How do we design curricula to foster innovation, motivation, and interest in STEM learning?

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Abstract

Purpose We designed a science and engineering curricular program that includes design features that promote student interest and motivation and examined teacher and students' views on meaningfulness, motivation, and interest.

Design/methodology/approach The research approach consisted of mixed methods including content analyses and descriptive statistics.

Findings The curricular program successfully included all four of the US National Academies of Sciences' design features for promoting interest and motivation through scientific investigation and engineering design. During interviews, teachers and students expressed evidence of design features associated with interest and motivation. After experiencing the program, more than 60% of all students scored high on all four science and engineering meaningfulness and interest survey items.

Originality A curricular program that extends science learning through the engineered design of solutions is an innovative approach to foster both conceptual knowledge development and interest and motivation in science and engineering.

Keywords Engineering design, Science education, Scientific investigation, 21st century skills

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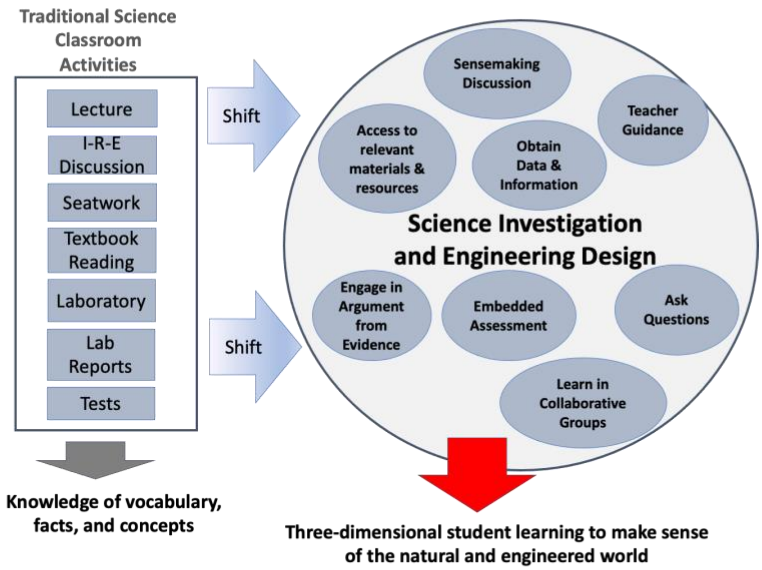
Education aims to create competent and contributing citizens out of every learner. In the United States, the National Academies of Science, Engineering, and Medicine (NASEM, 2021) is pushing for a greater emphasis on prioritizing science to contribute to the general economy and democratic status. However, research shows students begin losing interest in core subjects such as math and science as early as middle school (George, 2006). Due to ever-changing societal and global needs, business leaders have cited problem-solving, collaboration, communication, and creativity as essential skills needed within their fields (Fiore et al., 2017). This compounded need for increased student interest as well as socially-adapted content brings attention to the growing need for curricular changes.

Many existing Science, Technology, Engineering, and Mathematics (STEM) curriculum programs for pre-college students place an emphasis on textbook-driven learning, formulaic laboratory exercises, or lectures (NASEM, 2019). Research studies suggest that these learning approaches lead to knowledge of vocabulary, facts, or concepts, but not to student learning emphasizing problem-solving and making sense of the natural and engineered world (Figure 1). If our goal is to meet the needs laid out by business leaders of fostering problem-solving, collaboration, communication and creativity, we need innovative curricular programs specifically designed to foster problem-solving, collaboration, communication and creativity in ways that are relevant to student's lives, not only during their school years but long after. In other words, curricular programs must be restructured so that student learning shifts from passive learning of facts to active learning emphasizing problem solving and engineering design.

Figure 1

Shifts needed in science curricular programs (From NRC, 2019; p.83)



Conceptual Framework

Science investigation and engineering design at the center

Recent policy documents in the United States suggest that all STEM learning should be focused on science investigation and engineering design (NASEM, 2019), even in the elementary years. In this approach, the science and engineering knowledge is three-dimensional, with each performance expectation consisting of a disciplinary core idea, a cross-cutting concept, and a science or engineering practice (see Table 1).

Table 1

Example Next Generation Science Standard (see https://www.nextgenscience.org/)

HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**LS2.C: Ecosystem Dynamics, Functioning, and Resilience** ● Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.	**Stability and Change** ● Much of science deals with constructing explanations of how things change and how they remain stable.

