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Exploring How Contextual Factors Influence the Implementation of Middle School Engineering Curricula (Fundamental)

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Abstract

Through the semester-long STEM-ID curricula, middle school students complete a series of contextualized challenges that integrate foundational mathematics and science, introduce advanced manufacturing tools (CAD, 3-D printing), and engage students in the engineering design process. Funded by a National Science Foundation (NSF) STEM-ID grant, our project is in the process of scaling the STEM-ID curricula in a large urban school district. Over the previous two years, the project has enlisted two cohorts of engineering teachers to implement the curricula in nine middle schools. In addition to understanding *whether* and *how* the critical components of the STEM-ID curricula are implemented in diverse school settings, our research team's fidelity of implementation research investigates contextual factors that help explain *why* teachers and students engaged with the STEM-ID curricula the way they did. For this line of inquiry, we draw upon the Factor Framework, which provides a comprehensive set of potential factors known to influence implementation of educational innovations. The framework organizes these implementation factors into five categories: characteristics of the innovation, characteristics of individual users, characteristics of the organization, elements of the environment, and networks. After consulting this framework to identify potential factors likely to influence STEM-ID implementation, we analyzed teacher interview and classroom observation data collected over the course of three semesters of implementation to describe the degree to which various contextual factors either facilitated or limited implementation. For this paper, we focus on three categories of factors influencing implementation: characteristics of the curriculum, characteristics of users (teachers and students), and characteristics of organizations (district, schools). Characteristics of STEM-ID that facilitated implementation included features of the curricula and professional development including the perceived effectiveness of the curricula, the adaptability of the curricula, and the degree to which professional learning sessions provided adequate preparation for implementation. Characteristics of teachers identified as facilitating implementation included pedagogical content knowledge, self-efficacy, resourcefulness, and organizational and time management skills. Teachers reported that student interest in the STEM-ID challenges and STEM, more generally, was another facilitating factor whereas, to varying degrees, disruptive student behavior and students' lack of foundational mathematics skills were reported as limiting factors. Teachers also highlighted specific technological challenges, such as software licensing issues, as limiting factors. Otherwise, we found that teachers generally had sufficient resources to implement the curricula including adequate physical space, technological tools, and supplies. Across teachers and schools, we found that, overall, supportive school and district leadership facilitated implementation. In spite of an overall high level of support in participating schools, we did identify school and district policies with implications for implementation including school-wide scheduling and disciplinary policies that limited instructional time, policies for assigning and moving students among elective courses, and district-wide expectations for assessment and teaching certain additional engineering activities. We believe the findings of this study will be of interest to other researchers and practitioners exploring how engineering education innovations unfold in diverse classrooms and the array of factors that may account for variations in implementation patterns.

Introduction

As new approaches to teaching engineering are developed and scaled, there is a clear need to study not only *whether* they are enacted as designed (e.g. fidelity of implementation) but also *how* and *why* teachers and students engage with innovations in engineering education the way they do. There is a long tradition of education research that seeks to identify factors that influence how and why educational innovations are implemented in various settings [1,2]. Evaluation research conducted in the 1970s illustrated the ways in which administrative structures and material resources affect implementation of educational interventions [3,4]. Subsequent research on curriculum implementation brought attention to the importance of attending to the needs and concerns of practitioners as they enacted changes in their instructional practice [5,6].

Numerous studies have put forth frameworks or taxonomies enumerating the array of factors that either support or limit enactment of educational innovations [7,8,9]. For example, Ruiz-Primo [10] describes a multi-method, multi-source framework for examining fidelity of implementation in the context of inquiry-based science curricula. According to this approach, one dimension of studying implementation, Theoretical Stand, includes consideration of what teacher beliefs and values are important to effectively implement curricula. Ruiz-Primo argues that, when measured, teachers' beliefs and values can help make connections between implementation context, levels of fidelity, and the effectiveness of curricula. To this end, the framework defines site context (physical resources, teachers' characteristics, students' characteristics, and school dispositions) and teachers' beliefs and values about content, how student learn, how to support students, and how to identify student's needs as critical components to consider when studying curriculum implementation.

As researchers have identified factors affecting implementation, they have also sought to draw connections between these factors and implementation outcomes. For example, Durlak [11] describes how teachers' opinions or general instructional philosophies moderate fidelity levels, with higher fidelity among teachers with instructional philosophies matching the instructional approach of the intervention. Research on implementation factors also adds to the fields in understanding how and why teachers in various settings and with various backgrounds make adaptations as they implement curricula [1]. In their discussion of the importance of flexibility and fit of interventions, Harn, Parisi, and Stoolmiller [12] argue that "one of the best ways to match contextual and intervention characteristics to optimize implementation with fidelity over time may be to adapt evidence-based practices to better match school-level context."

Although research explicitly examining factors influencing the implementation of engineering curricula is scarce, studies on the enactment of engineering curricula describe challenges and opportunities related to contextual factors. For example, in their description of inclusive design principles that guided the development of the *Engineering is Elementary* curriculum, Cunningham and Lachapelle [13] highlight the importance of designing activities and lessons that are flexible to the needs of different kinds of learners and that require low-cost, readily available materials. In our previous research exploring the implementation of a curriculum [14] integrating engineering in middle school science classrooms, we found that school-level policies related to assessment, issues with time sufficiency, and teacher beliefs about engineering limited the degree to which teachers implemented aspects of the curricula designed to build student understanding of the NGSS Engineering Disciplinary Core Ideas. The current study aims to lend insight into future efforts to design, implement, and sustain innovative engineering curricula by exploring the role of contextual factors in the implementation of middle school engineering curricula, the STEM-ID course sequence, in one urban school district. The study is guided by the research question: What contextual factors influence the implementation of the STEM-ID curricula?

