Students' Science Talk During Engineering Design in Life Science-Focused STEM Integration Units

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***Abstract*—While STEM integration and engineering education have become increasingly important, most integration units use physical or earth science topics. Thus, the purpose of this research was to explore students' discussions during two life science-focused, engineering design-based STEM integration units to determine what types of connections within STEM students were making and whether these aligned with the life science learning outcomes of the units. This study employs a qualitative content analysis methodology to categorize the instances of science that students used during engineering design. The results show that students in both STEM integration units used science during engineering design, but how much life science vs. physical science used depended on the criteria given by the engineering challenge. This suggests that when developing life science-focused, engineering design-based integrated STEM units, curriculum developers need to carefully consider whether life science serves only as a context or whether it is required to develop solutions to the engineering challenge.**

Keywords—K-12 engineering education; life science; STEM integration

I. Introduction

The United States has increased its focus on science, technology, engineering, and mathematics (STEM) education in K-12 settings over the past 20 years, with K-12 engineering education receiving more attention over the past decade [1]. Evidence of this can be seen in state and national science standards, which influence what is taught in K-12 schools [2]. As of 2013, 36 states included engineering content and/or practices in their science standards either implicitly or explicitly [3]. Also in 2013, the *Next Generation Science Standards* (NGSS) were released [4]. In these national standards, engineering design is included with technology and other applications of science as disciplinary core ideas, and the eight practices are each described in scientific and engineering contexts. With engineering ideas included in the majority of science standards, it has assumed a place in K-12 education.

Several potential benefits to K-12 students are often cited in engineering education literature. By exposing more students to engineering, it should increase their knowledge about the work of engineers, especially the ways in which engineers contribute to the improvement of humanity [5], [6]. This would also interest a larger quantity and greater diversity of students to pursue engineering or other STEM careers [2], [5], [6], which is seen as necessary to keep the United States economically competitive [7]. Regardless of future career, K-12 engineering education has the potential to improve all students' technological literacy, which is their knowledge about technology and ability to make personal and public policy decisions relating to technology [2], [8], [9].

The potential benefit of K-12 engineering education that is most relevant to this research study is the potential for learning STEM. It is thought that doing and learning about engineering in K-12 settings may improve student learning of science and mathematics concepts and practices [6], [8], [10]. Students may be more motivated by the real world issues often posed in engineering design challenges, and the application of science and mathematics concepts to designing engineering solutions allows the students to think about the science and mathematics content in a unique manner. Additionally, making connections among the STEM disciplines may help students learn the core content and practices of each discipline [9].

Engineering design-based STEM integration is especially relevant for K-12 science classrooms. Undergraduate engineering education focuses heavily on learning engineering sciences, though the addition and integration of engineering design with engineering sciences has been a goal for many engineering educators [11]. In P-12 settings, this is analogous to integrating engineering design problems in science classrooms. Engineering design-based STEM integration is appropriate for thinking about engineering design in a K-12 science classroom because it has the potential to better prepare students for undergraduate engineering education.

Whether or not these potential benefits occur in real K-12 settings is still being researched. While previous studies have shown promising results with regard to student learning of physical and earth science content during engineering design-based units, very little research has been done with life science content. Thus, the purpose of this study was to do an initial qualitative exploration of students' discussions during life science-focused, engineering design-based STEM integration units in order to determine what kinds of STEM connections the students were making. We are digging deeply into the interactions between students to see whether the intended science learning outcomes are used while students generate solutions to an engineering design problem. Specifically, the research questions for the study are: *In student team discussions that occur during the solution generation phase of engineering design-based STEM integration units with a life science focus: a) which disciplines of science do students reference, and b) how do those science concepts align with the intended learning outcomes of the curricular units?*

II. Literature Review

A. Background Literature

Over the past decade, the results of the implementation of several STEM integration curricular units have been published in research literature. One type of STEM integration, design-based science or design-based learning, is particularly relevant. Design-based learning uses an engineering design problem as the foundation of the unit, but the primary learning goals are science content and practices [12], [13]. These studies have generally shown positive results in terms of student learning of science and attitudes towards STEM; however, the science involved is usually physical or earth science. Design-based learning and STEM integration units have been researched that focus on physical science topics of: heat transfer and thermal energy [12], [14], [15]; force and motion [13], [16]; buoyancy and density [17]; identifying and separating mixtures using physical and chemical processes [18]; and electricity and circuits [19]–[21]; to name a few. Earth science-focused design-based learning and STEM integration units are less common but also exist. For example, the *Learning By Design*™ curricula contain two earth science units, one in which students learn about Earth's structures and processes and another in which the topics are rocks and minerals, the rock cycle, and underground water [13].

