Cognitive Load, Transfer, and Instructional Decision-Making in an Informal Middle School STEM Integration Program

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Abstract

A challenge associated with Next Generation Science Standards (NGSS) implementation is the meaningful integration of science and engineering knowledge and skills in precollege teaching and learning. Instructors in informal settings have pioneered ways in which engineering design might be adapted for formal science classrooms. This includes interventions designed and taught by university engineers to promote interest in engineering among middle school students. The present study examined instructional decision making in an informal science and engineering camp for middle school students (grades 6-8). This summer program (*N*=40 students), developed and taught by university faculty and graduate and undergraduate students in electrical and computer engineering (N=5 instructors), physics, and science education, was designed to facilitate middle school students' engineering knowledge, design skills, interest, and motivation for learning electrical engineering applications in the context of physical science concepts. The conceptual framework was based upon theories in cognitive load, transfer, and instructional responsiveness. Through the exploratory case study design and pre- and post-interviews with course instructors, three main themes emerged: (1) cognitive challenges were often related to the abstraction and transfer of engineering concepts and skills; (2) comprehension was facilitated by fostering collaborative learning and autonomy; and (3) there were frequent timing issues with instructional pacing and differential rates of task completion. Findings suggest that STEM integration requires content mastery, pedagogical content knowledge, and attention towards transfer, particularly in the teaching of engineering design to reduce cognitive load. Scientific concepts such as energy transfer may not be easily recognized in a circuit when students cannot understand the function of individual components. Middle school learners may require verbal instruction and social interaction to minimize cognitive load when engaged with engineering applications. By examining middle school strategies in informal learning contexts, classroom teachers may learn from these findings to identify STEM-related learning difficulties and plan engaging, rigorous lessons. Additional implications for instructional decision making regarding cognitive and affective challenges are discussed.

Keywords: engineering education, engineering pedagogical content knowledge, informal education, middle school, STEM integration, NGSS

Introduction

The present study examined instructional decision making in a middle school informal engineering summer program; this research is intended to highlight ways in which middle school educators in informal science institutions and classroom settings might facilitate engineering knowledge, skills, and practices. This is in response to recent advances in precollege science, technology, engineering, and mathematics (STEM) education. The evolving engineering education landscape has necessitated new ways of teaching and learning that reflect rapid technological advances in the global economy. The Next Generation Science Standards (NGSS) have ushered in an era of STEM integration in K-12 science in the U.S. [1]. These standards, based upon A Framework for K-12 Science Education [2], proposed a new approach to STEM instruction that encompasses the three dimensions of disciplinary core ideas, crosscutting concepts, and science and engineering practices. The overarching goals of this approach are to: (1) prepare students in engineering design as a mechanism for developing technological solutions to everyday problems, and (2) strengthen students' knowledge of science by their applying disciplinary concepts to design solutions [1,2]. The success of these reforms is dependent upon devising ways for teachers to implement the standards with fidelity to strengthen science knowledge through authentic engineering tasks [3]. This often requires support, educational partnerships, and instructional models to inform pedagogical strategies [4].

The American Society for Engineering Education (ASEE) has also proposed a set of core principles stipulating that engineering learning may be considered three dimensional with a focus on engineering habits of mind (e.g., creativity, iteration, collaboration), engineering practices (design, optimization, constraint assessment), and engineering knowledge (principles, problem solving, and technological outputs) [5]. This approach diverges from the way STEM has typically been taught in U.S. middle schools, where science and engineering principles are rarely anchored in relevant phenomena [6]. Since teachers often assume the main responsibility for implementing engineering tasks in their classrooms to comply with the widespread focus on STEM integration, they may benefit from models of engineering and technology instruction in informal contexts that translate abstract constructs while considering students' cognitive challenges and prior knowledge [7]. There has been a well-documented need for research that examines developmentally appropriate engineering knowledge and practices that integrate STEM concepts and align with NGSS and ASEE standards [5,8,9]. The National Research Council (NRC) has suggested that STEM integration may connect concepts and representations that may not have been well learned independently, however, this approach may place heavy demands on cognitive processes such as working memory and transfer [9]. The present study examined how NGSS and ASEE standards may be implemented in an out-of-school outreach program in engineering design for middle school students (ages 11-14), and how instructors viewed the successes, challenges, and tensions of their students' laboratory experiences.