Theoretical Framework

Our implementation research is guided by the Innovation Implementation Framework [2]. Century and colleagues define implementation as "the extent to which innovation components are in use at a particular moment in time [7]." Accordingly, the Innovation Implementation Framework considers curricular innovations like STEM-ID as complex and componential, or comprised of essential components. The Framework delineates two types of components: structural and interactional. Structural components are "organizational, design, and support elements that are the building blocks of the innovation" and can be sub-divided into procedural components (organizing steps, design elements of the innovation) and educative components (support elements that communicate what users need to know). Interactional components include "behaviors, interactions, and practices of users during enactment", organized by user groups (e.g., teachers, students).

During the original project during which STEM-ID was developed, our research used exploratory classroom observations and consultations with STEM-ID developers to identify the critical components of the STEM-ID curricula (Table 1). Subsequently, our original implementation research used the Innovation Implementation Framework to explore fidelity of implementation during the initial implementation of the fully developed curricula [15]. At the commencement of the current project, we revisited the list of critical components with the project team to confirm that, given curricula refinement and further data analysis, the original critical components still reflect the elements essential to achieving the desired outcomes of the curricula.

Table 1
STEM-ID Critical Components

<table>
<tr><th>Structural – Procedural Component</th><th colspan="2">Structural – Educative Component</th></tr>
<tr><td>1. Course organized according to contextualized problem-based challenges.</td><td colspan="2">2. Utilization of STEM-ID Materials including: Teachers’ Edition, materials and supplies related to design challenges, challenge overviews, information on related Math and Science standards, instructions for preparing and utilizing technology (3-D printers, LEGO Robotics, CAD software), digital Engineering Design Logs</td></tr>
<tr><th colspan="3">Interactional Components</th></tr>
<tr><th>Component Area</th><th>Teachers</th><th>Students</th></tr>
<tr><td>Engineering Design Process</td><td>3. Teacher Facilitates Student Engagement in the Engineering Design Process</td><td>4. Students Engage in the Engineering Design Process</td></tr>
<tr><td>Math/Science Integration</td><td>5. Teacher Facilitates Integration of Math/Science and Engineering</td><td>6. Students Apply Math/Science Content and Skills</td></tr>
<tr><td>Advanced Manufacturing Technology</td><td>7. Teacher Facilitates Utilization of Advanced Manufacturing Technology</td><td>8. Students Use Advanced Manufacturing Technology</td></tr>
<tr><td>Collaborative Group Work</td><td>9. Teacher Facilitates Collaborative Group Work</td><td>10. Students Engage in Collaborative Group Work</td></tr>
</table>

Century and colleagues propose a number of additional concepts related to implementation research that inform our STEM-ID implementation research [2][7][16]. First, they underscore that innovations vary in the number and type of components and whether components are more explicit or implicit within curricula. Thus, innovations may prioritize either structural components or interactional components. While we included essential structural components, STEM-ID is comprised of mainly interactional components, which vary in how explicit they are within and across the sixth-, seventh-, and eighth-grade courses. Second, Century and colleagues argue that “full implementation of all critical components is not necessarily optimal, noting that appropriate enactment varies depending on contexts and conditions” [16]. Similarly, Century and Cassata draw a distinction between investigating implementation fidelity by comparing actual implementation to a theoretical ideal or pre-defined threshold, and investigating innovation *use* [7]. Given the consensus that innovations are rarely implemented exactly as designed, Century et al. suggest measuring how components of innovation are used rather than a focus on strict fidelity. This approach of prioritizing *innovation* *use* over strict fidelity characterizes our project's approach to studying STEM-ID implementation.

In addition to understanding how the innovation was enacted, we are also interested in contextual factors that help explain why teachers and students engaged with ***** the way they did. For this line of inquiry, we drew upon the Factor Framework [7] [16], which provides a comprehensive set of potential factors known to influence implementation of innovations. The framework organizes implementation factors into five categories: characteristics of the innovation, characteristics of individual users, characteristics of the organization, elements of the environment, and networks. Although we did not seek to explicitly measure the multitude of factors within this framework, we consulted the factors framework to identify the implementation factors most relevant to and likely to influence STEM-ID implementation, focusing on characteristics of STEM-ID, characteristics of teachers and students, and characteristics of the participating schools and district (Table 2). We then collected and analyzed interview and observation data to describe which of these contextual factors either facilitated or limited STEM-ID implementation.

Table 2
Contextual Factors Potentially Influencing STEM-ID Implementation

Factor	Description
Characteristics of the Innovation (STEM-ID)	
Attributes of STEM-ID that are uninfluenced by other factors at any given point in time.	
Complexity	The number of parts in the STEM-ID curricula and the extent of their interdependence.
Specificity	The level of detail in which the operationalization of STEM-ID is described.
Scope	STEM-ID's target area(s) within the field of education.
Empirical Effectiveness	Evidence that STEM-ID accomplishes desired outcomes.
Results Demonstrability	The extent to which the impacts of STEM-ID can be communicated/shown to others.
Characteristics of Individual users.	
The attributes of users of STEM-ID (teachers and students)	
Teacher Characteristics	
Self-Efficacy	Teachers' confidence in their ability to enact the STEM-ID curricula.
Understanding of STEM-ID	The extent to which teachers understand the strategies, components, and goals of STEM-ID.
Attitudes Toward STEM-ID	The extent to which teachers are in favor of (or not) using STEM-ID.
Attitudes Toward things related to STEM-ID	Enjoyment of topics/areas related to the innovation (also related to intrinsic motivation).
Intrinsic Motivation	Influence on teachers' decision-making that comes from their level of enjoyment of, sense of commitment to, and sense of ownership toward STEM-ID.

