Cross Cutting Concepts in an Informal Engineering Setting (Fundamental)

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Abstract

The participation gap between men and women in the E - Engineering component of STEM sectors is persistent. This gap may be traced back to several complex issues including perceived cultural concerns in engineering and young women self-selecting out of engineering career paths early in the middle school years [1]. Informal education settings may allow for a countermeasure to the cultural concerns which discourage female participation in the engineering sector. This case study reports on an informal engineering education program for 13 and 15-year-old girls, which fosters an environment where young women build interest, skills, confidence and an understanding of how their own goals, such as helping people, align with traditional STEM careers with a focus on engineering careers. This low-stakes setting, with high quality teachers, researchers and engineering students, allows for risk taking and experimentation which may be refined and expanded into the traditional classroom setting. Of particular interest, is how this informal setting may be used to strengthen this population's ability to make crosscutting concept connections in new ways and how this may be tied to motivation.

This informal education program includes building participants' understanding of how their prior knowledge ties into engineering practices, their science core content knowledge and their crosscutting concept connections. Most importantly, student learning is centered on how crosscutting concepts in science pair with observations, insights and innovation in engineering design and problem solving. Participants come to the program with varying knowledge of engineering and science practices, core science concepts and crosscutting concepts prior to their participation in the program and this diversity of experience is considered in the programming. The program curriculum developers use unique methods to help the participants learn more about engineering, creative problem solving, how they might see themselves in these fields and how these experiences tie into crosscutting concepts. This study reports on the mechanisms used to structure crosscutting concept development with engineering practice connections. Additionally, innovations that are developed in this low stakes environment may lead to teaching tools which may transfer into traditional classroom settings.

Introduction

In 2012, the *Next Generation Science Standards* introduced a three-dimension model which included core concepts, science and engineering practices and crosscutting concepts. The revised standards are an effort to generate contemporary education standards that are "rich in content and practice, arranged in a coherent manner across disciplines and grades to provide all students an internationally benchmarked education" [2]. Science is envisioned as both a body of knowledge and a process by which we build models and theory, based on evidence, that extend, refine, and revise knowledge continually. NGSS has been adopted in 19 states as well as the District of Columbia and is of interest to forty states.

The crosscutting concepts, delineated in Table 1, bridge disciplinary boundaries, embracing connections in science, technology, engineering, and mathematics. These concepts help students construct a coherent and scientifically based view of the world by providing them with an organizational framework for connecting knowledge across the disciplines. Many of these concepts are inherent and recognizable; tiles on a floor are often in a patterned tessellation, matchbox cars are to scale with their life-sized counterparts, and shifting weather systems indicate nature's cycles of stability and change. However, without the language to articulate this understanding, students cannot communicate the connections that they are establishing.

Concept	Explanation
Patterns	Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.
Cause and Effect	Events have causes, sometimes simple, sometimes multi-faceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
Scale, Proportion, and Quantity	In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change.
Systems and System Models	A system is an organized group of related objects or components, models can be used for understanding and predicting the behavior of systems.
Energy and Matter	Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.
Structure and Function	The way an object is shaped or structured determines many of its properties and functions.
Stability and Change	For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand.

Table 1 NGSS Crosscutting Concepts

How crosscutting concepts are implemented and assessed alongside core ideas and practices raises exciting opportunities to deepen student motivation and learning. Rich resources including NSF funded, University of Washington’s online STEMteachingtools.org provide a framework for asking deep reflection questions [3]. For example, questions range from statements like "How long is _____?" to "create a set of instructions for building [system] that another child can follow" and "draw a picture showing the factors which may cause the structure to become unstable". Though many educators recognize the importance and necessity of integrating crosscutting concepts alongside key concepts and practices, the formal classroom application may not be as frequent as the more established core content or even practices; this program may serve as a pilot for educators in developing additional resources for key integrating of crosscutting concepts in deepening student understanding and interest. This case study seeks to add to the literature on integration of crosscutting concepts alongside key concepts and practices in the informal teaching and learning space.

Implementation Strategies

This case study is based on an informal education program which provides students with an opportunity to dive into hands-on engineering. This program also serves as a laboratory setting for teacher-researchers to pilot new programming that they would not have the opportunity to try within the formal classroom. The program serves approximately 100 diverse 6th and 8th grade girls in an engineering summer program. The diversity of the educators may add to the innovation with formal educators including a secondary math teacher, K-5 STEAM specialists, an inclusion coordinator, a tech integration specialist, secondary science education undergraduates, engineering undergraduates and engineering education professors. These educators have had some experiences with the Next Generation Science Standards and its crosscutting concepts although NGSS is not the state standard. One teacher shared that "As I've become more familiar with NGSS, and based on my practice with middle schoolers over the years as well as research that's demonstrated the importance of using common vocabulary and linking new content to prior knowledge across disciplines, I've begun informal reference to crosscutting concepts in my computer science courses."