STEM integration and design-based learning curricular units that focus on life science are much less common in the research literature. In fact, two frequently cited design-based learning units are arguably more about modeling a biological system than developing a solution to an engineering problem. In one design-based learning unit for elementary school, the students built a model elbow in order to better understand the functions of muscles in the human body system [22]. Similarly, a middle school unit required students to create a model of a lung while learning about the respiratory system [23]. While these two designing models activities are clearly tied to life science content, they are not really engineering challenges.

The *Designer Bacteria* unit does require students to directly apply life science concepts to the engineering design challenge [24]. In this high school unit, students are tasked with designing bacteria via genetic modification to express new traits. In order to do this, they learned about genes, genetic expression, and how the environment affects cell division. During the engineering challenge, students were actually able to alter the genetics of bacteria in order to design a solution. While the *Designer Bacteria* unit demonstrates the potential for integrating life science concepts with engineering design challenges, it is one of the few units described in the research literature that does so.

In sum, most STEM integration and design-based learning units that have published results involve physical or earth science. There are a few units that use life science concepts, but only one uses those concepts to solve an engineering design challenge rather than design a model of an anatomical system. Therefore, STEM integration and design-based learning curricular units that focus on life science still need to be developed and researched. This paper explores two life science-focused STEM integration units in order to determine what kinds of scientific content, life science or otherwise, students use when generating solutions to engineering problems.

B. Conceptual Framework

This study is situated within a larger engineering design-based STEM integration project. Because there are several models of STEM integration [9], this project used a specific STEM integration framework as guidance [25]. The purpose of this STEM integration framework is to outline features of high quality STEM integration curricula. Engineering design is used as a way of incorporating all STEM subjects, and this includes opportunities to learn from failure and redesign. The context of the engineering problem should be meaningful in order to motivate and engage students. The science and mathematics content and practices of the units are standards-based and preferably taught with student-centered pedagogies. Finally, this STEM integration framework suggests that curricular units should include opportunities for students to practice teamwork and communication, which are important professional skills. The two curricular units used in this study, which will be described in the next section, were developed using these guiding principles. As such, the STEM integration framework acts as a lens through which the entire project, not just this particular research study, is viewed.

III. Research Design

A. Methodology

This study was conducted using qualitative content analysis, which is a descriptive qualitative approach [26], [27]. Similar to quantitative content analysis, qualitative content analysis is a way to systematically analyze texts and messages in order to describe the meaning of the material [27], [28]. While quantitative content analysis tends to focus on material with fairly standardized meanings, qualitative content analysis is useful for material that requires a degree of interpretation and to which context is important [27]. Qualitative content analysis relies on both deductive and inductive coding; therefore, final results could include not only frequency counts (as in quantitative content analysis), but also the final codebook and its categories and subcategories [27].

In this study, we used qualitative content analysis methods to analyze transcripts of two student teams' discussions while they were designing solutions to engineering problems. Both teams were in the midst of an engineering design-based STEM integration unit with a life science focus. The team from the 4th grade *Survival Suit* unit consisted of four male students, and there were three approximately 30-minute class periods worth of audio data. Within each class period's transcript, the classroom teacher and aide frequently checked in with the group, asking them about their design choices and reasons for those choices. The *Loon Nesting Platforms* team was made up of four 7th grade female students. For this unit, there were six transcripts of the students doing engineering design, but they ranged from 5 minutes to 30 minutes long. The transcripts include occasional whole-class announcements made by the teacher that seemed to influence the direction of the group's conversations, but the teacher only directly interacted with the team a few times. In total, there were 92 minutes of audio data for *Survival Suit* and 144 minutes for *Loon Nesting Platforms*. More information about the STEM integration units and the analysis procedures follows.

B. Context of the Study

This research was conducted as a part of a funded five-year professional development project. The aim of this project was to help upper elementary and middle school science teachers improve their understanding and practice of reform-based science instruction. In particular, the focus of this project was engineering design-based STEM integration, as guided by the STEM integration framework previously described. The three-week summer professional development provided teachers with multiple opportunities to engage in reform-oriented activities that focused on science and engineering teaching. Throughout this professional development, teachers were also asked to create an engineering design-based STEM integration unit with guidance from the STEM integration framework. During this curricular unit development process and later during the school year, teachers received support from the project team in the form of mentoring and coaching. Individual and curriculum writing team meetings were held monthly to help teachers improve their knowledge of instructional strategies for implementing reform-based practices in their science classrooms. The two STEM integration units used in this study were created by teacher teams as a part of this professional development project.