A challenge associated with NGSS and ASEE implementation is the meaningful integration of science and engineering knowledge and skills in precollege teaching and learning. Research has identified issues that science teachers encounter with integrated STEM instruction, including lack of relevant content knowledge, lack of administrative support, and weak self-efficacy in engineering pedagogy [4,10,11]. Research in STEM integration education has suggested that innovative instructional models and curricular resources are needed to demonstrate how science and engineering practices may be taught effectively [12]. Informal STEM education may serve as a model for traditional classroom structures since instructors in informal settings have pioneered ways in which engineering design might be adapted for formal science teaching. These include interventions designed and taught by university engineering faculty to promote interest in engineering among middle and high school students [13-18]. However, just as classroom teachers may struggle with implementing STEM integration [19-20], university engineering faculty and instructors also encounter challenges in their instructional innovations that require revised approaches [21]. The present study examines the nature of instructional decision making in response to students' cognitive load when engaging in middle school engineering tasks. This work will shed light upon the dynamic development of engineering curriculum and pedagogical strategies in response to students' experiences and challenges.

Background

The present study examined instructional decision making in a summer informal program that integrated physical science principles and electrical engineering skills and design. It is important to understand potential challenges that have been identified in the research that relate to engineering knowledge acquisition, the potential for modeling STEM integration in informal setting, and how an understanding of cognitive processes may influence how instructors respond to students' learning difficulties with engineering tasks. The background for the present study includes a critique of research on the nature of engineering learning and transfer among disciplinary domains, informal engineering teaching and learning, and a framework for connecting cognitive load, transfer, and instructional responsiveness.

Nature of engineering learning and transfer

The engineering principles and practices outlined by ASEE and the NGSS reflect the evolving understanding of the foundational roles of science and technology in designing solutions for everyday challenges. However, this represents a paradigm shift in the way science has traditionally been taught [1,2]. Rather than learning about STEM ideas in isolated contexts, an integrated approach may support conceptual understanding and how to transfer ideas from one disciplinary domain to another [9]. The implementation of STEM integration requires knowledge of science and engineering epistemology. Science epistemology may include beliefs about analyzing experimental data, identifying causal relationships, and formulating explanations based on observations [46,47], while the epistemology of engineering involves beliefs regarding the nature, structure, and justification of engineering knowledge, and how these beliefs influence thinking and reasoning [22]. Engineering knowledge has been considered multidimensional, in that students apply their scientific knowledge with systems thinking to design practical solutions with social and/or economic value [23]. This construct often contrasts with less sophisticated views of the nature of science, where students often believe science involves learning facts through notetaking and performing experiments with known outcomes [24].

Informal engineering teaching and learning

Since few STEM teacher education programs prepare educators in multiple disciplines [9], STEM integration is a particular challenge that may be informed by promising models in informal contexts. Previous research has highlighted the promise of informal engineering outreach programs in promoting awareness and interest in engineering among secondary students [13-15,25]. Informal STEM education is characterized by students pursuing contextually relevant activities of their own choosing; in doing so, students may develop positive STEM attitudes that facilitate a lifelong commitment to STEM learning [26]. The present intervention included informal designed experiences in which middle school students applied physical science principles to create electrical devices to solve everyday problems. In understanding the challenges that students may face in STEM integration, it is necessary to examine cognitive processes in more detail, along with how instructors may respond to these challenges.