These educators view the program as an opportunity to more fully develop teaching practices which optimize student learning through the crosscutting concepts lens. The program content is established by the educator team with an eye towards which crosscutting concepts lead to deeper understanding and connections with students' prior knowledge. Crosscutting concept focus questions are established along with the hands-on engineering design content before the program. For example, in the prosthetic hand engineering design activity, which utilizes low cost materials including plastic tubes and string, the educators set a clear goal of constructing a dialectical framework in order to draw out students' connections between the materials and the crosscutting concept of structure and function.

Implementation of crosscutting concepts included educator discovery of which timing and questioning is optimum for student learning. Educators tried several methods including using crosscutting connection questions as an anticipatory set before the engineering challenge, discussion/integration/posting of crosscutting concepts in chart form during the engineering challenge, and as an observation-reflection tool after an activity. Each method yielded unique benefits with continuous integration throughout the day. For example, teachers redirected student questioning and conversations back to structure and function in multiple engineering challenges from a prosthetic hand challenge to an ArtBot engineering design challenge to an engineering materials design challenge to a life preserver challenge. The crosscutting concept connections allowed for a rich discussion into the differences and similarities in key concepts and engineering design practices across engineering challenges. The repetition and diversification of ideas provided students with a more thorough understanding of the purpose and meaning of these concepts.

Research Questions and Data Collection

The driving research question for this case study is "to what extent may the inclusion of NGSS crosscutting concepts deepen students' connections to engineering/science practices and core science content?" Data was collected through surveys, program observations and teacher reflections in order to assess students' ability to recognize and articulate crosscutting concept patterns (and the crosscutting concept connection to core content and engineering practices) and in order to assess student internal motivation.

<u>Survey Findings</u> Students took pre-program and post-program surveys which consisted of multiple choice, short answer, and Likert-scale questions. Survey data points to the program deepening students understanding of the role of crosscutting concepts in science. Students were asked on both the pre-program and post-program surveys to respond to the statement: I think I could name two crosscutting concepts and give an example of one. *Figure 1, Change in student confidence of ability to name crosscutting concepts*, illustrates the strong shift in students' ability to name crosscutting concepts from the pre to the post survey. Before the program, only 11% of students agreed or strongly agreed with this statement. However, 48% of students agreed or strongly agreed with this statement after the program.