More specifically, the National Academies of Science, Engineering and Medicine (NASEM, 2019; 2021) suggest scientific investigation and engineering design as a way to connect STEM content to students' own personal experiences. Incorporating engineering design in learning enables students to work on twenty-first century skills, such as collaboration, critical thinking, and creativity (Hite et al., 2020). Furthermore, research studies document that STEM learning through science investigation and engineering design is more effective than traditional teaching methods because the activities engage students in doing science and engineering, increase their conceptual knowledge of science and engineering, and improve their reasoning and problem-solving skills (NASEM, 2019).

Motivation is a significant factor in students' learning achievement in many fields (Lazowski & Hulleman, 2016), including scientific investigation and engineering design (NASEM, 2019). Motivation in science drives the ability to use science in critical decision-making processes (Shumow & Schmidt, 2013). To foster learning through scientific investigation and engineering design, educators must consider how to motivate students' performance. For example, allowing students to participate in collaborative, hands-on STEM activities can improve their perceptions of STEM fields (Vela et al., 2020). Participating in engaging science activities allows students to develop a sense of identity as a member of the scientific community, thus driving interest to pursue other experiences, or even careers, in science (NRC, 2012). Another suggestion for increasing motivation is to make content more relevant by connecting it to material outside of class or using materials that are regularly available to them (Shumow & Schmidt, 2013). Students need to see how science and engineering are part of the solution to real-world problems (NRC, 2012), such as what we experienced during the COVID-19 pandemic or through evolving environmental crises.

A recent policy document from NASEM (2019) suggests four curriculum design features to promote interest and motivation in the classroom. These are:

(1) providing choice or autonomy in learning

(2) promoting personal relevance

(3) presenting appropriately challenging material, and

(4) situating the investigations in socially and culturally appropriate contexts (p. 67). In the following sections, we unpack each design feature.

Providing Choice or Autonomy

Research studies have demonstrated a number of positive outcomes associated with providing choice or autonomy and letting students make decisions about the direction of their learning. These positive outcomes include increased intrinsic motivation (Calabrese & Capraro, 2021), interest in content (Nieswandt & Horowitz, 2015), and improved test performance (Vansteenkiste et al., 2004). Arguing for increased student autonomy in education, Kenny (1993) states that this feature allows students to become knowledge producers rather than knowledge consumers. Autonomy, therefore, contributes to the development of future competent and contributing citizens as it gives students the freedom to question assumptions and take actions both independently and within communities.

There is some evidence, however, that providing abundant or arbitrary choices may not be beneficial. Without appropriate context and limits, choice provides no or even negative outcomes (D'Ailly, 2004). Therefore, instructors must deliberately design choices that support learning. Some of the factors that increase the utility of providing choice include supporting students' goals and interests, (discussed more in the following section), affording suitable complexity and number of choices, listening to students' perspectives, authenticity, helping students gain a sense of control, and giving rationale for choices (Assor, 2012; Huang & Benson, 2013; Katz & Assessor, 2007; Patall & Zambrano, 2019).

Promoting Personal Relevance

Understanding students' interest or lack thereof should inform what choices curriculum designers and instructors provide students. Kapon et al. (2018) acknowledges that structuring lessons that honor both disciplinary authenticity and students' interests is challenging. Students may not, after all, have an inherent desire to learn basic science concepts such as the differences between a particle and a wave or what features define a symbiotic relationship between organisms. Taking the necessary time to promote students' interest in, experience with, and investment in STEM topics often results in better educational outcomes than delivering facts and assigning exercises without providing that additional context (Yager, 1989).

Curriculum components that assist students in developing a personal desire to engage with and learn STEM ideas include connecting concepts to practical situations, art and media, and local or global issues (Hadzigeorgiou, 2005). It's often easier to engender personal relevance if topics are connected to things students care about *now* rather than recounting how learning STEM will be valuable in their future. Furthermore, interest in content can be situational according to students' determination of relevance (Nieswandt & Horowitz, 2015). For instance, topics such as the COVID-19 pandemic can be used to model real-world STEM concepts within a classroom setting (Sezer & Namukasa, 2021). Science curricula that situated learning within a real-world context are found to increase students' interest in science, their sense of agency surrounding scientific topics, and their scientific literacy (Ke et al., 2021; Kubsch et al., 2023; Redmond et al., 2011).

Presenting Appropriately Challenging Material

The degree of challenge of given content has the potential to increase student interest (Nieswandt & Horowitz, 2015; Renninger & Su, 2012). Science is often considered a difficult subject, though many students also report this as an attractive quality (Archer et al., 2010). Far from disliking challenges, most students are more willing to engage seriously with material that they feel is difficult or complex enough to be interesting, while remaining within their ability to understand and problem solve successfully (Sullivan et al., 2014).

