged on four criteria: “clear, creative, persuasive, and backed up with data.” This implies that students must not only make claims about their engineering design, they must also explain their reasoning and provide evidence to back their claims. While the students progress through the lessons, they must consider how the information they are learning helps them to develop the best design within the given criteria.

Another area of the curriculum that provided some indication that arguments may be developed was the use of questions, which are present in all but one lesson. Questions were found in two sections of the lessons: the introduction and the closing. The questions found at the beginning of lessons include questions such as: “What type of earth material is the most stable during an earthquake?” and “What kind of anchor system will keep an amusement park ride stable during an earthquake?” These two examples could be satisfied by the use of a claim and are representative of the majority of questions found at the beginning of the lessons. A few questions do require the use of claims as well as additional explanation. In one instance, the question prompts students to answer, “What site, anchoring system and additional rides will we recommend to the client and why?”, though the question does not state that students need to develop an argument. This question does imply expectations that three claims should be generated that are accompanied by further information to justify their statements. However, these questions do not explicitly identify the need to include data.

Questions provided in the closing of the lessons had the highest expectation of developing complete arguments. For example, a series of question prompts are provided asking students to consider the information they had learned in the lesson and make choices related to their engineering design. This series includes: “What did we find out? How do the graphs show this? Write down in your journal which four rides you would recommend to be included in the new amusement park and why.” When taken together, these questions provide the expectation that students will make claims, use data to support their claims, and provide explanations to justify their claims. However, questions that expect all three components of argumentation were only identified in two of the five lessons.

Another possible use for argumentation within the curriculum may be found within student conversations, though the curriculum does not state this directly. This occurs in a couple of places in the curriculum. In the first case, students are asked to “brainstorm ideas and focus on or steer discussion toward surveying kids at school.” When students are asked to brainstorm, one might expect elements of argumentation beyond claims to be used; however, this reasoning would not be required. The second case occurs when student teams are planning their anchor system designs. The lesson plan states that “groups discuss and sketch ideas for anchor system.” Like the brainstorming example, students are generating ideas. They may also include reasoning supporting these ideas, but it is not explicitly present.

### Case 3: *Human Impact on Mississippi River Recreational Area Design*

This is a 5<sup>th</sup> grade earth science unit. Students are introduced to an engineering project where Ms. Harriet, the local president of the Mississippi River Fossil Foundation, requests help from the local community to design a recreational area. Students are provided criteria, which are that the outdoor recreational area needs to support a variety of activities while also preserving the natural attraction with a budget of \$600,000. Students are asked to create a land-use proposal to convince Ms. Harriet, her committee board, and other potential investors to use their preservation design as the Mississippi River’s newest park highlights. In the following lessons, students collect information to help them meet the challenge. They test the properties of soil, examine rainfall data, explore the impact of runoff, and research current issues related to human impact on a local and global scale. The students complete the unit by presenting their recommended designs to their client.

Argumentation occurs implicitly throughout this unit. The most significant use of argumentation in this unit is in the proposal to the client. Once students have completed their designs, they are required to draft a letter and create a presentation that explain how their design meets the design requirements and why they made the choices they did, in essence creating an argument for why their design should be chosen by the client. The curriculum gives a sample prompt that outlines the expectations for the students’ final write up, saying “in your written document, you’ll need to inform the Ford Restoration Project about each item that you’ve put into your park design and how it helps make sure humans are having a helpful impact in your design.” Additionally, Figure 2 displays the text of the letter students receive from the client after they have submitted their initial proposals, which outlines the requirements for their final projects. Although the letter from the client does not explicitly use the words *argument*, *claims*, or *evidence*, the phrase “explain the final choices in your design” indicates that the teacher is asking the students to provide

justification. Additionally, repeated mention of making sure that the “design fulfills our requirements” in the client letter implies (but does not directly state) that data and evidence should be provided indicating that the students’ designs do, in fact, fulfill the requirements. The importance of these aspects of argumentation is further reinforced in the rubric for evaluating the students’ final designs. One of the four categories evaluated in the rubric is “Ability to Persuade Client,” and this category is scored based on the amount of evidence provided to justify design decisions.