C. Description of STEM Integration Units

Since both of the curricular units were created within the same project, their development was guided by the same principles. These were the principles of the STEM integration framework, which has already been described. Most notably, this view of STEM integration uses an engineering design challenge as the foundation of the integration, with standards-based science and mathematics used to solve the design problem. In this project, both units focused on life science content, as well as mathematics related to data analysis and measurement. The science content learning goals for both engineering design-based STEM integration units are shown in Fig. 1.

1) Survival Suit: The setting for the *Survival Suit* unit is a future in which the United States' environment has drastically changed to only include five major sectors of habitats: mountain, desert, tundra, jungle, and prairie. The engineering challenge posed to the students is to design a survival suit that will allow people to travel in these extreme climates. The suit needs to be able secure food and allow a person to safely travel within the environmental constraints. This means that the suit needs to: be strong enough to protect from predators of humans, be flexible enough to move in, have appropriate thermal properties for the habitat climate, have a foot shape that allows the person to comfortably walk in the environment, and visually blend in with the environment. Each student team is assigned a different habitat to design for, and the redesign requires them to make their suit also work for the prairie habitat. While students do not actually create their survival

***Survival Suit* Science Content Learning Outcomes:**

Students will...

1. identify the structures and functions of plants and animals.
2. predict how those features help organisms.
3. identify how the covering of an organism's body provides advantage for survival in its environment.
4. identify how the structures of an organism provide an advantage for survival and mobility.
5. identify how the structures of an organism provide an advantage for survival and acquiring food.
6. create a food web of organisms in a prairie and explain the relationship between the organisms.
7. collect data and create graphs to make claims, with evidence, about what would happen to an environment and its organisms if one of its parts were changed.

***Loon Nesting Platforms* Science Content Learning Outcomes:**

Students will...

1. identify different ways that humans have impacted wildlife and the environment.
2. categorize and rank human impacts on the environment.
3. summarize basic characteristics of Common Loons based on the results of a scavenger hunt.
4. define key ecology vocabulary terms and represent the relationships between them.
5. differentiate between producers, consumers, and decomposers.
6. create a food chain.
7. create a food web.
8. describe how energy flows through a food chain and a food web.
9. differentiate between abiotic and biotic factors in an ecosystem.
10. analyze a data chart containing qualitative and quantitative data to make a decision.
11. use spatial representations such as maps, graphs, and aerial photographs to assist them in making a decision on suitable nesting lake.
12. match common birds and their nest.
13. compare different types of bird nests.

Fig 1. *Survival Suit* and *Loon Nesting Platforms* learning outcomes related to science.

suit in full, they plan what they would do for each component based on the science they have learned and the data they gathered from previous experiments related to the components. Fig. 1 shows the science learning outcomes of the unit, which align with elementary life science standards about animal and plant adaptations as well as habitat features.

2) Loon Nesting Platforms: The Common Loon is the state bird of Minnesota. However, due to increasing developments along lake shorelines, the amount of space available to loons to build their nests is decreasing. Therefore, the Minnesota Department of Natural Resources wants the student engineers to design floating platforms that would allow loons to build their nests on the platforms in the middle of lakes, away from humans. There are five criteria by which the students' designs are judged: it floats when a model loon is placed on it, it remains stable in wind and waves, it provides protection from predators, it allows adult loons and chicks to access the platform from the lake, and cost. In middle school, life science standards address human impacts on the environment, food webs and the relationships within (e.g., predator/prey), and vocabulary related to ecosystem parts (e.g., abiotic and biotic factors, populations vs. communities, organism). The life science learning outcomes specific to *Loon Nesting Platforms*, which are related to those standards-based topics, are shown in Fig. 1.

D. Data Analysis

After reviewing the transcripts and being immersed in the data, the first step of analysis was to choose the unit of analysis as an instance of student speech that involved a science concept. (Teacher speech was used as to help contextualize certain instances of student speech, but this speech was not coded.) Each instance of student speech did not have to be a complete sentence, since the students often spoke in phrases. However, there needed to be enough information to determine what the student was trying to say in order to be able to classify the instance as a topic of science. For example, during the *Survival Suit* unit, a student responded "Because you cannot stretch" to a teacher's question of "Why didn't your group choose the strongest material?" This indicates that the student was aware of the material they were discussing and its properties of strength and flexibility, even though the actual instance of speech was limited to a short phrase.