While students may favor a challenge, support and scaffolding from the teacher is essential (Nieswandt and Horowitz, 2015). Perhaps the most well-known representation of this principle is Vygotsky's (1978) zone of proximal development; that is, student learning and motivation are optimal when tasks are just beyond their ability to achieve independently (Sivan, 1986). Instructor demonstration, peer collaboration, proposing and eliminating unproductive solutions, and practice-community emulation are just some of the tools available to instructors to help students move from "cannot" to "can" (Tudge, 1992). When selecting from among these tools, instructors must consider what knowledge and skills students have, what the learning objectives are, and what constitutes an appropriate challenge, keeping in mind that "appropriately challenging" constantly changes as students gain mastery.

Situating the Investigations Socially and Culturally

Situating investigations in socially and culturally appropriate contexts helps develop interest and facilitate retention of learned content. Students seek a sense of belongingness, which naturally fosters a link between social and cultural influence on educational perspective (Bergin, 2016). Similarly, as standards and values change by community, so do interest and participation (Azevedo, 2013). Therefore, connecting the curriculum with aspects of students' personal experiences can increase engagement and motivation (NASEM, 2019).

Including diverse contexts and customs into science learning can be beneficial to both students and the science itself (NRC, 2012). Situating STEM content through an emphasis on scientific phenomena and personal experience has a greater potential to sustain a wider range of students' interest in science (Tan et al., 2013). Additionally, students that participate in collaborative learning rooted in culturally-relevant pedagogy achieve higher science test scores. Numerous research studies indicate that students increased their science learning and social and emotional learning while participating in project-based learning environments in their science classrooms (e.g., Krajcik et al., 2022). Thus, providing students with an environment that aligns with their social and cultural backgrounds encourages them to be actively engaged with the learning materials.

A curricular approach that centers on scientific investigation and engineering design

Drawing from established curricular approaches, we have created and evaluated a curricular approach that centers on both scientific investigation and engineering design. This approach accentuates the marriage that often exists between scientific investigation and engineering design in practical settings (Songer & Ibarrola Recalde, 2021). For example, in practical settings, engineers do not isolate their knowledge of engineering and science, but rather rely on their understanding of both to address real-world problems (NRC, 2012).

We call our curricular approach solutioning because the approach guides students to ask questions, gather data and analyze data and then apply the science they have learned to the engineered design of a solution to a local environmental problem. The skeletal framework of our curricular approach comes from Bybee's (2006) 5E learning cycle which consists of five phases of activities: Engage, Explore, Explain, Elaborate, and Evaluate (Bybee, 2006). In the Solutioning curricular approach, the first three phases are similar to Bybee's (2006) and are similarly titled: Engage, Explore, and Explain (see Table 2). However, the last two phases in our approach are different to emphasize extending the science learning through an engineered design of a solution (Engineer) and the sharing of that solution with others (Educate) (Songer et al., 2023).

Table 2

The Five Phases of the Solutioning Curricular Approach

Phase	Description
Engage	Students **ask questions** associated with an introductory activity that engages their curiosity and provides a purpose for studying local environmental issues.

Explore	Students **collect data** to **use as evidence** to understand a local issue.
Explain	Students **use evidence** from the Explore phase to **construct arguments** to address their scientific questions.
Engineer	Students extend their understanding through the **design of a trap and a plan** that meets specific design criteria and constraints. Students **test** their solutions through feedback and data collection to determine if their solution is optimal for addressing the problem.
Educate	Students synthesize key ideas from their designs to inform and **educate** local stakeholders about possible implementation in their area.

Independently, the 5Es learning approach and the idea of teaching either through science investigation or engineering design is not particularly innovative. On balance, the design and manifestation of a modification of a well-established learning approach that builds on and deepens science investigation through engineering design is an innovation worthy of study. In particular, solutioning sets itself apart in three ways: A focus on a local phenomena, learning activities based on the practices of both science and engineering, and a solution design process that includes a presentation for local stakeholders (Songer & Ibarrola Recalde, 2021). Like the design process used by engineers that builds from investigation and data analysis towards solution generation and evaluation (NRC, 2012), solutioning offers a unique way to integrate scientific investigation and engineering design to solve local problems, thereby modeling the practices of professional engineers and scientists.