Extrinsic Motivation	Influence on teachers' decision-making that comes from external incentives such as recognition, money, and power, or to avoid negative consequences from an external source.
Innovativeness	The extent to which teachers seek out, create, and/or enact new ways of doing things.
Resourcefulness and Coping	The ability of teachers to combat stress and persist with difficult goals/tasks.
Networked-ness	The tendency for a teacher to participate in a social network (inside or outside of the organization).
Time Management and Organizational Skills	The act or process of planning and exercising control over the amount of time spent on specific activities, especially to increase efficiency or productivity; skills that enable people to carry on activities effectively, to put order to a situation, objects, or people.
Teacher Perceptions of STEM-ID	
Perceived Adaptability	Teachers' perceptions of STEM-ID's permissible flexibility.
Ease of Use	Teachers' perceptions of STEM-ID's ease of implementation.
Perceived Effectiveness	Teachers' impressions that STEM-ID accomplishes desired outcomes.
Descriptive Characteristics of Teachers	
Demographics	Includes gender, age, SES
Education	Includes formal education and training.
Experience	Includes number of years teaching, number of years teaching engineering, prior STEM-ID experience.
Characteristics of The Classroom (Students)	
Student Behavior	The extent to which teachers perceive that student behavior issues disrupt STEM-ID instruction.
Student Ability to Learn Engineering	The extent to which teachers perceive that students are able to learn engineering.
Characteristics of the Organization (School and District)	
Organizational Structures	The formal rules, policies, and guidelines for operations of an organization in which STEM-ID is enacted. Includes decision-making structures, reporting structures, supervisory structures.
Resource Sufficiency	The extent to which teachers feel they have enough resources (financial, material, human) to implement STEM-ID.
Time Sufficiency	The extent to which users feel they have enough time to implement STEM-ID.
Physical Environment	The characteristics of the physical space in which STEM-ID is enacted.
Extraneous Events, Initiatives, and/or Incidents	Events or initiatives within or around the organization that cause distraction from or support for STEM-ID implementation.

Methods

The study triangulates observation, interview, and survey data gathered across participating school sites to identify contextual factors either supporting or limiting implementation of STEM-ID. Each of these data sources is described below, following the description of the curricular context and participants.

Curricular Context

STEM-ID is a multi-year course sequence designed for implementation in 6th, 7th, and 8th grade engineering classrooms. Each of the three semester-long grade level curricula are organized around a series of contextualized problem-based challenges intended to engage students in engineering practices while reinforcing foundational mathematics and science. In each course, students build skills through Data Challenges, Systems Challenges, and Visualization Challenges, that they ultimately apply in a culminating Design Challenge. In the 6th grade “Carnival Tycoon” course, students explore the engineering design process and entrepreneurial thinking as they develop a pitch for a carnival stand, design and test a new carnival gameboard, and re-design a catapult cradle to change the performance characteristics of their carnival game. In the 7th grade “Flight of Fancy” course, students take the role of aeronautical engineers as they test various wing configurations using Styrofoam gliders, design the interior of an airplane for a new airline, and use CAD software to prototype and test their own balsa wood glider design. The 8th grade course begins with a short Design Challenge in which students use CAD to design and prototype a 3D printed cellphone holder for another student serving as their client. Students then turn their attention to the “Robot Rescue” Systems, Investigation, and Design Challenges in which they use CAD and robotics to explore the systems and behavior of a walking robot as it navigates various terrain under different operating conditions.

Participants

Teacher participants include a total of eleven engineering teachers from nine public middle schools located in a large urban school district in the Southeastern United States. The teachers represent two cohorts. The first cohort of six teachers was recruited to participate in the project beginning during the 2022-23 school year. Three of these original cohort members only participated during this first year because they either retired or changed school districts. One of the participating schools had two teachers in Cohort 1, an engineering teacher and a computer science teacher who co-taught the curricula. Although the computer science teacher did not implement the curricula in 2023-24, she continued as a participant in the project as a mentor to other teachers and to assist with ongoing professional development. The engineering teacher at this school retired, he continued working with the project to support Cohort 2 teachers. The first cohort was joined by a second cohort of five teachers for the 2023-24 school year. All teachers were recruited to participate through presentations and communications with engineering teachers facilitated by the researchers and partnering school district. As summarized in Table 3, teacher participants began the project with various levels previous teaching experience overall, as well as varying previous experience with the STEM-ID curricula, teaching STEM and engineering, and professional and educational backgrounds.

Table 3
STEM-ID Teacher Participant Background

Teacher[a]	Cohort	Total Years Teaching	Years teaching engineering	Years teaching STEM-ID	Professional/ Educational Background	Demographics
Sally	1	15	0	0	Former Math teacher B.A. and MAT in Education	White Female
Neil	1	29	8	4	Former Science teacher B.A. and MAT in Education	White Male
Kathryn	1	5	0	4	Computer Science Teacher B.A. in Education	White Female
John	2	0	0	0	Industry Background: 20 years as Computer Science Engineer B.S. in Computer Science	White Male
Stephanie	1	18	1	1	Former Math teacher B.A. in Mathematics, MAT in Education	Black Female
Jeanette	1	28	2	2	Former Science teacher B.A. in Biology, MAT in Education	Black Female
Pete	1	21	3	2	Former Science teacher B.A., MAT, and PhD in Education	White Male
Shannon	2	6	1	0	Former Science teacher B.S. in Communications, MAT in Middle Grades Math and Science	White Female
Ellen	2	8	0	0	Former Language Arts teacher BASc in Secondary Education and Teaching	Hispanic Female
Alan	2	10	0	0	Former Science teacher B.A. in Education	White Male
Jim	2	21	21	0	Career engineering teacher B.S., M.A. in Social Sciences	White Male

Notes: [a]teacher names are pseudonyms to protect confidentiality.