Dear Ford Plant Renovation Agreement Applicants,

As city representative for the City of Saint Paul, I am writing to inform you on your design submission. The city has strict rules and regulations about how to deal with previously contaminated Ford plant site reconstruction project. As your design criteria was submitted to the City of Saint Paul’s website we regret to inform you that you did not supply enough written or verbal verification of safety, ability to withstand changes from rain, snow, temperature differences, runoff, weathering and natural erosion.

This was a common issue with many of our design participants. Therefore due the high number of interest and the desire to allow all applicants to complete this challenge, we have decided to extend the submission deadline to May 1, 2014.

To make sure that your design fulfills our requirements, we ask that you submit written documentation as well as a presentation of your design. Your written documentation could be a poster to accompany the map of your finished design, a letter to the City of Saint Paul advisory board, or a typed document explaining the final choices in your design.

The final requirement is that we ask that you team up with a company interested investing in the Ford Plant Renovation Agreement. The goal of this is to show that your design is sustainable and will maintain interest from the community and business supporters of our great city of \_\_\_\_\_.

We look forward to seeing your resubmission of your design!

Mr. \_\_\_\_\_

Figure 2. Letter from the client given to the students outlining the requirements for the final presentation.

Elements of argumentation are also present in other aspects of the unit. Although the lesson plans and supplemental materials do not explicitly state that students will develop arguments, terminology suggestive of argumentation, words such as *conclusion*, *evidence*, *reasoning*, *why*, *how*, *explain* and *persuade*, appear frequently within this unit. For example, in the second lesson of the unit students examine the flow of water over different materials. The lesson plan states that the teacher should “Ask students why they think the water went faster in one cup and not the other.” Later in that lesson, after examining the properties of the materials, the lesson includes the prompts, “How big are the pieces found in each? How close do the pieces sit together? Does that affect how fast the water flows?” The questions asked throughout the activity follow the

structure of an argument while attempting to encourage critical thinking. The arguments are generally developed throughout the lessons but are put together into a meaningful statement at the end of the lesson, which is then used as an assessment tool. In this lesson, for example, students are asked to create a poster that includes “the soil mixture, what they observed, and what conclusions they can create from their observations.” Students also fill out a worksheet which includes questions such as “What can you conclude about your observations? (Remember to support your reasoning with evidence).” Additionally, the lesson ends with an exit slip where the students respond to the prompt, “How does the soil type affect how the water flows through?”

In the example above, argumentation is used to structure the lesson that guides students to learn a specific mathematics or science concept needed to solve their problem. The initial questions are predictive or inferential in nature. For example, the students are to generate the justification and evidence after performing their investigation. The worksheets that accompany the activity clearly define the argument that students will be forming by asking a set of questions that tell the students what they need to do and the expectations which are all elements of an argument. The structure of the lessons themselves mirror certain aspects of an argument by making predictions, collecting data, and drawing conclusions by providing reasons and data to support their claim.

#### Case 4: *Ecuadorian Fishermen*

This unit was designed for 6<sup>th</sup> and/or 7<sup>th</sup> grade physical science. Students are asked to help a small business in Ecuador that has discovered that some of the Ecuadorian fishermen need help keeping their fish fresh during transport on small boats and also need a means to cook the fish so they can be sold. Students explore density, heat transfer, and insulators to design a freezer for the fishermen. Students investigate conduction, physical and chemical changes, and specific heat to help them design, build, and test a cooker. This curriculum may be done as one large unit or may take place over two years, with the freezer problem the first year and cooker problem the second.

This unit uses argumentation throughout both parts of the curriculum. The lessons plans and supporting materials provide detailed descriptions that strongly indicate that students are expected to participate in the argumentation process. The curriculum clearly identifies frequent instances where students not only need to make claims, but also provide evidence and/or justification to back up those claims. This expectation for argumentation is seen in the students’ final letter to their client and through whole class and small group discussions that are usually led by questions from the teacher or worksheets. We describe each of these instances with the aid of examples.

The clearest instance of argumentation in the curriculum is when the student groups write to their client to communicate their final engineering design solution. In both the freezer design problem and cooker design problem, the unit begins by having students read a letter from their client that outlines the problem. These letters help direct what the students need to learn in order to solve the problems posed and provide an explanation of the type of information that the clients require. These requirements, which the students must address in their final letter to the client, are shown in Figure 3.