Prior research has demonstrated that connecting scientific investigation with engineering design leads to student improvements in using evidence to construct a scientific argument (Songer et al., 2023). However, less is known about teacher and students' interest and motivation associated with a curricular approach that combines science investigation and engineering design to solve local issues. In this study, we aim to answer the following research questions:

RQ1: What science investigation and engineering design features are present in a solutioning curriculum program?

RQ2: When implementing a curricular program with science investigation and engineering design features, what evidence of interest and motivation are present?

Methods

Setting and Participants

The present study took place in two middle school classrooms in the western United States. Group A is a set of five sixth-grade classrooms (n_A = 108) with the same teacher located within a suburban school district. Group B (n_B = 10) is a single eighth-grade classroom in a charter school located in an urban area. The ages of the participants range from approximately 11-14 years.

According to 2022-2023 enrollment data (Board of Education, 2022), the school in which Group A is embedded has approximately 1,039 students enrolled in grades 6 and 7. The demographics of this district are listed as 81% White, 14% Hispanic, 3% Multiple Race, and less than 1% each for American Indian, African American/Black, Asian, and Pacific Islander. Additionally, approximately 15% of students in the school have a registered disability, and approximately 5% are English Learners (Board of Education, 2022). Finally, 25% of the students come from economically disadvantaged homes, i.e., are eligible for free or reduced lunch (State Legislature, 2022).

Group B is located in a 7-12th grade school with approximately 117 students enrolled. The demographics of this school are 50% White, 33% Hispanic, 5% Multiple Race, 4% Asian, 3% American Indian, 3% African American/Black, and 1% Pacific Islander. Additionally, approximately 26% of the students in the school have a registered disability, and 16% are English Learnings. Finally, 42% of the students in the school are eligible for free or reduced priced meals (Board of Education, 2022).

In addition to the student participants, the researchers interviewed the teachers of each classroom. Teacher A teaches sixth-grade science and has been a teacher for nine years. Teacher A participated in the pilot curriculum and thus has one year of prior experience with the program. Teacher B teaches eighth-grade science and has been a teacher for seven years. The curriculum implementation in the present study is her first exposure to the curriculum.

Data Collection

To examine the occurrence of the NASEM (2019) design features within the solutioning program, the researchers analyzed the self-created curriculum. It is worth noting that the curriculum was not originally designed with NASEM's (2019) document in mind, rather to meet state curricular requirements. To capture a holistic view of the design elements within the classroom, the researchers collected data in three forms: classroom observations, teacher interviews, and student surveys.

Classroom Observations

Throughout the implementation of the curriculum, the researchers observed student participants. In Group A, the researchers visited all five of the classrooms at different points to observe different students' engagement with the content. The researchers also visited the classroom in Group B at multiple timepoints to observe the students' experiences in different phases of content. During classroom observations, the researchers recorded the content being implemented that day. Additionally, the researchers recorded field notes with description of student progress and any noteworthy quotes from the students or teachers during instruction or small group discussion.

Teacher Interviews

Upon completion of the intervention, the researchers conducted individual interviews with the teachers. The interviews were semi-structured (see Appendix for questions) and lasted approximately 20 minutes. During this time, the teachers were asked to comment on topics such as student motivation, benefits and weaknesses of the curriculum, as well as any other aspects of the implementation that they wished to discuss. The researchers recorded and transcribed the interviews. A second researcher proofread the transcripts to ensure accuracy.

Meaningfulness and Interest Survey

Upon completion of the curriculum, the researchers administered a short survey with the students. The survey consisted of both open-ended and Likert style questions. For the purposes of the present study, only the Likert questions were used. These questions were adopted from Christensen et al.'s (2014) version of the STEM Semantics Survey. Due to the focus of the curriculum, the researchers elected to focus on the science and engineering aspects of the survey. Additionally, in consideration of instructional time and age of the participants, the researchers limited the Meaningfulness and Interest Likert items to four questions (see Figure 2), as younger students respond better to shorter surveys (Jones, 2018).

Figure 2

Meaningfulness and Interest Questions

1. To me, SCIENCE	Means nothing	O 1	O 2	O 3	O 4	O 5	Means a lot
2. To me, SCIENCE is	Boring	O 1	O 2	O 3	O 4	O 5	Interesting
3. To me, ENGINEERING	Means nothing	O 1	O 2	O 3	O 4	O 5	Means a lot
4. To me, ENGINEERING is	Boring	O 1	O 2	O 3	O 4	O 5	Interesting

Data Analyses

The present study utilizes a mixed methodology with convergent parallel design (Creswell & Plano Clark, 2007). The researchers prioritized the qualitative data from the classroom observation notes and interviews. However, analysis did not occur until all data was collected.