The second step of analysis was to inductively code each unit of analysis, or instance of student speech. We developed categories based on the science topics addressed in student discussions. This categorization required a degree of interpretation and an acute awareness of the context of the discussions, both of which are features of qualitative content analysis [27]. We are deeply familiar with both units' curricular documents, the implementation of the units, and state and national science standards. Therefore, we were qualified to do this interpretation, determining what science topics students discussed in each instance.

In order to answer the research questions, deductive coding was also required. To answer research question *a) which disciplines of science do students reference*, we decided which discipline of science each topic fell into. We determined the boundaries of these disciplines based on descriptions in NGSS [4] and in *A Framework for K-12 Science Education*, the national report upon which NGSS was based [8]. The discipline of physical science included properties of materials and flotation. Life science included animal adaptations, information about habitats, and relationships within ecosystems. While learning about climate and weather in a general sense are earth science content, understanding the specific climates associated with particular habitat environments is considered part of life science content in NGSS [4]. Deductive coding was also required for research question *b) how do those science concepts align with the intended learning outcomes of the curricular units?* Since the intended learning outcomes were included in the curricular documents, we used them as a guide. These learning outcomes are shown in Fig. 1.

IV. Results and Discussion

In this section, we present the results of the analysis and discussion together. Results are presented in three ways: a figure showing the science topics, their connections, and the number of instances they were used in discussion; explanations of the topics; and examples from the audio text to clarify certain science topics. These results are used to answer the first part of the research question, what disciplines of science do students use when generating engineering solutions, and then they are compared to the learning outcomes in Fig. 1 to answer the second. Both parts of the research question are addressed for each STEM integration unit, followed by a comparison of the results of the two units.

A. Survival Suit

Fig. 2 is an overview of the science topics that students discussed while designing their survival suit. The topics that fall within the life science discipline are on the left, and those that are more closely related to physical science are on the right. Within the life science discipline, there were two main areas that students talked about: adaptations of their suit and the habitat they were assigned. This student group was assigned the tundra environment for the initial design, and then they were to design a suit that would work in both tundra and prairie for the redesign. When students were making design decisions, they spoke of the colors of the tundra, what kinds of food (animals) are in the tundra, and what the climate was like in terms of temperature and kinds of precipitation. These conversations about habitat features were necessary to set a context for the adaptations they needed to design.