**Requirements from the client regarding the freezer design:**

We are asking you to help us find the best design for a freezer to assist the fishermen. In doing so, we request that you write us a letter addressing the following points:

- A recommendation of *what concentration of ice* would be best to put the fish on in the freezer.
- A clear recommendation of *what type of freezer we should build and* what specific materials we should use.
- A detailed explanation of *why you chose to use those materials*.
- A *description of the process* you went through to arrive at the best plan for a freezer including data, cost decisions, and considerations made for keeping a low mass of the freezer.

**Requirements from the client regarding the cooker design:**

We are asking you to help us find the best design for a cooker to assist the fishermen. In doing so, we request that you write us a letter addressing the following points:

- A clear recommendation of *what type of cooker we should build and* what specific materials we should use.
- A detailed explanation of *why you chose to use those materials*.
- A *description of the process* you went through to arrive at the best plan for a cooker including data and cost decisions.

Figure 3. Excerpts from the letters from the client for each of the design problems of the *Ecuadorian Fishermen* curriculum.

The requirements in each of the letters, along with other descriptions in the lesson plans, strongly support that students are engaging in the process of argumentation. In the requirements in both of the letters, students first must make claims regarding their recommendations for the final design, including what type of materials to use. They must back these claims up by evidence, since the clients explicitly request “data” and a “description of the process” the students went through. This is also shown in the lesson plan of the freezer design problem, where the instructions to the teacher state that while students are writing their letters, “Have them use their data and graph from the...lab in lesson 1...to give evidence for why they chose to recommend the type of material they did.” Explaining their reasoning is also a requirement from both letters, since students must explain why they chose their materials. This is more clearly tied to explaining their reasoning using their science knowledge in the teacher instructions. For example, in the freezer problem, the instructions state, “Have [the students] use their...knowledge of density, diffusion, and dissolving to help explain how they came to their conclusion about the ice.” Additionally, students “must also explain using their knowledge of insulator, heat transfer, and how heat travels to help justify the best recommendation for a freezer design.” The rubric used to evaluate the students’ written communication to the client also emphasizes that the students refer to their science knowledge about density and heat transfer to provide reasoning for their design recommendations. These materials most clearly show that students are engaging in all three aspects of argumentation: making claims, supporting them with data/evidence, and justifying them with science content knowledge.

Argumentation is also used and developed through questions that teachers pose to students through whole class discussions and worksheets. However, questions alone do not necessarily prompt argumentation; the type of questions also determines whether and how much of the argumentation process could be present. Both units have many questions that elicit claims without reference to evidence or reasoning with scientific content knowledge, which does not represent even partial argumentation. For example, in the freezer engineering problem unit, students are asked in both a worksheet and later a whole class discussion, “What do you think will happen to the mass of the water if you add salt?” before they perform a dissolving experiment. This question only elicits a predictive claim, but it does not ask students to explain their reasoning behind the prediction. Another example of this is from the cooker engineering problem unit. After completing a lab, the teacher asks the whole class, “How did you melt the ice and how did you reverse it?” At least in this example, students will be making claims based on the evidence from their experiment, but they do not have to provide further reasoning for their answer.

However, both units have several examples of questions that prompted partial or complete argumentation. These typically come in sets of questions, a “what” or “how” question followed by a “why.” One example of partial argumentation occurs during the testing of students’ initial design solutions while the teacher moves through the room and checks in with student groups. Suggested questions for the teacher to ask groups are, “How did that work?” and “Why do you think that it did or did not work?” Student groups must make a claim (i.e., how their design worked) and back it up with some other information. We coded this partial argumentation because it was not clear whether students would answer the “why” question with data from their design testing, reasoning from their science content knowledge, or both. If student groups do use both, this would be an example of full argumentation, but they are not explicitly prompted to do so. Several examples of full argumentation occur in the freezer design problem unit when the lesson plans provide question-by-question examples of the conversations that are expected to happen when the teacher leads a whole class discussion, including exemplar student responses. One of these examples happens in a whole class discussion, with similar questions being asked on the student worksheet, after the students have completed a dissolving lab and watched a simulation of dissolving on the molecular scale. The unit plan provides a script of how the discussion might go. A sample of this is quoted in Figure 4 below where the teacher’s questions are followed by expected student responses in italics.