Data Sources

The project utilized teacher interviews, classroom observations, and implementation surveys to explore STEM-ID implementation. Each of these data sources are described below.

Classroom Observations

Researchers conducted observations in purposively selected teachers' classrooms each semester of the 2022-23 school year and during the fall of the 2023-24 school year. Two types of classroom observations were conducted: intensive observations and short observation visits. For intensive observations, researchers observed implementation for full class sessions in each grade level over a two- to three-week period at the end of each semester, as teachers were scheduled to implement the culminating Design Challenges. A total of 170 class sessions were observed during these intensive observation visits. Short observation visits were intended to provide a snapshot of implementation and to help track teachers' progress through the curricula. For these short observation visits, researchers observed one class period and had a short consultation with teachers regarding their progress implementing STEM-ID. A total of 46 short weekly observation visits were conducted during the Spring 2023 and Fall 2024 semesters. Due to scheduling conflicts and one teacher resigning from the project at the end of the Fall 2022 semester, we were not able to conduct observations at all school sites or with all participating teachers. Although observations were somewhat unevenly distributed, the overall breadth of the observation dataset, when analyzed alongside other data sources, provides considerable insight into teachers' experience with the curricula and the factors influencing implementation. Observations were guided by a semi-structured protocol intended to provide guidance on specific elements related to critical components while remaining sufficiently general to be used for all three grade level courses. The protocol included both checklist items and space devoted to both general field notes and field notes related to each critical component. For example, in the section of the protocol aligned to the Engineering Design Process, observers indicate which of the six stages of the process students engaged in and then record accompanying written observations in the space provided. The protocol also includes space for observers to note evidence of contextual factors influencing implementation, rate the overall level of student engagement, and describe adaptations. See Table 4 for an excerpt from the Observation Protocol.

Table 4
Example Items from STEM-ID Observation Protocol

Critical Component	Item
Student Engagement in Engineering Design Process	Select stage(s) of the EDP students engaged in during the class session: Identify the Problem Understand Design Requirements & Goals (Background Research) Ideate (Brainstorm design ideas, sketch to communicate) Evaluate (Strengths/Weaknesses, Rate designs, Design Selection) Prototype & Test (Technical drawings, Models, Tests) Communicate Solution (Share, Justify design, documentation). None. Students did not engage in EDP. Engineering Design Process Notes:
Math/Science Integration	Select math/science integration activities students engaged in during the class session: Math – Measurement Math – Data Analysis Science - Experimental Procedures Math Concepts - Students or teachers reference math concept(s). Science Concepts – Students or teacher reference science concepts.

	Note specific concepts, vocabulary, practices:
Use of Advanced Manufacturing Technology	Select any advanced manufacturing technology utilized by the students or teacher during this class session: 3d Printing Iron CAD Robotics Other (describe below). Advanced Manufacturing Technology Notes:

Teacher Interviews

Semi-structured interviews lasting 45-60 minutes were conducted with all teachers implementing the curricula. Interviews were scheduled at the end of each semester, as teachers were completing implementation of the STEM-ID courses. Four researchers conducted a total of eleven interviews during the 2022-23 school year and seven interviews at the end of the Fall 2023 semester. In order to allow researchers to pose follow-up questions related to observations, interviews were conducted by the same researcher who had conducted intensive observations in the teachers' classroom. First semester interviews were guided by a semi-structured protocols developed by project researchers. In addition to questions intended to document implementation and elicit reflections on teachers' experience with the curricula, the protocol includes questions and follow-up prompts aligned to each critical component along with questions pertaining to potential factors influencing implementation. This first semester protocol was adapted for second semester interviews to include prompts asking teachers to describe any changes in their practice over their two implementations of *****. Based on emergent findings suggesting the important role of teachers' pedagogical content knowledge (PCK), a stimulated response question designed to elicit reflections on a particular instance of enacted PCK (ePCK) noted in observation data was also added to the second semester interview. This same protocol was used for the Fall 2023 interviews. See Table 5 for example items from the interview protocols. All teacher interview sessions were audio-recorded and transcribed for analysis.

In addition to individual interviews, teachers participated in a series of seven online group discussions ("check-ins") held monthly over the course of the 2022-23 school year. In these discussions, teachers were invited to share updates, questions, and collaboratively troubleshoot any challenges related to STEM-ID implementation. Thus, check-ins served both as a strategy for fostering the project's professional learning community (PLC) and a method for tracking teachers' implementation progress and learning about factors influencing implementation. Check-in discussions were conducted using Zoom video conferencing software and were video recorded.