Analysis of Curriculum, Transcripts, and Observation Notes

In order to examine which design features are present in the solutioning curricular program, the researchers completed a content analysis of the curriculum. Using descriptions provided by NASEM (2019), the researchers examined each lesson to determine whether it included or emphasized any of the design features. In this context, a lesson was considered to have included a design feature if the feature was present but not a focal point. A lesson emphasized a design feature if all tasks in the lesson required the use of that feature. For example, in Lessons 2 and 4, students conducted observations outdoors and recorded notes. Lesson 2 *includes* autonomy in that there are many choices in where and what they observed but limited to what was recorded; however, Lesson 4 *does not include* autonomy as the observation location is assigned by the teacher. Finally, in Lesson 14 students designed their traps for capturing their invasive insect. Lesson 14 *emphasizes* autonomy in that the students had total freedom in how they designed the trap and were only limited by the provided materials, which still included several options. The researchers completed this analysis individually with 94% agreement. The researchers then discussed discrepancies until they reached 100% agreement.

When analyzing the teacher interview transcripts and observation notes, the researchers followed a similar procedure. First, the researchers individually coded each quote. The researchers included quotes that provided examples both of how the curriculum portrayed the four NASEM (2019) design features as well as any potential areas where these features may have been lacking and thus would have improved the curriculum if added. Additionally, the researchers coded evidence of learning or motivation as described by the teachers or observed during the classroom observations.

Analysis of Meaningfulness and Interest Survey Items

As the curricular program only lasted six weeks, the researchers did not anticipate any notable change in student attitudes toward science and engineering (Mistler-Jackson & Songer, 2000) and thus did not compute a pretest-posttest comparison. To analyze student interest and motivation, the researchers computed descriptive statistics for each category.

Converging Results

The researchers separately examined the qualitative and quantitative data before interpreting the results together. The convergence process consisted of comparing the frequency of inclusion or emphasis of the design features with descriptive statistics from the survey responses. That is, the researchers interpreted students' overall rating of the meaningfulness of science and engineering and their interest in each subject through the lens of how frequently each design feature was presented within the curriculum.

Results

RQ1: Design Features in Solutioning Curriculum

The first research question focuses on which of the National Academies of Science, Engineering and Medicine (NASEM, 2019) design features were present in the solutioning curriculum program. To address this question, we conducted a content analysis of the entire curriculum to find evidence of these design features that promote motivation and interest, i.e., Providing Choice or Autonomy, Promoting Personal Relevance, Presenting Appropriately Challenging Material, and Situating the Investigations Socially and Culturally. The curriculum consists of eighteen different lessons. Of those, ten lessons strongly emphasized at least one of the design features, with six of the lessons strongly emphasizing multiple design features. Furthermore, sixteen lessons included at least one design feature, and six lessons included multiple design features. Table 3 shows the distribution of the inclusion or strongly emphasized design features by lesson.

Table 3

Distribution of Inclusion and Emphasized Design Features

	Unit 1							Unit 2				Unit 3						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Providing Choice or Autonomy		I				I		I					I	E	E	I	E	E
Promoting Personal Relevance	E	E		E	E							I	E	I	I	I	E	I
Presenting Appropriately Challenging Material			I		I				I	I	I		I	I	I	E	I	I
Situating the Investigations Socially and Culturally		I		I									E	E	E	E	E	E

**Note:* E indicates strong emphasis and I indicates inclusion of a design feature within the lesson

Providing Choice or Autonomy

In this program, four lessons could be categorized as strongly emphasizing the Providing Choice or Autonomy design feature, and five more included the design feature. Each of these lessons were part of the third unit, which focused specifically on the engineering design process. In Lesson 14, the students collaborated in groups to design four different trap designs based on their prior research on an invasive insect (see example trap designs in Figure 3).