Conceptual framework: cognitive load, transfer, and instructional responsiveness

The conceptual framework for this research is based upon theories of cognitive load, transfer, and instructional responsiveness (Figure 1). Cognitive load is an important consideration in STEM integration since instructors need to have an awareness of students' disciplinary knowledge in science domains and how this may be challenged and stressed with increasing mental demands [9]. Instructors are called upon to facilitate knowledge and self-efficacy through their own disciplinary mastery and pedagogical content knowledge, with attention towards the counterintuitive, abstract nature of engineering design and cognitive load reduction [27]. Middle school learners' prior science knowledge often influences the extent of intrinsic and extraneous cognitive load with regard to schematics and other visual displays [7]. Consequently, instructors must think about strategies to diminish cognitive load when introducing new concepts or the connections among them. Verbal instruction and social interaction have been shown to reduce cognitive load in science inquiry [28,29]. Cognitive dissonance may occur when students' prior knowledge conflicts with scientific knowledge, which necessitates instructional strategies and activities to strengthen and refine students' conceptual understandings [30].

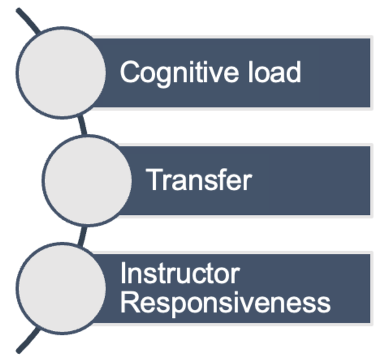

Figure 1. *Conceptual Framework.*

A related principle to cognitive load is transfer. This is a particular challenge in K-12 education since STEM teaching and learning often involves didactic practices, memorization, and limited understanding of combined linguistic and spatial representations [9,48]. Integrated STEM experiences typically require students to apply knowledge and skills from one discipline to another. Such transfer competence is required in engineering – although science is often considered context-free and objectively generalizable, engineering tasks are often dependent on contextual constraints and require transfer of skills among domains [3,31]. Instructional responsiveness is required when faced with the challenges of reducing cognitive load and facilitating transfer capabilities with middle school students. The engineering design process is an essential component of integrated STEM and typically involves authentic challenges that require modeling, evaluating, and optimizing functionality [32]. Engineering instructors often encounter pedagogical challenges when implementing design tasks [21], consequently, facilitating instructional responsiveness to cognitive dissonance is essential for maximizing student learning [33]. The present study analyzed instructors' views of sources of cognitive dissonance, cognitive load, and their instructional changes in an informal engineering program for middle school students. These findings may help all middle school educators, both in informal and formal settings, as they devise reformed instructional practices in STEM integration.

Research questions

The present study examined instructional decision making in an informal science and engineering camp for middle school students (grades 6-8, ages 11-14), in an effort to understand how this decision making occurred with consideration to cognitive load and transfer. This summer program, developed and taught by university faculty, graduate students, and undergraduate students in electrical and computer engineering, physics, and science education, was designed to facilitate middle school students' engineering knowledge, design skills, interest, and motivation for learning electrical engineering applications in the context of physical science concepts. The overarching research questions guiding the study were the following:

1. What challenges did middle school engineering instructors encounter in relation to students' cognitive load, interest, and motivation?
2. How did middle school engineering instructors modify their instruction to mediate the cognitive and affective challenges of their students in an informal science and engineering out-of-school program?
3. What factors influenced the pedagogical decision making of middle school engineering instructors?

Methods

The qualitative research methods were designed to elicit the views of the university instructors in a summer outreach program concerning potential challenges and their pedagogical responses as they sought to optimize middle school students' learning. The following sections outline the research design, context, programmatic structure, data collection, and analysis. The iterative coding process identified major thematic elements based on the frequency of responses and the triangulation of these responses with direct observations of class activities and student artifacts.

Research design

The present study employed an exploratory cross-case design in analyzing the experiences of five university instructors in an informal middle school engineering summer program. An exploratory case study examines experiential phenomena where the outcomes are multifaceted and subjective [34,35]. Qualitative data (pre-/post-interviews, classroom observations) were collected and analyzed utilizing an emergent, iterative design and inductive approach to discern patterns in teachers' responses [36]. By linking data to theory as a conceptual basis for analysis, the researchers identified relevant constructs to inform university educators in an outreach program (and indirectly, middle school educators) on challenges and solutions in teaching integrated STEM content and skills.