Table 5

Example Items from STEM-ID Interview Protocols

Topic/Critical Component	Interview Question/Prompt
Self-efficacy for STEM-ID	Overall, how confident do you feel about teaching the STEM-ID curricula? • What aspects have been most challenging for you as a teacher? • Can you share an example of a time you felt particularly successful? • Can you share an example of a time you have struggled?
STEM-ID Implementation	Were you able to implement STEM-ID as you had hoped this semester? • If not – what factors influenced your ability to implement STEM-ID? Were there parts of the curricula you didn't get to implement this year? • Tell me about how you decided not to do ______.
Facilitation of the Engineering Design Process (EDP)	How have you helped students' progress through the engineering design process? Are there particular stages that have been more challenging than others to facilitate?
Integration of Math/Science and Engineering	Tell me about your approach to incorporating math and science. • Did you introduce additional connections to math/science? If yes, can you share examples?
Utilization of STEM-ID Materials	How did you use the STEM-ID website? • How often did you refer to the website as you were implementing STEM-ID? (e.g., daily, weekly…) Overall, how well did the STEM ID materials work for your students? • Were there any student materials that you didn't use?
Implementation Factors	We realize that there are many factors that may influence STEM-ID. Out of everything we've talked about, what would you say are the most important things that influence how you use STEM-ID?" • School/District Requirements – Any requirements from the district that have affected your implementation of STEM-ID? • Extraneous Events – Can you describe any events or initiatives at the school that may have caused a distraction from STEM-ID? • Resources/Technology – Do you feel that you have had the resources and technology necessary to implement STEM-ID? • Time – Do you feel that you have enough time to implement the STEM-ID curricula? • Leadership – Do you feel like your school leaders support your implementation of STEM-ID?
Pedagogical Content Knowledge	We are very interested in learning more about how teachers use their expertise to make pedagogical decisions when they are implementing STEM-ID. When I was visiting your classroom, I noticed (provide a brief but detailed description of observed PCK episode) Do you remember that? If yes: • Tell me about your decision to _________. • What previous experience do you think you were drawing on in that moment? • Where did you learn about how to teach in that way? • How has your experience with that group of students influence how you taught _____?

Implementation Surveys

Teachers were asked to complete a short online implementation survey upon completion of each STEM-ID challenge. Each survey included a checklist of key student and teacher actions for each challenge along with open-ended response items for teachers to note any challenges and adaptations that occurred during implementation. Links to implementation surveys were sent to teachers via email, along with frequent reminders to complete surveys as soon as possible following implementation of STEM-ID challenges. Response rates across teachers were mixed, with some teachers completing all implementation surveys and others completing very few. We also found that teachers rarely provided rich, detailed responses to the open-ended questions in the implementation surveys. Given these limitations, implementation surveys were utilized as a supplementary data source to corroborate data gathered through observations and interviews.

Findings

Taken together, observation, interview, and survey data provide insight into the contextual factors influencing STEM-ID implementation over the course of three semesters. Facilitating and limiting factors associated with the characteristics of the STEM-ID curricula, characteristics of users (teachers and students), and characteristics of the organization (school and district) are summarized in Table 6 and further described below.

Characteristics of STEM-ID: Facilitating Factors

Characteristics of STEM-ID that facilitated implementation included features of STEM-ID curricula as well as aspects of the STEM-ID professional development program. Teachers concurred that they saw evidence of the effectiveness of STEM-ID in their classrooms, citing a range of student outcomes including engagement, increased understanding of the engineering design process, development of problem solving, communication, and collaboration skills, and strengthening foundational math and science knowledge and skills.

Teachers also frequently commented on the adaptability of the curricula, noting that they appreciated the flexibility to tailor STEM-ID to their teaching styles and their students' needs. For example, several teachers noted that they appreciated being able to teach STEM-ID using their choice of CAD programs, based on their students' readiness to work with more advanced software. In interviews, Neil, who had several previous years' experience co-teaching STEM-ID with Kathryn, described how they had "put our own spin on things":

> *Kathryn and I have done this together for so many years and I feel like we're starting to, um, we're comfortable with the curriculum and so we've started putting our own spin on things and trying different pedagogy type things in how we teach it.*

Table 6
Contextual Factors Influencing STEM-ID Implementation

	Facilitating Factors	Limiting Factors
Characteristics of Innovation (STEM-ID)	• STEM-ID Professional Development • STEM-ID Professional Learning Community (PLC) • Adaptability • Empirical Effectiveness	• Scope – Ambitious amount of STEM content, duration of curricula and number of engineering challenges. • Complexity – Reliance on Technology (e.g. LEGO)
Characteristics of Individuals (Students/Teachers)	• Pedagogical Content Knowledge (PCK) • High Self-efficacy (for STEM-ID, teaching) • Positive Attitudes about STEM-ID, perceived effectiveness • Resourcefulness	• Low teacher self-efficacy in specific areas (CAD, Robotics, 3d printing) • Student behavior • Attitudes about teaching EDP, lowered student expectations
Characteristics of Organizations (School/District)	• Supportive school leadership • Supportive district leadership • Resource sufficiency – space, physical environment, materials and supplies	• Resource insufficiency – Technology (ex: software licensing issues, support) • Interruptions of STEM-ID instructional Time • Policies/practices – scheduling, student discipline, support for students with special needs • Non STEM-ID Curriculum expectations • Isolation of engineering teachers

Similarly, in interviews and check-in discussions, teachers detailed specific strategies and additional resources they had developed as they implemented the curricula. For example, Neil and Kathryn discussed how they had come to find that using stations where small groups of students rotated through activities related to the challenge was an effective approach to facilitating students' work with catapults in the 6th grade Carnival Tycoon challenge and glider testing in the 7th grade Flight of Fancy challenge.