<p>How did the volume of the water change when salt was added to both beakers? <i>It stayed the same.</i></p> <p>Why do you think that is? <i>The salt dissolved.</i></p> <p>What does it mean when we say the salt ‘dissolved’? <i>When salt dissolves, it doesn’t ‘go away’. Instead the salt molecules break down in the water and fit into the tiny spaces between the water molecules.</i></p>
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Figure 4. Teacher questions followed by expected student responses in italics.

This line of questioning is organized so that the students begin by making a claim that is based on evidence from a lab they just completed, and then they must provide reasoning related to their content knowledge about dissolving. The teacher and worksheet guide the students through

the process of argumentation by asking a set of scaffolded questions that elicit each piece of an argument. Both of these examples from the lesson plans and worksheets showed evidence of students participating in partial or full argumentation due to the types of questions asked.

Another place that argumentation had the potential to be present but was more difficult to see was in some student group and whole class discussions. In the freezer engineering problem, instructions sometimes begin with “Discuss...” without any specific follow-up questions. While these discussions could elicit argumentation, it is not explicitly evident from the information provided in the lesson plans. A similar example occurs in the engineering portion of the cooker problem unit. After reading the introductory letter from the client, the lesson plans state, “Break the students into their lab groups and allow them to brainstorm ideas for the fish cookers.” Based on only this information, this is not argumentation; however, the process of brainstorming design solutions in a small group could elicit at least partial argumentation. The cooker design problem unit does provide some instructions for partial argumentation, using the following phrase for several instances of whole class discussion:

When trying to have a class discussion, insist that students take turns raising hands and listen to each other’s explanations. When students answer questions ask them *why* to help them further their thinking and to explain their reasoning. . . If others agree or disagree have them explain why and allow other to comment on their reasoning.

This suggests that students are expected to make claims and provide reasons for those claims. If students do not elaborate or volunteer an argument, then the teacher is to prompt the students by asking them questions that help them develop their arguments. In addition, students are encouraged and permitted to either add to the arguments presented by their peers or to offer a counterargument. Here the students are socially engaging in the argument process. However, this clarity of the argumentation process was not present for many of the discussions as they were written in the lesson plans.

### **Cross-case analysis**

In this section of the paper, each of the cases is compared and discussed using a cross-case analysis. First, we describe some of the ways in which argumentation is used within the integrated STEM curricula. Next, we examine how argumentation is used to support K-12 engineering.

### **Incorporating Argumentation**

In these four cases, three themes regarding patterns of argumentation emerged. These patterns related to the final communication to the client about student teams’ design solutions, teacher-posed questions, and discussions. These patterns have already been described in each case, but they are summarized as a set below.

In three of the four curricula (i.e., all but *Thermal Energy*), the task of student teams communicating their final designs to their client was the strongest example of the process of argumentation in the unit. Whether students write a letter or create a presentation, they are required to first give a claim stating their final design solution. They must also provide evidence of their solution’s success through testing results and an explanation of their design’s features in

terms of their science content knowledge. These aspects were not just suggestions by the teacher but rather were either requirements explicitly given by the client, a rubric used to grade the communication item, or both. Based on the four curricula examined here, situating a unit around a client driven problem and then asking students to communicate their ideas to the client appears to offer great potential for including argumentation in an integrated STEM unit.

The second pattern to emerge from the cases was the importance of questioning in terms of both frequency and type of questions. A major reason that the *Ecuadorian Fishermen* curriculum contained 75 instances of parts of argumentation is that the curricular plans have an abundance of questions asked by the teacher either in whole class discussions or worksheets. In other words, the more that the teacher asks the students questions, the more potential there is for argumentation to occur. The other three units each only had 14-18 instances, due in large part to a much smaller number of questions explicitly written in the units. However, this lack of written-out questions in the plans may not be representative of what is executed in the class, so it is difficult to draw definitive conclusions from these data about the frequency of questions contained within a curriculum.