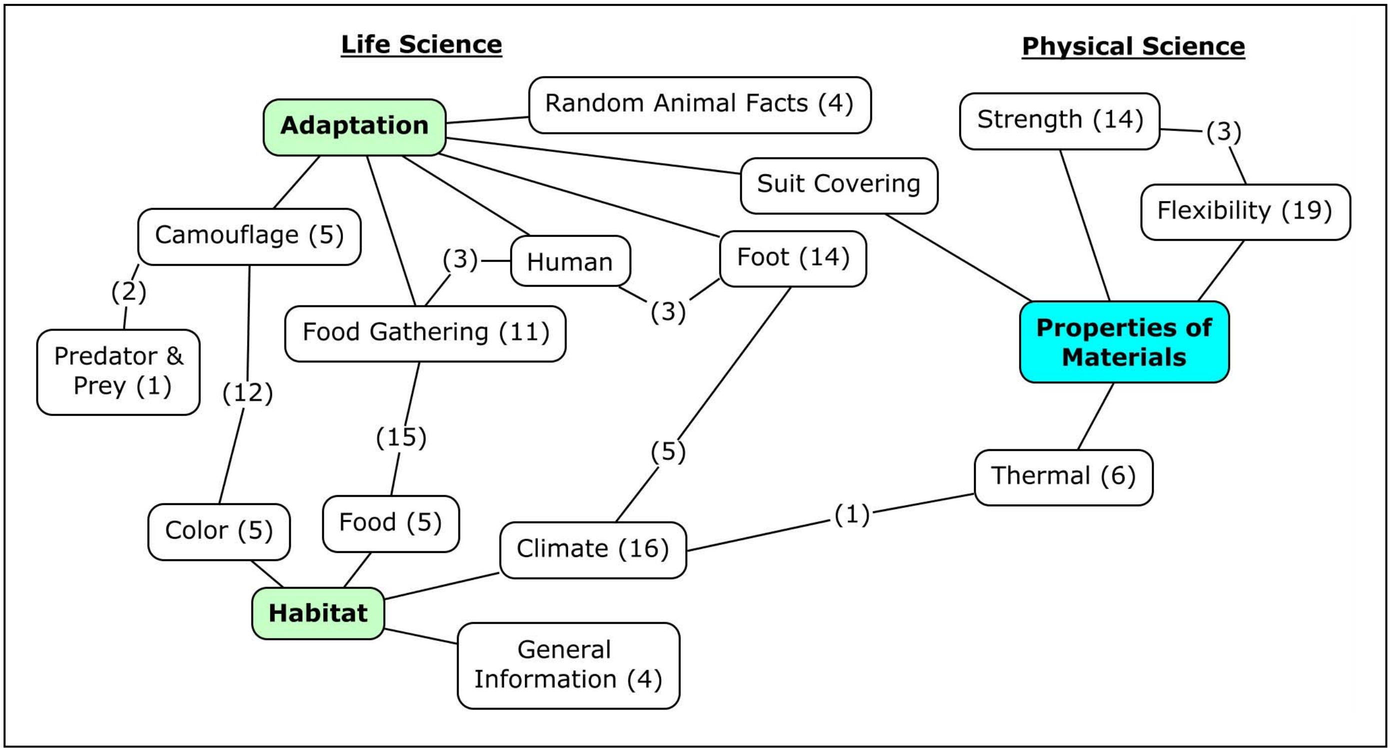

Fig. 2. *Survival Suit* science topics discussed. Numbers indicate the number of instances that topic was spoken by students. Numbers in between topics represent instances where two topics were related to each other in the same instance.

The first adaptation the team had to consider was how and why to camouflage their suit. Instances that were just about the pattern of the camouflage were put in the "camouflage" category, but those that involved deciding what colors to include in order to match the surrounding environment were coded as both "camouflage" and "habitat color". An example of this occurred after the team had agreed on light green, dark green, and brown. One of the students had a realization, "Dude, we should've done white too! Because it's going to snow. There's snow in there too. How are we going to camouflage in snow with brown and all this stuff?" Students also briefly spoke about the purpose of camouflage, once to say it would protect them from predators and once to say it would help them catch prey.

Students also had to choose a hand attachment as their "food gathering adaptation". For this, they had to discuss what the options were, how well each option performed on a timed test picking up different sizes of objects, and what sizes of food would be available in the habitat of the tundra and prairie. For example, one student said, "Because for prairie, prairie has big food like gazelle and the pink hair clip, it had, seeds are the biggest food on here, and it picked up 24 of them." This shows that the student has a knowledge of what kinds of animals live in the prairie, "habitat food", and thus wants to choose the option that picked up the most of the biggest object they tested. The logic that choosing a food adaptation option that did well picking up seeds, the biggest food tested, would also do well getting large animals was repeatedly used by the team members. At one point, the teacher attempted to correct this this misconception but left before anyone on the team realized the flaw in their logic.

Another design feature the team had to make a decision about was the "foot adaptation", i.e., which foot shape would work best for walking in the climates of the tundra and prairie habitat. During a previous science lesson, students had pushed various foot shapes (e.g., duck, rabbit, eagle) into different surfaces to see how far they sank down. Most of the discussions involved the types of feet and their performance, but for five instances, they also connected this information to the specific "habitat climate": snowy and dirt surfaces.

One student was confused about why they couldn't just use the adaptations they already have as humans for the "foot adaptation" and "food gathering adaptation" options. For example, he expressed his frustration with, "I don't wanna – those things [clips] are stupid, how are we gonna have hands like that. We're gonna have hands like *these* [human hands], so we can grab everything." Neither his teammates nor the teacher's aide had a response for his inquiries about why they couldn't just use human hands, but his teammates did eventually point out that humans use shoes to walk on snow and thus choosing a foot adaptation made sense.

The final piece of the suit that students had to choose was the covering, or skin, of the suit. Prior to the engineering design, students had tested the strength/puncture-resistance, flexibility/stretchiness, and thermal/insulating properties of materials that represented various animal skin types. For the most part, the student team debated between leather and amphibian skin, which was represented by a yoga mat. These two materials involved a trade-off between strength and flexibility. As one student pointed out, "Because the leather, yeah, we chose the second strongest because the leather did not stretch far." During these debates, students frequently referred to the data from the puncture and stretchiness tests they had performed earlier. Ultimately, the team decided to use the yoga mat/amphibian skin because it was almost as strong as leather, it was more flexible than leather, and it would work better in the hot and cold tundra environment. An interesting note about this particular design feature is that all three components of it – strength, flexibility, and thermal properties – are considered properties of materials, which is part of the physical science discipline. Hence, these topics were placed on the physical science side of Fig. 2. However, in this case, they are strongly associated with a life science context. The students on the team rarely spoke about the properties of "the yoga mat"; rather, they spoke about the "amphibian skin." In this unit, the physical science topics were used very purposefully in a life science context.