Teachers unanimously reported that the professional development provided by the STEM-ID program was effective in preparing them to implement the curricula. In interviews, teachers often connected their experiences in professional development to their STEM-ID implementation. For example, here Stephanie reflects on a number of ways in which her participation in the summer professional development improved her implementation of STEM-ID including increased understanding of the organization and flow of the curricula, increased ability to troubleshoot technical challenges, and increased ability to make connections to mathematics and science:

> *I think the PD was sufficient enough to, so that I was prepared to know exactly what you were expecting from each of those challenges, because prior to that I was just winging it and I had no idea like the flow and how it made sense and how it tied into any of what we would call our AKS, which is our standards…So after the professional development I was able to at least hands-on be able to take, you know, for instance, the catapult, even though it didn't work at first, I was able to pull it out like and see like put all the pieces together and try to get it to work, whereas before I just pulled it out and I was like, 'I don't know what this is, I don't know what I'm doing'. Um, I was able to take, uh, some of those concepts and connect it to science, which is not my background. And I was able to talk about air pressure and the flow and all of that stuff. I was able to, um, use my strengths and math for the data, um, and really have kids, um, expand on how they created that menu and make it sort of a, a whole class thing.*

As intimated above, professional development sessions and monthly check-in sessions gave teachers a chance to share their subject-matter expertise and lessons learned through previous experience with the curricula within the burgeoning STEM-ID PLC. Interview and observation data confirm that teachers used advice and resources shared within the PLC to help facilitate implementation. It was not uncommon for researchers to observe a new resource developed by one teacher implemented by another member of the PLC. For example, on one short observation visit Alan shared that he was using a spreadsheet developed by John as he facilitated his 7th grade students experience designing the interior of an airplane for the Flight of Fancy Systems Challenge.

Characteristics of STEM-ID: Limiting Factors

The main characteristics of STEM-ID that tended to limit implementation were the scope and complexity of the curricula. As evidenced by the uneven implementation across teachers, we found that some teachers found it difficult to implement semester-long curricula and to prioritize STEM-ID over other engineering activities they had implemented in previous years. For example, Neil and Kathryn opted to implement a roller coaster challenge that they considered one of their favorite projects in lieu of the 6th Grade Design Challenge. The complexity that comes with simultaneously learning and implementing three different semester-long, grade level curricula was also a challenge for some teachers. Specifically, teachers identified the amount of ongoing preparation required for implementation and the reliance on relatively complex technology (CAD, LEGO Robotics, catapults) as factors that, at times, limited their ability to successfully implement STEM-ID. As described further below, this was particularly true when teachers encountered technical difficulties with curriculum materials.

Characteristics of Teachers and Students: Facilitating Factors

There were a number of teacher characteristics that clearly facilitated successful implementation of the STEM-ID critical components. Beginning with teachers' discussions in the 2023 professional development sessions, we began to see evidence of teachers utilizing their pedagogical content knowledge (PCK) in science, mathematics, and engineering to inform their work with the curricula. One of the areas where we saw this clear evidence of PCK was teachers' informing their teaching of STEM-ID with prior understanding about alternative understandings students may have or concepts they may find particularly challenging. For instance, in the following reflection, Pete describes how he applied his understanding of students' conceptual understanding in science:

> *As a science teacher, you not only understand the content, but you also know how students learn that content. And you also understand this is important too, where they have issues with it. For example, mass and weight, that's something that kids struggle with. Um, and then calculating velocity and acceleration, they have trouble with that too, so you can kind of, so I can guess, kind of anticipate and plan for when they may have trouble with something.*

In addition to utilizing their PCK, we also noted that teachers generally expressed high self-efficacy for teaching, generally, and increasing self-efficacy for teaching STEM-ID, specifically. Similarly, all teachers shared positive attitudes about STEM-ID and its effectiveness. Even, Pete, who chose not to participate in the project during the spring semester reviewed STEM-ID positively, stating:

> *The curriculum is solid, and you've covered a lot of different angles - you have things in there that keep their hands busy, but also keep their minds engaged, and that is difficult to pull off, and I think you guys have done a great job with that.*

We also found that teachers who were successful implementing STEM-ID demonstrated excellent organization and time management skills along with resourcefulness that enabled them to navigate any challenges that arose during implementation. For example, observation data showed that teachers who demonstrated key organization and time management skills, including preparing materials in advance, assigning roles during group work, and setting clear goals for each class session, were generally able to guide students through the STEM-ID challenges in the time estimated within the curricula's materials. Additionally, we found that teachers' who were able to adeptly manage student groups working at different stages of the engineering design process tended to make more progress with implementation than teachers' who moved students through the process in a more rigid, lock-step fashion. Teachers' resourcefulness was particularly evident as they faced technical issues that required troubleshooting and sometimes development of alternative strategies. For example, when teachers found that the software previously used with the LEGO NXT robotics kits was no longer supported, they worked with the project team to identify various workarounds to ensure students could still complete the majority of the activities in the 8th grade Robot Rescue Challenge. At the same time, we found that, given the demands of teaching middle school, there were limits on the amount of time and energy teachers were willing to devote to solving technical issues. Additionally, we found that teachers who were relatively new to engineering were particularly susceptible to feeling overwhelmed when it came to troubleshooting technical issues. In her interview, Shannon highlighted the challenge of balancing the need to address a technical challenge (e.g., issues with catapult batteries charging) with her other priorities as a middle school teacher, describing materials and supplies as a "little bubble" in contrast to "bigger bubbles" representing more pressing concerns:

> *So it's like materials and supplies are a little bubble in a bigger bubble for me. So it's kind of like, alright, I can't spend that much time on this little bubble when I've got in my bigger bubble, like parent phone calls, remediation sessions, extra help, actual lesson planning meetings. And then it's like I can't also add trying to learn how to do this other thing. There's a little bit of time for that, but then it's adding, 'okay, go make a battery jumper'. I can't. So it's just like there's just too much on my plate and it's probably something really simple if you know what all that means, but I know this is my first year teaching engineering.*

Although we did not collect student interview data, teacher interviews and classroom observations suggest that strong student interest in specific areas such as CAD and robotics, helped facilitate effective implementation by teachers. For example, we observed that students who had taken an interest in CAD developed a level of proficiency that ultimately enabled them complete additional iterations on their designs and help their classmates with CAD. Several teachers also reported strong student interest in the entrepreneurial aspects of the curricula, particularly in the 6th grade course. For example, Shannon explained how she spent more time than planned on the 6th grade carnival stand design activity because "they were so engaged with some of it that I kind allowed them to sort of extend it, especially they were getting really into the profits and the calculations and what is a logical offer that I can make to this business."