Argumentation depends not just on the quantity of questions but also the type of questions. Each of the four units used questions, typically beginning with “what” or “how,” that only prompted claims; claims alone were not even considered partial argumentation. Those questions that included “why” raised the likelihood of students referring to evidence they gather through labs or developing explanations and justifications to support their claims. This would elicit a partial argument at minimum and possibly a more complete argument, depending on how the students approach answering this type of question. Examples of these kinds of questions were given in the *Rocking Good Times*, *Mississippi River Recreational Area Design*, and *Ecuadorian Fishermen* case descriptions. It is clear from the examination of the questions in these units that although integrated STEM units are ripe with opportunities to engage in argumentation, explicit efforts must be made to encourage students to support claims with evidence and justification, not just to make claims from data.

The final major theme that emerged from these data was the uncertainty of argumentation in group and certain whole class discussions. In some of the curricula, particularly in the *Ecuadorian Fishermen* unit, directions were given to the teacher to “discuss...” an idea, but the rest of the directions weren’t developed enough to determine whether or not argumentation was present or whether this was meant to be a student or teacher driven discussion. This occurred in both science and engineering contexts. Whether whole class or small group, discussions can be a natural place for argumentation. However, this depends on the enactment of the discussions, which could not be seen by an evaluation of the curricular plans and supporting materials. Furthermore, since simply encouraging discussion leaves ambiguity in how the discussions are implemented, this indicates that curricula should consider carefully explaining how argumentation can be incorporated into classroom discussions.

### **STEM Argumentation Used to Support Engineering**

To examine the way that argumentation can support engineering in integrated STEM units, we categorized the instances of argumentation identified above by their relationship to aspects of

engineering education described in the *Framework for Quality K-12 Engineering Education*<sup>31</sup>. Instances of partial and full argumentation found in these units aligned with four of the nine indicators from the framework: Process of Design (POD); Application of Science, Engineering, and Mathematics Knowledge (SEM); Engineering Thinking (EThink); and Communication in Engineering (Comm-Engr). Explanations of how argumentation fits into these indicators is described next section.

**Process of Design (POD):** Argumentation had a varying presence within POD. Of the three parts within POD, Problem and Background (POD-PB), Plan and Implement (POD-PI), and Test and Evaluate (POD-TE), argumentation was most prominent in POD-PB. In each of the four units, students are asked to identify the problem. This is done through a story or letter received from a client. In the *Rocking Good Times*, *Mississippi River Recreational Area Design*, and *Ecuadorian Fishermen* units, this sets the stage for formulating an argument by giving students requirements of what would need to be in their final communication to the client. These requirements include not only the students teams' designs (i.e., claims), but also some sort of additional information (i.e., evidence, reasoning with science, or both). These letters or stories from the client also provide motivation for collecting background information through science and mathematics in order to be able to justify the designs, which will be discussed further in the SEM section.

Within POD-PI, it was more difficult to see examples of argumentation. While there are several instances where there was great potential for argumentation, it was not explicitly written that students would be using the argumentation process. Examples of these are the activities related to brainstorming and generating ideas in the *Rocking Good Times* and *Ecuadorian Fishermen* units. One clear example of at least partial argumentation during the planning and implementing phase occurs in the *Ecuadorian Fishermen* unit during the freezer engineering design. As students submit their plans and gather materials needed to build their design, they are required to answer questions such as, "What will you use this material for?" and "Why are you using this shape?" These questions prompt answers that are a mix of claims and some other information backing up the claims, which could be evidence from previous labs or reasoning with science content knowledge.

For POD-TE, most of the curricula showed at least partial argumentation. For the *Thermal Energy* and *Ecuadorian Fishermen* curricula, students are required to discuss their designs after testing. This discussion includes whether or not the design was successful and why the student team thought that was the case, which demonstrates a partial argument structure of claims backed up by either evidence from the test or reasoning based on science content knowledge. The *Rocking Good Times* curriculum took this a step further by asking questions in the evaluation stage that explicitly required students to provide a claim about the success of their design, evidence from the testing, and a justification of their design. These examples show that in order to evaluate the success of their designs, students have to engage in at least partial argumentation.