In the *Survival Suit* unit, the topics the students discussed while making engineering design decisions aligned fairly well with the stated science learning outcomes of the unit. Learning outcomes 3, 4, and 5 asked students to identify how certain structures of an organism provide an advantage for survival in an environment. These outcomes match the properties of the suit covering and camouflage, foot adaptation shape, and food gathering adaptation topics students frequently spoke of. There is also some evidence of students using their learning about food webs (i.e., learning outcome 6), since the students were familiar with the types of animals that would be present in certain habitats and predator/prey relationships. Learning outcomes 1 and 2, identifying structure and functions of plants and animals and predicting how those features help organisms, are somewhat vague. The science topics used by the students during the engineering solution generation process are about structures and functions of certain animal features, though plants are not needed for the design. Finally, the student engineering design conversations do not seem to address learning goal 7 at all, which was to make claims about what happens to an environment and its organisms if one part changes. In sum, most of the science learning outcomes of the *Survival Suit* unit were at least partially addressed during students' design conversations.

B. Loon Nesting Platforms

Fig. 3 provides a visual overview of the science topics that the students talked about during the engineering solution generation phase of *Loon Nesting Platforms*. Similar to the *Survival Suit* topics in Fig. 2, the topics that fall within the life science discipline are on the left, and those that are more closely related to physical science are on the right. The life science discipline featured one major topic that was very specific to the engineering context, which was the characteristics of loons and their needs in a platform. Several of these characteristics and needs were not explicitly given to the students as criteria, but they discussed how they might be useful to the loon. There were three instances in which students discussed the need for the platform to look natural and real. For example, one student shared an idea to "have, like, some plastic wraps and moss around it to make it look kind of a little island or something." The "other" topic is a grouping of three other concerns students had: how large a loon was in real life, where the nest would be located on the platform, and whether the platform surface needed to be soft. These examples show that the students were thinking about loon needs beyond the given criteria.

However, their primary focus was meeting the criteria. The two life science-related criteria of the engineering problem were that the loon was protected from predators and that both adult loons and chicks had access to the platform from the water (i.e., a ramp for the chicks). While a few instances involved students speaking generally about predators and protection, one team member frequently spoke specifically about protecting the loon chicks from eagles. When the students shared their initial design ideas, this student said, "The wooden stakes would go up and they'd form, sort of, like an X,