Characteristics of Teachers and Students: Limiting Factors

Just as teachers' high self-efficacy for teaching facilitated implementation, we also found that lower self-efficacy in particular areas limited individual teacher's ability to implement STEM-ID. Several teachers discussed the "steep learning curve" for CAD, describing how they continually work to build their proficiency with the CAD software they are using in their classrooms. Although most teachers have been able to achieve a working understanding of CAD, mastering CAD software was an obstacle for some teachers. For example, in the following reflection, Pete described his novice CAD skills as one of the reasons he opted not to continue with STEM-ID in the spring semester:

> *I believe that for my kids and at my current skill level, Autodesk is too difficult. Right. Um, I'm not Autodesk certified. I would certainly like to be if I continue in this position, um, but I, I strongly feel like the students should be using something like Sketch Up or TinkerCAD, which are more accessible for the kids because these kids are coming in with no CAD skills…I just, I just feel like with what we have currently and my skill level, it's just something that creates too much stress in me…I just, I feel like my technical knowledge with some of my technical knowledge and skills just need some development.*

Another teacher characteristic that was somewhat limiting was a tendency toward more traditional, teacher-centered teaching methods when guiding students through the EDP along with relatively low expectations regarding what students could achieve when engaged in the EDP. These tendencies were most evident in the interview and observation data collected from Jeanette. Although she describes her teaching style as student-centered, using a "gradual release" model that begins with minimal direct instruction and transitions to more hands-on, student-centered activity, we found that there were certain aspects of Jeanette's approach to teaching the EDP that were much less experiential than recommended by STEM-ID. Specifically, Jeanette reported assigning case studies where students read scenarios and identified relevant stages of the EDP, which were not part of the STEM-ID curricula. She also shared her belief that students required "a lot of prep" and vocabulary lessons prior to beginning STEM-ID:

> *When we jumped into our engineering design process, it was basically introducing the steps to them. I did a lot with vocabulary at the beginning, because again, the groups that I have, I'm finding that they, they just do not have an engineering background. So, they, they needed a lot of prep with the vocab and getting ready.*

As evident in this teachers' progress with the curricula, devoting time to this sort of direct instruction where students learn about the EDP at the beginning of the semester meant that students had limited opportunities to actually engage in the EDP through STEM-ID.

Although student behavior typically did not disrupt STEM-ID implementation, there were instances in particular schools that did appear to limit the degree to which students could fully engage with the curricula. For example, both Jeanette and Pete shared their reluctance to allow students to use certain supplies, such as scissors, due to safety concerns. Although engagement tended to be moderate to high, occasionally students were observed engaging in disruptive behavior (e.g., horseplay), spending time on non-academic activities (e.g., shopping, playing games), or becoming completely disengaged in classroom activity (e.g., sleeping). In these instances, the progress of individual students and the groups they worked with was limited.

Characteristics of Schools and the District: Facilitating Factors

Although our data collection did not focus extensively on identifying school and district characteristics that facilitate or limit implementation; however, we did note certain trends reported by teachers and captured in our observation data.

Across teachers and schools, we found that, overall, school and district leadership to be supportive of STEM-ID implementation. In interviews, all teachers noted that their school leadership encouraged them to participate in the project and we did not encounter any issues with leadership supporting teacher participation in STEM-ID professional development. Similarly, monthly partner meetings with district-level leadership indicated strong support for implementation of STEM-ID along with cooperation in recruitment efforts.

With the exception of the technical issues with software noted above, we also found that teachers had sufficient resources to implement STEM-ID. All teachers' classrooms were well suited for STEM-ID activities, with adequate physical space, instructional technology, and supplies. In rare instances where materials were unavailable, teachers communicated effectively with the project team to procure what they needed to implement STEM-ID.

Characteristics of Schools and the District: Limiting Factors

In spite of an overall high level of support in participating schools, we did note that certain school policies had clear implications for STEM-ID implementation. For example, in Jeanette's school, issues with student behavior resulted in school-wide policies that limited instructional time available for STEM-ID. For example, the school had a restroom policy that required teachers to take whole classes to visit the restroom at the beginning of the class period, which consumed 10-15 minutes of instructional time. Jeanette also reported that she frequently had students added to her class roster throughout the semester due to a school practice of re-assigning students with behavior issues to different classes. During several observation visits, we observed students from other classes being sent to join her class and noted the difficulty of integrating new, sometimes disruptive students, into ongoing instruction. Similarly, Alan reported that in his school a large subset of his students were pulled out of his classroom, sometimes for weeks, to participate in remediation or other specialized programs for struggling students. School policies regarding the support of students with special needs and students with limited English proficiency also emerged as a limiting factor. Observation data noted several instances, across schools, where students who had an aide to assist them in other core classes were not afforded the same support while in their engineering classes. For example, in one school, a blind student was not accompanied by the aid who typically assisted him with reading non-Braille materials. This lack of support for students with special needs had a clear impact on teachers' ability to engage these students in the STEM-ID curricula. School scheduling policies also clearly impacted STEM-ID implementation. Specifically, we found that schools with block schedules where teachers see each class for longer periods 2-3 times a week versus all students for shorter periods each day could limit time for implementation, particularly when either the student or teacher were absent or other school events disrupted the regular schedule.