Context

The context for this study was a middle school outreach program at a research university in the Northeast U.S. The engineering summer camp was part of a comprehensive NSF-funded initiative to attract middle and high school students to engineering, develop and implement informative workshops for teachers and counselors, and provide early interventions for engineering students traditionally underrepresented in the field. The engineering camps were full-day, one-week long summer programs that introduced middle school students to engineering knowledge and design concepts in the context of physical science principles. The activities focused on electrical and computer engineering and computer science, combining explanations of theoretical concepts with hands-on activities. The camp occurred twice in the summer of 2019, enrolling a total of 40 students (20 each week).

The camp instructional activities included four major projects; in each case, students built a physical device they could take home. The activities emphasized disciplinary core ideas in the physical sciences and core components of engineering design [37], incorporating a conceptual progression and increased in complexity chronologically. All activities were aligned with disciplinary standards and skills articulated in NGSS [1] and ASEE [5] (Figure 2), including engineering habits of mind (creativity, iterative design, collaboration), engineering practices (design, optimization, conforming to constraints), and engineering knowledge (problem solving, technical outputs). These activities are described below:

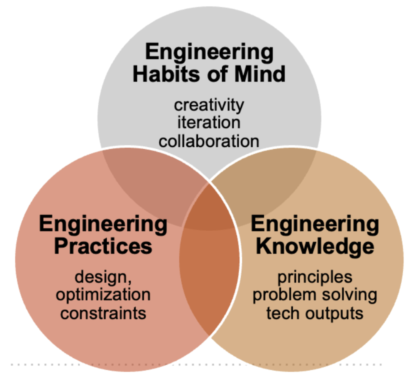

Figure 2. *Standards Alignment.*

1. **3D printing spiral graph**. Students programmed a design for a spiral graph device, a well-known tool for creating geometrical images. They were introduced to the Autodesk Tinkercad, a web browser software for 3D design and engineering, to design the 3D spiral graph model using concepts taught in mathematics. The designs were printed with a 3-D printer and used by the students for mathematical and artistic purposes.

2. **Night light**. Students built a night light for vision in darkened settings. The design consisted of two basic components and a breadboard – light emitting diodes (LEDs) and resistors. The conceptual focus was on electronic concepts related to voltage, current, and resistance, and theoretical concepts related to Ohm's law, voltage dividers (splitting voltage across various components in the circuit), and energy flow and transfer [38]. These disciplinary concepts were also the basis for the home security system and traffic light.

3. **Home security system**. This activity scaffolded skills learned previously and introduced soldering to construct a home security system. The design included two simple main electrical components: a photo transistor and a buzzer soldered to a prefabricated circuit board [39]. Students were introduced to each component and learned its function within the subsystem of the device. Related concepts included conductors and insulators, basic electronics, and soldering. They designed, built, and refined the engineered product given a set of constraints.

4. **Traffic light**. Students wrote a functional code of a traffic light and prototyped the light circuit hardware before building the device. [40]. This activity utilized hardware and software components and introduced students to the engineering design cycle including design, simulation, prototyping, and production. The initial focus was on the simulation phase of the cycle where participants were given hands-on experience using TinkerCAD Circuit, a circuit simulation software. Later, they scaffolded newly learned concepts and constructed a smart streetlight using sensors and integrated circuits. To add functionality to the design, participants learned basic programming to write a simple code to make an LED blink.

Data collection

Data collection included ten interviews with teacher participants, six classroom observations, and the review of student artifacts produced in the camp. The instructors included one faculty member from electrical and computer engineering, three graduate students, and one undergraduate student. Instructors were interviewed to provide retrospective insights once after the first week of camp and once after the second week of camp (two interviews, 45 minutes each, for a total of ten interviews). In addition, the researchers observed six instructional sessions (two to four hours in duration) during the camps to record field notes that informed interview questions and identified relevant thematic elements; these observations also provided triangulation for interpreting the interviews. In this way, the researchers could analyze the instructors' challenges and instructional decision making as they formatively processed their pedagogical effectiveness. Student artifacts were observed during the classroom observations to understand the curricular fidelity of the planned activities [38-40]. This study was approved by Stony Brook University's Institutional Review Board (#574341), and voluntary consent was provided by study participants.