Figure 3a

Group 1 Trap Designs

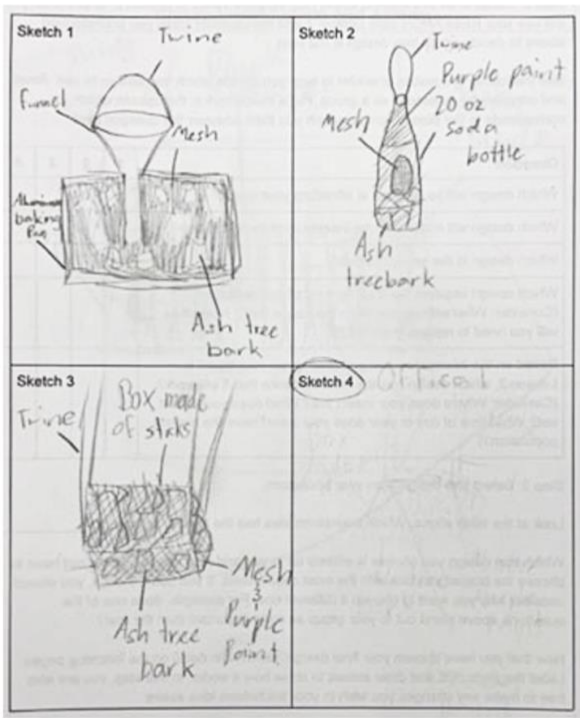
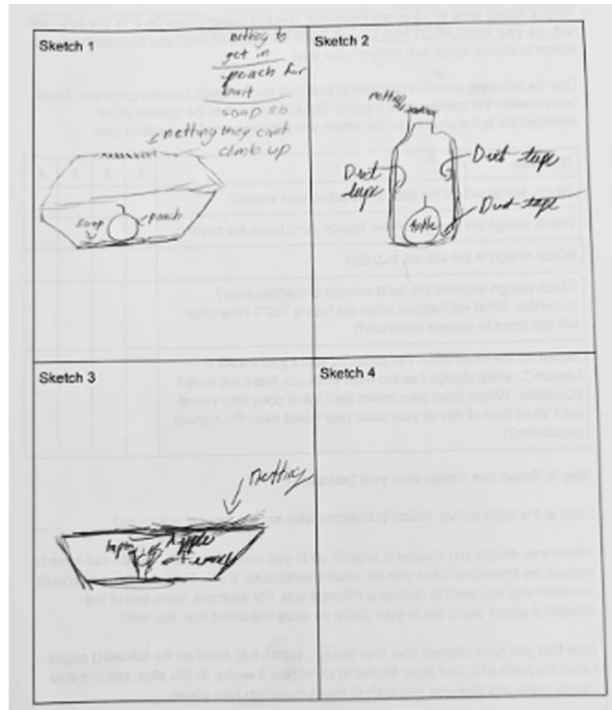


Figure 3b

Group 2 Trap Designs



In Lesson 15, each group chose one of their trap designs to construct. In Lesson 17, students created a list of three or four possible locations for trap placement, including the pros and cons of each location and time of year for placement. They had the ability to look at locations on Google Maps and consider the information they found during their research on their invasive insect. In Lesson 18, students created a presentation with the purpose of educating others on their invasive insect and solution. Students had choices regarding the presentation type (e.g., video, poster, etc.) and audience (e.g., school, group, etc.). Additionally, other than basic requirements for the presentation, students had creative freedom as to the overall design of the presentation.

Promoting Personal Relevance

In regards to Promoting Personal Relevance, the program displayed a strong emphasis in six lessons and inclusion in five lessons. In Lesson 1, the researchers introduce the theme of the curriculum by including a simulated letter from the Department of Agriculture. This letter contains information on some invasive insects in the state and their impact on the environment. In Lessons 2 and 4, the students conduct observations outside of their school building. During this time, the students record notes on the animals they saw, the quantity, the weather conditions, and location of the animal (e.g., tree). In Lesson 5, students compiled observation data from the entire classroom and compared the animal populations in their schoolyard to that of a local body of water. In Lesson 13, the students conduct research on one of the four insects that was introduced in the letter in Lesson 1. Their research includes a physical description of the insect and its lifecycle, habitat, and introduction to the local environment. Finally, in Lesson 17, the students use Google Maps to find a location where they can place their traps. The students record three to four possible locations including a description and justification.

Presenting Appropriately Challenging Material

Although a case could be made for the subjectiveness of the term "appropriately challenging", the researchers agreed one particular lesson strongly emphasized Presenting Appropriately Challenging Material, and 10 lessons included activities that supported appropriate challenges. In Lesson 16, students worked in pairs to present their trap design to each other. Next, the teams complete a peer evaluation complete with constructive feedback for improvement. Finally, each team reviewed the feedback and made plans for improvements.