We also noted that some teachers felt pressure to balance certain non-STEM-ID expectations with their implementation of the curricula. Specifically, there are certain engineering activities teachers are expected to implement district-wide, including short units on safety and a unit introducing students to Career-Technical Student Organizations as well as a district-mandated standardized final assessment at the end of the semester. These activities did not seem to hinder STEM-ID implementation for most teachers, but we did have instances of teachers attributing delays in implementation to the need to meet these other expectations. Additionally, we observed that the district outfitted several of our teachers' classrooms with large pieces of new equipment (e.g., woodworking equipment, laser engravers) that were not necessary for STEM-ID implementation. Although teachers were thankful for new resources, they also expressed the concern that that the equipment would come with expectations to use it for new projects and limit their implementation of STEM-ID.

Discussion

The impact of contextual factors will come as no surprise to anyone with experience facilitating the implementation of STEM curricula in complex school and classroom contexts. As Harn, Parisi, and Stoolmiller note, "practitioners are all too familiar with the often unpredictable and sometimes chaotic realities of schools and classrooms that impact their ability to select, implement, and sustain evidence-based practices with fidelity [12]”. While accounting for the vast array of contextual factors exerting their influence as curricula unfold in engineering classrooms may be impossible, guided by the Factors Framework [16], our project has been able to systematically investigate how characteristics of the curricula, its users, and its organizational context influencing implementation of STEM-ID.

This particular study’s goal of identifying salient contextual factors influencing implementation dovetails with the project’s larger goal of scaling the curricula to reach a range of school contexts and student populations. Given the uniqueness of every implementation context, documenting the types of contextual factors that emerge as teachers in diverse schools work with the STEM-ID curricula provides useful insight into the variety of circumstances that may either facilitate or limit successful implementation. Some of these circumstances are fairly obvious pre-conditions for implementation, such as the need for sufficient space and certain resources (e.g. 3d printers, CAD software). Others are less obvious. For example, given the complexity and scope of the curricula, one might expect previous experience teaching engineering to be prerequisite for successful implementation of STEM-ID. However, our data suggest that other teacher characteristics, including organizational skills, time management skills, and attitudes about the curricula, may be more influential that previous teaching experience when it came to implementation of the critical components of STEM-ID. These findings highlight the importance of teacher preparation, both in terms of formal teacher professional development offered as part of the project as well as professional development that can foster individual teacher skills related to time management, adaptability, and resourcefulness. Additionally, our findings suggest PCK as an important teacher characteristic influencing implementation. Because so few engineering teachers enter the classroom through a traditional route, instead coming from teaching other subject areas or professions, engineering classrooms provide a particularly interesting context for examining how teachers develop and use their PCK. Our project is currently designing case study research that will looking more closely at how teachers’ different backgrounds, including PCK for math, science, engineering, and other subject areas, influences enactment of the curricula.

Our findings regarding facilitative teacher factors also have particular relevance for scaling and dissemination of the curricula, as our data increasingly show that the curricula can be successfully implemented by a broad range of engineering teachers. At the same time, some of the limiting factors we’ve identified, such as policies related to student enrollment in engineering classes and expectations for other mandated curricula or assessments, suggest that successful implementation of STEM-ID may not be possible in all school settings. We’ve learned a great deal from examining implementation in less than ideal conditions that provide a sort of stress test for the curricula to determine how much influence from contextual factors it can withstand and still produce desired outcomes. As our project continues, we will be carefully considering contextual factors to provide guidance on the necessary preconditions that make for a good “fit” with the curricula.

This study focuses on identifying limiting and facilitating factors. As noted above with regard to the relative influence of teacher experience versus other teacher characteristics, we can make some inferences about which factors may be more influential than others. However, this study does not aim to quantify the impact of contextual factors or to examine relationships between contextual factors and particular implementation outcomes. As the project continues, future data collection and analysis will aim to more precisely measure how certain contextual factors affect implementation. Having documented adaptations teachers make to the curricula through classroom observations, we are interested in looking more closely at teachers' decision making related to these adaptations in relation to various teacher and school characteristics. We believe that deviations from the curricula are not necessarily counterproductive for student learning or teacher practice and may even advance refinement of the curricula in important ways. In their work documenting co-design with science teachers, Severance, Penuel, Sumner and Leary [17] describe how, by engaging with the project's tools and routines, teachers can shape curricular design to mitigate constraints arising from their teaching contexts. As we employ our own project's routines to collaborate with our teacher participants and deepen our understanding of the nuances of their experience with the curricula, we anticipate learning more important lessons about how teachers adapt STEM-ID to work in their own unique teaching contexts.

Although the Factor Framework [16] categorizes factors according to the curricula, teachers and students, and their organizational context, our data indicated numerous examples of overlap across these spheres of influence. For instance, resourcefulness emerged as a key teacher characteristic largely in light of factors related to the curricula (complexity, technical difficulty) and organizational context (resource sufficiency). Future analysis will look more closely at the ways in which the different categories of factors interact.

Using the Factor Framework, this study illuminates salient factors that are likely at play in other engineering education initiatives; however, the results of the study cannot necessarily be generalized beyond the context of our particular project. Indeed, because innovation implementation is time and context-bound, occurring in a particular setting under specific conditions with specific students and teachers, our project must be conscientious about generalizing beyond the current phase of implementation even for teachers and schools in our study. As conditions in schools are everchanging and teachers are continuously developing their expertise and skillsets as they engage new groups of students, who themselves bring unique characteristics, we would expect new contextual factors to surface as significant in future implementations of the curricula. By adding to the evidence base related to contextual factors identified in this and other studies, we hope to meaningfully contribute to efforts to design, implement, and sustain innovative approaches to engineering at the K-12 level. In spite of the inherent "messiness" of studying implementation factors, this work has yielded valuable lessons about how the unique contexts in which engineering curricula are enacted influence what ultimately happens in real schools and engineering classrooms.

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