**Apply Science, Engineering, and Mathematics Knowledge (SEM):** The science and mathematics lessons of the units are important for argumentation in two distinct ways. First, they provide students with the background information necessary to be able to later justify their

engineering design solutions with science content knowledge. This aspect has already been discussed in other contexts within this paper. Second, in the *Mississippi River Recreational Area Design* and *Ecuadorian Fishermen* curricula, students participate in building scientific argumentation for the purpose of understanding the science. These curricula are organized to have students make claims, statements, or predictions at the beginning of an investigation, collect data through experiments or observations, interpret the data, and finally draw conclusions supported by justifications and evidence. While the students do not always participate in the full scientific argumentation process, there are several instances where they complete at least partial argumentation. Examples of this have already been given in the case descriptions of these units, and other instances were found throughout the units but not included in this paper.

It is important to note that this process of building scientific argumentation does not occur consistently in all units. All of the questions used in the *Thermal Energy* unit's science lessons prompt only claims, with no requirement for evidence or reasoning. There are no examples of partial argumentation found in the one science-only lesson in *Rocking Good Times*, but there are examples of engineering science argumentation. The example given in the case description where students are asked "What type of earth material is the most stable during an earthquake?" and are expected to answer with a claim and justification displays this. Finally, while the other two units have examples of partial and full argumentation in a science lesson context, they also both have plenty of instances of questions that elicit claims only.

**Engineering Thinking (EThink):** Critical thinking skills are one component of EThink that are supported by argumentation. This was most evident by the use of questions. The scaffolded questions used directly in the lesson plan, as well as those used in worksheets, provide prompts to guide students through the development of an argument, or at least part of one. The descriptions and types of questions vary from unit to unit. The units that require a higher level of content understanding, such as in the *Ecuadorian Fishermen* unit, also expect more thorough arguments. Based on the documents provided, it is not clear, in any of the units, if the formation of arguments is supportive of independent thinking or of collective thinking. In addition, students must use reflective thinking in order to make an argument. Reflective thinking occurs when students are asked to analyze and make judgments about what has happened. An example of this occurs in the *Rocking Good Times* unit when students have finished testing the different soil types for stability during an earthquake. The students have to use reflective thinking to analyze their data and make a judgment about which soil choice is the best; this type of thinking is required in order for them to form a partial or complete argument.

**Communication Related to Engineering (Comm-Engr):** As stated previously, communication between the client and the students was the strongest use of argumentation to support engineering within the curricula. Each of the four integrated STEM units asks students to design something for a client, evaluate their design and redesign, and present the information. Three of the curricula indicate that either written or oral arguments would be presented to the client, while the *Thermal Energy* unit's final presentation does not necessarily include the client. Regardless, all the units include prompts for students to develop some level of an argument. Writing letters or preparing presentations for the purpose of convincing a client that a proposal, design, or recommendation should be considered above others is an important aspect of the engineering profession. Thus, having students communicate their design solutions to a client not only

engages them fully in the process of argumentation, but it also requires them to practice an engineering skill.

## Conclusion

This case study has provided cursory insight into the use of argumentation within the development of integrated STEM curricula. All of the curricula contain elements of argumentation, though the number and completeness of opportunities available for students to practice the process of argumentation varied. The curricular plans all use questions and discussion prompts that produce claims, but the follow-through with evidence from student activities and justification with science reasoning is inconsistent. The findings of this research also provide an initial understanding of how argumentation supports engineering in these four units. Examples of argumentation were found in four indicators in the K-12 engineering education framework, all of which are critical elements of engineering: POD, SEM, EThink, and Comm-Engr. Argumentation may have been present in other elements of engineering, but the curricula do not capture them.

A limitation to this study is that it does not represent how the curricula were carried out by each of the teachers in their classrooms. It only captures what the curricular team chose to include in the written documentation. Additionally, engineering indicators such as teamwork may have used argumentation when each curriculum was enacted. Due to the nature of the data, it is difficult to examine students' team dynamics and interactions. Further studies examining how teachers enact curriculum and how students participate would provide a deeper understanding of how argumentation is used by the teachers and the students.

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