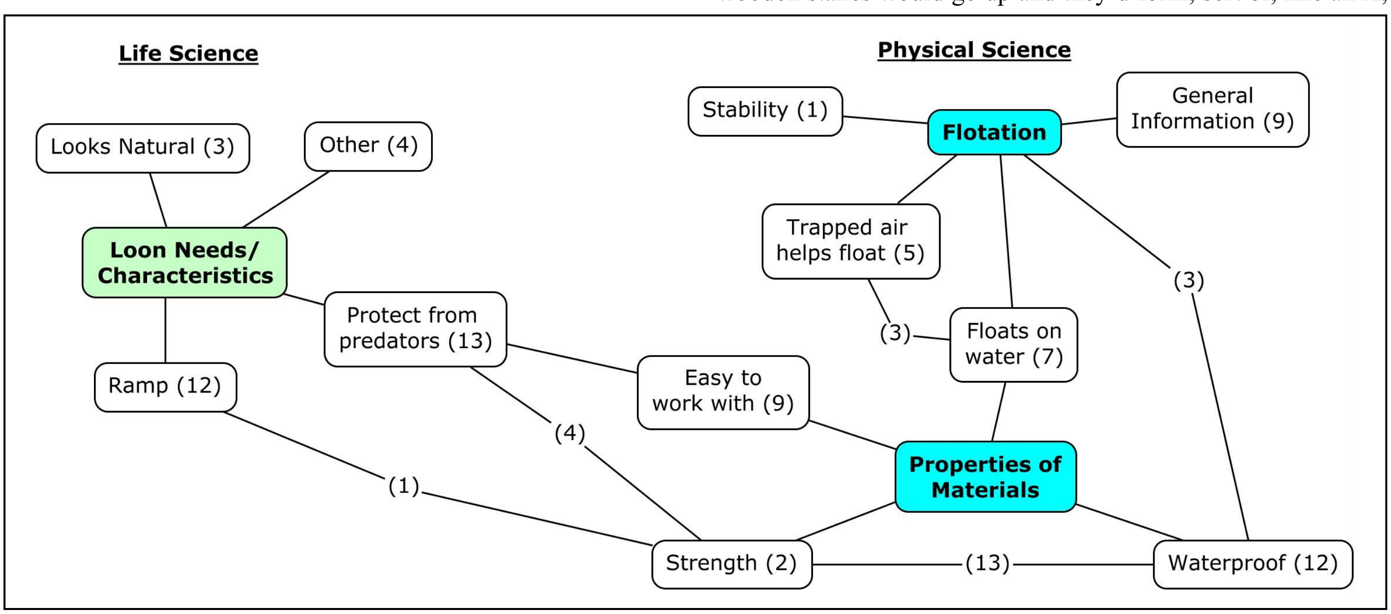

Fig. 3. *Loon Nesting Platforms* science topics discussed. Numbers indicate the number of instances that topic was spoken by students. Numbers in between topics represent instances where two topics were related to each other in the same instance.

I guess? And that way it would stop eagles from being in, and moss would hang down from it, so it would be protected like that." This barrier-like frame structure became a feature of the platform design, and constructing it required the students to also use physical science knowledge about properties of materials. First, the students used four instances of speech to debate whether straws or sticks would be stronger for the frame. Second, they discussed whether moss, Easter grass, or pipe cleaners would be easier to work with in terms of their ability to be physically separated into pieces and to be hung from the barrier structure as extra covering. Most of the conversation about loons needing a ramp was simply that the baby birds would need the ramp while the adult loons would not. However, there was one instance in which a student pointed out that the material used to create the ramp would need to be strong.

Most instances of science talk were about the primary criterion of the engineering challenge, which was that the platform would float, even when the weight of a model loon was placed on top. This criterion required students to consider two major physical science topics: flotation and properties of materials, as seen in Fig. 3. The smaller topics of science were often related to each other.

The first material students chose to work with was cardboard as the base of the platform, which prompted several science topic connections. The students acknowledged that while cardboard was stiff and strong when dry, it would lose its strength and bend if it got wet because it would absorb the water. (All of these types of comments combined to form the 13 instances category relating "strength" to "waterproof", or in this case, lack thereof.) They also related the lack of waterproof-ness of cardboard to it sinking (i.e., not floating) three times. In order to prevent the cardboard from absorbing water, they discussed how to cover it with other materials that are waterproof. For example, one student said, "I know aluminum foil won't absorb it [water] and it'll just kind of keep it [cardboard] dry. What about foam, will foam absorb it [water]?" While brainstorming which waterproof materials to use, the students also briefly discussed the strength of one of those materials, aluminum foil, in the sense that it rips/breaks easily. These instances of science talk show that students knew strength and waterproof properties of basic materials.

The other part of the challenge was for the students to figure out how to make the platform float. These conversations used three physical science topics: the property of whether a material floats on water, the idea that trapped air helps make things float, and the relationship between these two topics. For example, one student proposed the use of bubble wrap, since "then the air bubbles would have air, so we'd be able to hold more [weight]". In addition to getting the platform to float, there was only one comment concerning the stability of the platform while it was floating, which was the last criterion. The student stated, "This [gluing the edges of the cardboard] will help it float, but the ping pong balls will help it from falling over." After this, stability in waves and water was not discussed again.

The science topics that the student team discussed in *Loon Nesting Platforms* did not align well to the science learning outcomes listed in Fig. 1, though a few learning outcomes were slightly related to the topics. Learning outcome 3, which was about basic characteristics of loons, was addressed when students discussed the sizes of the adult loon and chicks and how these sizes were relevant to their ramp design. Additionally, the students' suggestions about how to make the platform look natural were based on characteristics of the loon's habitat that they learned about in the lesson addressing learning outcome 3. Learning outcomes 5-8 were to understand the roles of organisms and energy flow in food chains and webs and also apply them to the Common Loon's ecosystem. For these learning outcomes, students addressed them in one specific manner: they understood that eagles were a predator of loon chicks. Beyond this fact, any information about the roles of organisms and energy flow in the loon's ecosystem was not spoken about during the design challenge. Finally, the student concerns about where the nest would be located on the platform and whether the platform surface needed to be soft were possibly built upon learning outcomes 12 and 13 (i.e., matching birds and nests, comparing different types of bird nests). However, this is a weak connection.