Data analysis

The interviews were recorded and transcribed, and the researchers used their field notes to compare the instructors' narratives with what was directly observed in the classroom, both in terms of their pedagogy and the artifacts produced by the students. Data were analyzed through an observational phenomenological approach, with a priori provisional coding of the interview transcripts with elements of grounded theory to collect and categorize interview data to formulate an emerging explanatory framework [41]. Rather than quantifying data through a traditional deductive approach, grounded theory is an inductive approach to data analysis that generates hypotheses from qualitative information [42]; the observations and analysis of student artifacts allowed the researchers to build these hypotheses by comparing their notes with the teachers' self-reported experiences.

Four different stages of coding were used to group data: open, axial, selective, and theoretical. Open coding organized the responses into categories by common themes [43]; these initial, open codes were comparative and tentative yet situated within existing research. Axial coding reorganized the open codes in more concentrated categories. Descriptive codes were systematically categorized, and emerging links identified [44]. Selective coding configured constructs into connecting strands aligned with the conceptual framework [45]. Finally, theoretical coding specified relationships, integrated participants' perspectives on common experiences, and allowed construction of a linear narrative to provide thematic insights on STEM integrated instruction. The coding also focused on how the instructors may have shifted their instruction between the first and second weeks of the summer camps, which was clarified by comparing responses in the two sets on interviews. After independent coding, discussions between the two researchers resulted in convergent interpretations.

Findings

Several themes emerged in the qualitative analysis (Figure 3). These themes are organized into three major categories: (1) cognitive challenges related to the abstraction and transfer of engineering concepts and skills; (2) collaborative learning and autonomy; and (3) timing issues with differential rates of task completion.

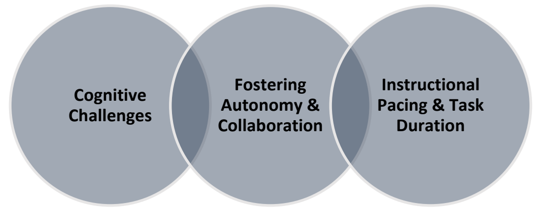

Figure 3. *Emerging Themes*.

Cognitive challenges

The first theme related to conceptual abstraction and cognitive load, with middle school students experiencing difficulty with various engineering tasks. Several instructors noted that many students had significant problems understanding how the components in a system contributed to functionality, especially with later tasks; this also related to difficulties with component placement and directionality. The first activity that involved physical, non-programmed construction was the night light, which students tended to enjoy and build successfully. As one instructor stated:

> *It was probably maybe the simplest electronics one, like circuit-wise. There were fewer components. And at the end, you ended up with something that was really, that you could really use, I guess. They could plug it into the computer at home and have it as a nightlight. And you could paint it. So that was cool.*

Students were generally able to comprehend invisible aspects of the breadboard, in terms of "…the rails on the side are connected together vertically and then the other side is horizontal," even though they could not see these physical connections directly. However, when it came to the home security system and traffic light, which required more complex design elements, instructors encountered some pedagogical difficulties. As one instructor shared, students tended to enjoy and master soldering techniques with time:

> *I guess when we started soldering, they like were a little bit reserved and scared and they wanted me to supervise more. Once they got the hang of it, they definitely engaged a lot more. Once it was more hands-on, they engaged more.*

Although students were engaged with the process of soldering and largely were successful in developing this laboratory skill, the placement of components was a consistent problem. Students had difficulty transferring the schematic visuals to the physical construction; this required understanding a mapped visual to the degree required to reproduce its arrangement in a somewhat complex physical system of circuit elements. One instructor discussed ideas regarding improving this aspect of instruction:

> *I think we could make an improvement in that regard. From plugging the components in the breadboard to the nightlight, we could have emphasized it similar to the connections*

to the schematic. And then when we did the memory element of the home security, they could have been given the latitude to do that themselves.