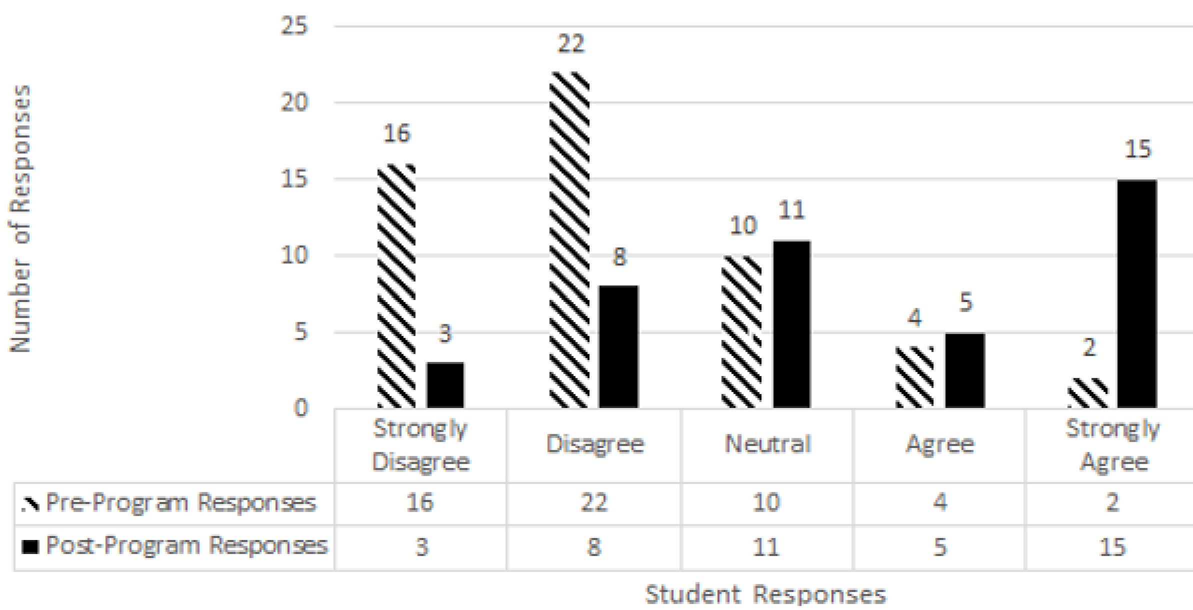

Figure 1 Change in student confidence of ability to name crosscutting concepts

The program is offered five times and interestingly, student ability to name crosscutting concepts increased significantly from the first program offering to the last program offering, with the highest report of student ability to name crosscutting concepts occurring with the final offering. It is speculated that the educators' ability to influence student confidence increased as educators assessed student self-reports and educators refined their crosscutting concept coaching through questioning.

The student self-report of ability to name crosscutting concepts was further probed by questions which tested students understanding of crosscutting concepts directly. Post-program surveys included the request that learners name a crosscutting concept and give an example, of which 60% of respondents accurately listed one of the seven concepts and provided a corresponding example. Most interesting is a comparison of students' confidence that they could name a crosscutting concept and their ability to actually name a crosscutting concept as tabulated in *Figure 2, Confidence and ability to name crosscutting concepts*. The crosscutting concept which was most frequently specified was cause and effect, with 68% of responses including cause and effect as a crosscutting concept as a concept they could name.

Perhaps greatest insight into student learning was gleaned when students were asked to connect a crosscutting concept to a program activity. The activity which has the greatest impact is a traditional engineering materials lesson which includes concrete cylinder testing, concrete mixing, and a forensic engineering failure discussion, specifically bridge failures. Students shared cause and effect connections including, "massaging the concrete and water mixtures makes an exothermic reaction and it makes it warm" and "when the bridge fell the cause was that it was under-designed and the effect was it collapsing". Other crosscutting concepts that students connected the engineering materials lesson to included patterns, with one participant noting that "one crosscutting concept that we talked about today was patterns, and an example of patterns can be seen in the bridges, where triangles are the most predominant shape." Why this program experience is most heavily discussed by students is something of interest to the program designers.

Percent	Response to "I can name crosscutting concepts CCC"	Actual ability
45%	Strongly agree/agree with "I can name CCC"	Correctly named
2%	Strongly agree/agree with "I can name CCC"	Incorrectly named
10%	Neutral response to "I can name CCC"	Correctly named
17%	Neutral response to "I can name CCC"	Incorrectly named
5%	Strongly disagree/disagree with "I can name CCC"	Correctly named
21%	Strongly disagree/disagree with "I can name CCC"	Incorrectly named

Figure 2 Confidence and ability to name crosscutting concepts

Observational Data Program staff members completed multiple observation charts throughout the program. Observations were made on general program context, specific teacher and student quotations, and specific questions addressing the research questions. In reference to implementation of the crosscutting concept questioning, one observer noted that a teacher introduced crosscutting concepts with a brief sentence or two, gave students a moment to look at the list, and then asked, "what kinds of things did you see this morning?" By allowing the students a visual list of the concepts and asking them to make the connections, students drew connections between their prior experiences and the new academic language presented to them. Often, it was noted that our teachers also built on student responses through affirmations or questions such as in the conversation below:

> *Student* "We saw energy and matter in the energy to crush the cement block."
>
> *Teacher* "Ah, and did we lose that energy?"
>
> *Several students* "no"
>
> *Student* "Energy can't be created or destroyed."

Student 2: "Maybe we lost energy when it cracked?"

Student 3 "Or maybe as it dried because it was moving."

In this example, the teacher builds off a student's response and in turn other students are encouraged to contribute to the conversation and connect science knowledge to new material. Most of the written notes of observations on crosscutting concepts begin with teachers initiating the conversation. Many students connected concepts to things they did during the program such as this student who shared "structure and function, the structure of the hand and how we created them was specific to the challenge we had and its function of picking up the cardboard tube" and "stability and change; cement is stability but we see the change when we poured the water and mixed it and we felt the change in the temperature in the water to make concrete."

Observations allowed for a check on the program implementation strategies. It seems that in addition to deepening students' knowledge of science crosscutting concepts that educators were able to modify their coaching and facilitation skills in real time to optimize student learning. It may be that teachers improved their pedagogical methods and in turn student understanding and confidence increased from the first program offering to the last program offering.