Situating the Investigations Socially and Culturally

Though situating the learning and promoting personal relevance are noticeably similar, the researchers distinguished socially and culturally situated learning as physical experiences and social elements. Two lessons were situated socially and culturally (Lessons 2 and 4). In both lessons, students worked in groups to observe insects or animals outside their school. Six lessons strongly emphasized the design feature (Lessons 13-18). These are the lessons in which students complete the engineering design process. These lessons contain both a social element in that they are working in groups and a cultural element in that the focus is on a local problem with an everyday solution.

RQ2: Evidence of Motivation and Interest

In this study, we analyzed interview and observation data to answer the question, When implementing a curricular program with science investigation and engineering design features, what evidence of interest and motivation are present? The following sections first provide qualitative findings from interviews and observations,followed by quantitative results from surveys.

Qualitative Findings

Providing Choice or Autonomy. Teacher A had facilitated the prior year's version of the solutioning curricular program which was in its initial cycle at the time. When asked to reflect on any positive differences in the implementation for the present study, she emphasized the element of choice that was included in this curricular unit.

"Like everybody made, like they designed them just on paper. And so I think giving them an opportunity to all create. And last year they all researched the exact same bug, so this year there was like more options."- Teacher A

During observations, the researchers also recorded comments the students made.. Interestingly, a student also commented on wanting to take advantage of the opportunity to have choices rather than dive straight into the work.

> *"I think we should do our own research first before we start answering questions as a table."* - Student 1

Naturally, during the engineering design process, there was a lot of opportunity for expressing choice. Rather than having one uniform set of instructions or allowing one student to lead, students expressed their opinions and made decisions as a group.

> *"Maybe we could put the green sticks on top instead of the sides and then cut a hole in the top to let the insects in"* - Student 2

Promoting Personal Relevance. During the interviews, both teachers expressed that the students appeared to be more excited or motivated during the solutioning curricular program than in other lessons. In their explanations of this increased excitement and motivation, the teachers emphasized that the unit was more concrete than other science units. Because students had seen some of the invasive insects prior to the lesson, the material made a connection to something they were familiar with outside of the classroom. Furthermore, through their research, the students learned about how harmful invasive insects could be to the area. In fact, one student shouted excitedly when they realized that the insect was in the part of the state that they lived in.

"I think it gave them, like, more of an experience that they actually cared about." - Teacher A

"I think they're more excited with this because it was something they could actually do, and they could kind of visualize doing it in our school yard. They're like, 'This is real. This is tangible,' so I felt like they were quite excited." - Teacher B

"It is in the part of [the state] we live in!" - Student 3

Presenting Appropriately Challenging Material. Rather than deeming one or two particular lessons "appropriately challenging", the teachers pointed out specific ways that the solutioning curricular program challenged the students. Teacher A placed emphasis on students' reflection of their traps after the building phase was complete, whereas Teacher B described the budgeting and trap design.

"They were so excited like once we actually built, some of them were like, 'But if I would have done this again, I would have used like these materials' or like so many of them put

the fruit in day one, but it had like fermented overnight, so they're like 'I should have waited to put the fruit in.' So it was, like, cool that they were able to see like kind of a process of fail and succeed." - Teacher A

"I like the idea of making them sit and think about it." - Teacher B

Furthermore, during the observations from the engineering design phase, the students were heard having a discussion about improving the trap while it was still being built.

"I don't think a Boxelder Bug can fit through that." - Student 4
"Oh, let's cut a bigger hole in the middle." - Student 5

Situating the Investigations Socially and Culturally. Although Teacher B did not specifically mention anything in regards to the social or cultural situation of the curriculum, Teacher A put extra emphasis on this. The solutioning curricular program's focus on a local issue allowed students to draw on what they have experienced in their own lives, and allowed them to create a solution to this issue using easily-obtainable materials. By involving their community and household items, students were immersed in the content.

"I feel like they're more engaged in ecosystems because they understand it, they get it. They see life everywhere they see, like if there's like too many of one thing, it affects

things, so I think this strand alone kids connect to because they can experience it." - Teacher A

"I think it's cool that the kids were able to, like every resource that was there was something that most of them have in their houses" - Teacher A

Quantitative Results

After experiencing the program, students had a moderately high score on all four meaningfulness and interest survey items. The lowest average score in any category was 3.75 in the engineering meaningfulness survey item, and the highest score was 3.86, which was in both science survey items. The standard deviations ranged from 0.90 (science meaningfulness) and 1.10 (engineering interest). Furthermore, in each category, at least 60% of the students provided a score of 4 or 5 indicating that the students found both science and engineering to be of moderate to high interest and meaningfulness. Overall, less than 5% of students gave a 1 in any of the categories, and less than 11% gave a 2 for any category (see Table 5).