This instructor intended to make improvements during the second week of the camp by reinforcing the use of a circuit schematic as a model for understanding the physical aspects of component placement. Also, they believed students could have been given more autonomy in figuring out where to place the memory element, which may have helped develop their abilities to identify mistakes in the circuit construction. In doing so, as another instructor pointed out, students could become more proficient in troubleshooting their designs and optimizing their functionality from a systems approach:

> *When it comes to troubleshooting, you have to really understand the entire systems. What does what and what other components affect that certain component that's being troubled. So, like the LED is out, you have to figure out what's connected to it. Is there a microcontroller? Is there a switch? And then once you've identified that area, you have to go through each of those components and test them.*

This instructor recognized that simply pointing out the connection of a singular element would diminish students' understanding of the overall system. They shared his strategy with other, less experienced instructors so they would embrace a more holistic approach in helping students translate the schematic representation to breadboard construction.

An additional consideration in making abstract concepts real to students is presenting each task as a technological solution to an everyday problem. The instructors felt they could improve their introductions to hands-on exercises by emphasizing the practicality of their devices. As one instructor stated:

> *I think if we have any weakness, we don't introduce a problem and then define how we are going to – make the lecture very confined to that problem and then do the solution and then talk about it afterwards. That would be a really good way of doing it. I think we've switched to something more like general-purpose lectures, it's not actually totally tackling the problem.*

This instructor noted that the lectures introducing the tasks were somewhat limited in focus, that is, they did not connect the product to the solution of a technological challenge. During the following week of the camp, this instructor planned for group discussions after task completion to reflect upon the purpose of the activity and how it relates to everyday life as well as scientific advancement.

Fostering autonomy and collaboration

The second theme in the qualitative analysis was individual vs. collaborative learning. The instructors generally felt that students learned more and were more efficient when working in collaborative groups. This somewhat contradicted their initial teaching experiences in the program, where students first tended to work alone in programming designs and creating prototypes. With time, students were more likely to work collaboratively. As one instructor stated, “and there was also something between friends, so they worked better with their lab partner sharing the computer and all that…,” meaning that as students became more comfortable with each other, they shared work and socially constructed knowledge. This seemed to lead to a more efficient working environment:

> *But after a while a lot of the girls got to know one another, it got a little bit more energetic, but the difference that I felt is discipline. That's one definitely. Two, retaining of – I don't know if it's retaining of the information or they're actually paying more attention.*

Students who worked in teams not only completed tasks in a more timely manner, but it was observed by the researchers they also understood more concepts and retained that knowledge for subsequent engineering tasks. This was evident in students’ discussions and the time it took for them to complete the goals associated with each engineering challenge.

Another tension that instructors encountered was their desire to facilitate socially constructed knowledge while encouraging independent thinking. This was rooted in the nature of some activities, which relied upon jointly created designs. One instructor commented that the 3-D printing activity only allowed for one design per team to be printed:

> *I would rather have such a project where every student has their own computer so they can utilize more of the design time and what not… It would have been maybe kind of more creative to have each student have their own design rather than have one design for each print.*

This challenge was difficult to solve since the students were tightly scheduled to complete several complex designs during the one week-long camp. Some instructors focused their efforts on encouraging active participation among each participant in the groups, which would promote agency and ownership of the final design. One instructor noted that the activities became more streamlined towards the end of the weeklong program, which often resulted in students collaboratively creating more advanced designs:

> *We did like the first test program which was just like light up one LED and it’s just like one line of code. Like light LEDs and then string the binary. Once everyone saw that and how that corresponded to what’s happening on the boards, I think everyone really pretty much got it. A bunch of people just immediately went with their own program to do, like I had a group of girls who did a spiral which looked really good.*

These experiences helped the instructors understand the value of balancing group work and autonomy, which motivated their students to persist with more complex designs after completing baseline tasks.