Teacher Reflections Educators used crosscutting concept discussions to build student knowledge and to connect prior learning. Educators noted that as they slowed down the group activity to allow for reflection and connections these discussions seemed to help students in activities later in the day. Student groups built shared language and experiences which allowed for a collective approach to solving new challenges. Specific strategies were helpful for both teachers and students including printed student sheets with crosscutting concepts listed, eliciting prior knowledge from the students, connecting to the day's shared activities, and using engagement techniques.

As simple as it may seem, a student packet sheet with the crosscutting concepts listed was an important anchor item. The words were displayed at angles, somewhat randomly, avoiding a sense of some being more important than others. Visual learners gravitated to this representation. Offering white space gave opportunity for sketching examples, defining or describing which filled a need for some learners as well. Seeing the concepts in one place gave quick thinkers and deliberate processors a chance to "work ahead" and be prepared for discussion. It also helped students make connections and build relationships between concepts. Students could use this sheet as a graphic organizer to see that energy and matter patterns were connected because they both were addressed in this activity.

A key focus was connecting the crosscutting concepts to the day's activities. During the first session, the concepts were presented *before* the first engineering challenge. Students listened politely and shared some examples from school. When the crosscutting concepts were introduced *after* the first engineering challenge, students had *many* responses to questions like the following: "Where did you see this today?" "How is this crosscutting concept important for the overall project?" "How do these concepts overlap or interrelate on this project?" "What artifacts in the room might also connect?" When students discuss a shared, recent experience, their observations were richer and more relevant. In either event, introducing the crosscutting concepts formally made the future group and individual conversations related to the concepts more meaningful. Allowing for wait time for students to look at the list of concepts and also between conversations surrounding ideas was crucial in helping students process this new academic language. As students referred to the same concepts in multiple engineering challenges throughout the day, they were doing more than solving a specific problem. They were knowingly looking for cause and effect, asking what structure might best serve a function, even trying out a small model before going on to create a more complex model, and seeing the crosscutting concepts at work in multiple settings. Having a teacher bring these key ideas into focus by asking questions about how a particular task/discussion/idea tied to the crosscutting concepts, and adding to a board designated to note where the concepts appeared as we progressed through our day, offered an opportunity to continually connect these terms to experiences and reinforced key academic language.

Focus on the crosscutting concepts pushed participants to connect the dots between domains of science as well as across different disciplines – science, technology, engineering, mathematics, and arts – and reflect on the similarities amongst these seemingly separate areas. This felt especially impactful to deepen these girls' self-efficacy in STEM. Making this connection supports an internalization of STEM as an area of personal strength and success as well as deepening individual understanding of the areas involved. This is akin to systems thinking, the ability to look at a whole by identifying its constituent parts and how they work together to make the whole function. Understanding and identifying crosscutting concepts helps students see the relationships between the different domains, simultaneously spreading and deepening understanding of a larger overarching STEM picture.

Lastly, using classroom engagement techniques mattered here as with any topic presented to students. As teachers increased use of such techniques such as having students pick a marker to add to the whiteboard "mural," gaining interest and relevance by creating something fun before discussing concepts, and using warmth and humor to create a safe, positive space, the number of student volunteers increased as did the complexity of the responses.

Next Steps

Many important lessons were learned by both participants and program designers in this informal learning setting when NGSS crosscutting concepts were introduced to the program. There is evidence that the participants deepened their understanding of science crosscutting concepts, engineering and science practices and core science concepts. And the educators deepened their own understanding of how to best coach learning with crosscutting concepts. This experience created a deep motivation for the educators to continue learning in the future. For example, the educators look forward to improving the program by including more student voices; one simple approach may be to toss a beach ball labeled with cross cutting concepts where students think of an example from the day that fits the concept touched by the right thumb. Students might also play "give one, get one" where they would have a short time to generate a list of crosscutting concepts in action during the day and then go partner to partner giving an example from their lists and getting a new one to add, seeing how long of a list they can create. And deeper learning may be achieved by providing a framework where students drive review of what they have learned. Varying the teaching-learning format may create opportunities for greater participation since students may have diverse learning preferences.

In any educational setting, crosscutting concepts provide a framework for teachers to coach students to connect the dots across disciplines and domains. Students connect new information to prior learning in a meaningful and ongoing manner when considering the NGSS framework. Lessons learned from this informal environment are provided as a case study which might inform new implementation strategies for the cross cutting concepts for teachers who may be seeking examples of how to coach and facilitate student crosscutting concept connections with the goal of deepening students understanding of core science content and science and engineering practices. The informal learning space also allows teachers and students to learn together, providing a strong bond that is essential to excite students about engineering and allow girls to feel that STEM fields are an option for them.

References

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