Six learning outcomes were not addressed during students' solution generation conversations at all. Learning outcomes 1 and 2, which were about how humans impact the environment, helped set the context of the design challenge, but students did not speak about them while they generated solutions to the challenge. They also did not mention any instances of science related to learning outcomes 4 or 9, which were both were about defining ecosystem terms (i.e., organism, population, community, ecosystem, abiotic factor, biotic factor) and understanding the relationships between them. Learning objectives 10 and 11, using information in a data chart and maps to choose a lake on which to test their platform prototype, were not addressed while students discussed solution generation of their platform prototype. Choosing a lake was one aspect of the engineering design problem posed by the client and was an activity the students had done immediately prior to designing platform prototype solutions. However, none of the information from this smaller component of the design challenge was brought into the larger design problem, which was to design a floating platform prototype onto which loons could build a nest. In conclusion, only seven of the thirteen learning outcomes of the *Loon Nesting Platforms* unit were even partially addressed during students' science talk while generating a solution to the main engineering problem.

C. Comparison of Curricula

While the *Survival Suit* and *Loon Nesting Platforms* units were both designed to focus on life science in engineering design-based STEM integration, there are major differences between them. First, in terms of overall instances of science used during the design challenge, the team of 4th grade students had 148 instances while the team of 7th grade students had 101, even though there were more data for the 7th grade team. The most likely explanation for this difference lies in the criteria of the challenge. For the *Survival Suit* unit, all of the criteria were related to science concepts, whether physical or life science. However, one of the five criteria used to judge the success of the *Loon Nesting Platforms* was cost. Because the unit of analysis of this study was defined as an instance in which students used science, any instances of the 7th grade students discussing cost of materials were not included. In other words, because the *Loon Nesting Platform* design challenge required students to account for a criterion that was not related to science, they did not use science as much as the *Survival Suit* team which only had to consider science-related criteria.

A second difference between the two units was the amount of physical science vs. life science used by students, in terms of both number of instances of science talk and number of science topics included. Fig. 2 shows that most of the *Survival* Suit science topics are considered part of the life science discipline, while only a few are physical science. (And, as discussed before, they were physical science properties of materials that were deeply intertwined with the life science context of choosing a survival suit covering/skin.) In contrast, the *Loon Nesting Platforms* distribution in Figure 3 is much heavier on the physical science side. Also, the major physical science concepts addressed in this unit, flotation and properties of materials, are not nearly as intertwined with the life science. The engineering challenge of creating a floating platform is purely a physical science problem; that it will hold a loon and its nest does not influence the design's flotation criteria.

The third difference between the engineering design-based STEM integration units was how well the instances of science talk aligned with the science learning outcomes of the unit. Both units had science learning outcomes that were strongly tied to life science standards. Thus, since the *Survival Suit* design challenge used more life science instances and topics, it aligned with the written learning outcomes better, directly or somewhat addressing six of the seven outcomes. In comparison, the *Loon Nesting Platforms* unit's science topics discussed during engineering solution generation phase only somewhat matched seven of the thirteen learning outcomes, and most of those seven had very weak connections between the learning outcomes and science topics discussed.

V. Conclusions and Implications

The results of this study are promising in terms of engineering design-based STEM integration. In both units, students made connections between science content and the engineering design challenge; making connections between the disciplines of STEM is one of the major goals of STEM integration [9]. Additionally, students showed some evidence of making connections among disciplines of science, specifically between physical science (i.e., properties of materials) and life science. Making connections within science is a goal of NGSS [4], [8]. These results are potentially relevant for teachers who are hesitant about introducing engineering in their classrooms, since these data show that students can still use science content within the engineering practice of designing a solution.

However, these results also demonstrate the importance of thinking carefully about how well an engineering design challenge aligns with desired science learning outcomes. Especially in the *Loon Nesting Platforms* unit, the students used science during engineering solution generation, but it was often not related to the intended life science learning outcomes. If the desire is to truly integrate life science with engineering design, curriculum developers will need to consider whether life science concepts are actually needed to generate an engineering solution or whether they merely serve as the context of the design problem.

A limitation of this research was that it did not directly measure student learning. Using science topics to make engineering design decisions suggests that students have at least partially learned those topics. However, not all students on the team may have understood what the science in the conversation meant, and even those that stated instances of science talk may not have understood them outside of that specific context. Alternatively, just because students did not discuss topics related to science learning outcomes during the solution generation phase does not mean that they did not learn them. It only means that they were not needed for the design challenge. Future research could account for this limitation by measuring students' science learning gains as well as listening to their design discussions.

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