Instructional pacing and task duration

Finally, the third theme related to timing issues. The instructors struggled with different students completing tasks sooner or later than others, which could lead to frustration for all.

Consequently, between the first and second weeks of the camp program, which involved different groups of students, the instructors discussed ways in which their pedagogical timing could be improved to meet the needs of all students. This was in response to their own feelings that this aspect of the experience needed improvement. Instructors realized they had to have options prepared for students who finished their work before the others to provide opportunities for advancement, for example, one observed:

> *Some students took it to the next level. They started building their own stuff and started creating their own color patches and being proud of it. One of the students programmed his own traffic light before we actually gave them the code… being able to change that on his own was really great.*

Once instructors realized the variations in completion times, they generated additional suggestions for students to complete more complex design elements. As one stated:

> *… If the students finish a little bit earlier, but the age difference, they are able to finish faster, that's good for them to have something to keep them busy.*

One instructor was amazed how well students could advance when given opportunity to further adjust the functionality of their devices:

> *I had another student that wanted – so that the nightlight they have, there are 16 LEDs. Eight of them are green, four of them are yellow and four of them are red. So one student wanted to do it as an explosion like to make it go green, red, yellow. And they started actually numbering the LEDs in order to be able to write a code. And they did it.*

This experience allowed the instructor to understand the value of scaffolding tasks to increase independence and autonomous achievement. Overall, it was important for instructors to come to the realization that students differed in prior knowledge, spatial skills, speed of knowledge acquisition, and motor skills. These differences required pedagogical flexibility and additional planning to provide fast-moving students with opportunities for modifying device functionality. This also served to promote autonomy, agency, and engagement.

Discussion

Understanding how engineering instructors identified and responded to students' cognitive and affective challenges may inform instructional decision making and curriculum planning for both informal science educators and middle school science teachers. The instructors reported student issues with cognitive load, particularly when asked to transfer knowledge from a visual model (circuit schematic) to a device they were designing or building with their hands. This challenge required instructors to alter their pedagogical strategies, for example, by emphasizing the authentic value of their device, which was self-reported and observed by the researchers, or by repeating instructions with small groups after the main lecture, which was also directly observed. In both cases, their decisions reflected an understanding of student challenges and a willingness to alter their techniques to maximize learning. This involved consideration of the abstract nature of engineering learning, which may be met with cognitive load reduction to lessen cognitive dissonance so students might transfer skills and knowledge from one domain to another [3,27,31].

Implications

This study is relevant to STEM educators for several reasons. STEM integration requires content mastery, pedagogical content knowledge, and attention towards transfer, particularly in the teaching of engineering design to reduce cognitive load. Scientific concepts such as energy transfer may not be easily recognized in a circuit design when students cannot understand the function of individual components. Middle school learners may require verbal instruction and social interaction to minimize cognitive load when engaged with science and engineering applications. By examining middle school strategies in informal learning contexts, classroom teachers may more easily identify student difficulties and plan engaging, challenging, and cognitively rewarding lessons.

Limitations

The present study has several limitations, both contextual and methodological. The sample size of students and instructors was relatively small, which may limit generalizability. Although teachers were interviewed before and after the program, interviews with students would allow for more nuanced understandings of programmatic impacts. Also, future research may measure students' cognitive and affective outcomes on a larger scale quantitatively, which would provide more evidence for pedagogical effectiveness.

Conclusions

This research has identified informal engineering instructors' perceptions of pedagogical challenges and cognitive load. The reflective educators profiled in this study revealed their instructional decision making, which provided insights into ways in which informal STEM programs may maximize student outcomes. The instructors recognized how the engineering tasks sometimes challenged cognitive load and the ability of students to transfer science knowledge and engineering design practices across various tasks. In doing so, they enacted strategies to foster autonomy, facilitate collaborative problem solving, and provide opportunities to meet the needs of diverse learners. These strategies may be useful considerations for middle school teachers who integrate STEM in formal science classrooms.

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