Table 5
Meaningfulness and Interest Response Distribution

	Meaningfulness		Interest	
	Science	Engineering	Science	Engineering
1	2.5%	1.7%	4.2%	2.5%
2	4.2%	6.8%	6.8%	10.2%
3	20.3%	28.0%	20.3%	23.7%
4	**50.8%**	**41.5%**	**36.4%**	28.0%
5	22.0%	22.0%	32.2%	**34.7%**

Discussion

Our research studies provide evidence that as the NASEM (2019; 2021) and NRC (2012) policy documents suggest, the integration of scientific investigation and engineering design in one curricular program is feasible. Content analysis of our solutioning curricular program provided evidence of design features that have been shown to improve students' interest and motivation. Additionally, at the conclusion of the program, both teachers expressed evidence of the elements of the four design features associated with motivation and interest. Student comments also demonstrated three of the four design features associated with motivation and interest, namely Providing Choice or Autonomy, Promoting Personal Relevance, and Presenting Appropriately Challenging Material, with direct evidence of Situating the Investigation Socially and Culturally proving more difficult to demonstrate in activities. Both student and teacher comments were done so without direct knowledge of the design features themselves.

In a time where we are especially in need of problem solving and critical thinking skills, exposure to content is simply not enough. Motivation and interest have become critical components to students' STEM learning (Lazowski & Hulleman, 2016) and an important component in encouraging individuals to pursue STEM fields (NRC, 2012). Middle school is a critical point at which students' interest in STEM falters (George, 2006). After experiencing the program, students had a moderately high score on all four meaningfulness and interest survey items in science and engineering. While we cannot directly connect the presence of these design features to students' survey responses, our results are consistent with others' research connecting these features to student attitudes (choice and autonomy-Nieswandt and Horowitz; 2015;

promoting personal relevance-Sezer & Namukasa, 2021; presenting appropriately challenging material-Archer et al., 2010; situating socially and culturally-Pinkard et al., 2017).

One component worth discussing is the lack of the four design features in the second unit of the program. In this unit, students learn the basics of a balanced ecosystem, including the relationships between plants, insects, and animals. The students complete a series of simulations that show the impact an invasive species can have on that ecosystem. This unit contains an essential part of the local science content requirements and is an important foundation for understanding the purpose for the trap design. While this is not to say that the content cannot be or was not taught with the inclusion of any of the design features, the content was considered supplementary rather than focus for the program.

It is also worth noting that the engineering design unit contained noticeably more design features than the other units. While this was unintentional in terms of the planning of the curriculum, the researchers feel that this is in part an example of Fisher and Frey's (2008) Gradual Release of Responsibility. In the beginning of the program, students receive more guidance and straightforward work. While there were open ended questions in the first two units, this does not necessarily indicate autonomy or choice as described by NASEM (2019). Furthermore, the researchers acknowledge that offering trivial or superfluous options during instruction has the potential to inhibit productivity (D'Ailly, 2004). However, as the curriculum develops and an educational foundation is set, the students gain choice and autonomy as the Gradual Release of Responsibility model suggests.

Conclusion

In this study, we examined a solutioning curricular program and its implementation in the classroom. This work showcases how curriculum developers and instructors can include design features to foster interest and motivation in STEM content. We welcome conversation about additional research to explore student learning approaches that help us to get closer to the iterative and productive dynamic between the learning and design of science and engineering.

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Appendix: Semi-structured Interview Questions

1. In what ways do you feel students may have benefitted from the curriculum?
2. More generally, in what ways do you feel students may have struggled with the curriculum?
3. Did your students seem more or less excited or motivated than in other science units? If so, in what parts of the curricula or activities?
4. What changes (if any) did you make to the lessons or resources in units 1 and 2 of the curriculum?
    - Do you recommend we adopt these changes as a regular part of the curriculum? Why or why not?
5. How did students engage with the engineering design process?
    - Which stage or stages did you or they find particularly useful?
    - Danny noticed that students changed their designs after the brainstorming or feedback activities. Can you tell us more about the changes you observed?
6. What changes did you make to unit 3, the engineering design process, provided in the curriculum?
    - Did you change the order of the parts/gears?
    - Did you add or skip any gears?
    - Is there something else that you think should be changed about the engineering design process specifically?
7. Are there any other changes that you think would be useful for future implementation?