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Board 417: Understanding the Implementation of the STEM-ID Curricula in Middle School Engineering Classrooms (Fundamental)

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Understanding the Implementation of the STEM-ID Curricula in Middle School Engineering Classrooms (Fundamental)

Through a series of contextualized challenges, the 18-week STEM-ID curricula incorporate foundational mathematics and science skills and practices and advanced manufacturing tools such as computer aided design (CAD) and 3D printing, while introducing engineering concepts like pneumatics, aeronautics, and robotics. Our current project, supported by an NSF DRK-12 grant, seeks to examine the effectiveness of STEM-ID when implemented in diverse schools within a large school district in STEM-ID. Investigating implementation of STEM-ID in diverse settings represents a major priority of our project's research agenda. To this end, the project applied the Innovation Implementation framework [1] to launch its fidelity of implementation research in the fall of 2022. Over the course of the 2022-23 school year, we gathered data through classroom observations, interviews, surveys and focus groups to understand the critical components of the curricula, necessary support factors, and challenges related to the successful implementation. This paper highlights illustrative findings from our research exploring the implementation of critical components of the STEM-ID curricula.

The Innovation Implementation framework

Century and colleagues provide a useful conceptual framework for examining innovation implementation, defined as "the extent to which innovation components are in use at a particular moment in time [1]." As implied by this definition, the innovation implementation framework conceptualizes curricular innovations like STEM-ID as complex and componential, that is, comprised of essential parts or components. The Framework defines 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 further divided into procedural components (organizing steps, design elements of the innovation itself) and educative components (support elements that communicate what users need to know). Interactional components include the behaviors, interactions, and practices of users during enactment, generally organized according to user groups (e.g., teachers, students). Within the category of interactional components, pedagogical components focus on actions expected of teachers whilst implementing the intervention and learner engagement components focus on student engagement when participating in the innovation.

During the original project in which the curricula were developed, our research team conducted exploratory classroom observations and consultations with STEM-ID developers to identify the critical components of the STEM-ID curricula (Table 1). At the commencement of the current project, we reviewed the STEM-ID critical components with the project team to confirm that, given curricula refinement and further data analysis, these critical components continue to represent the key elements essential to achieving the desired outcomes of STEM-ID.

Table 1
STEM-ID *Critical Components*

<table>
<tr><th colspan="2">Structural – Procedural Component</th><th>Structural – Educative Component</th></tr>
<tr><td colspan="2">1. Course organized according to contextualized problem-based challenges.</td><td>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><td colspan="3">Interactional Components</td></tr>
<tr><td>Component Area</td><td>Teachers</td><td>Students</td></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>

In addition to the componential approach to identifying and categorizing critical components, Century et al. [2] describe several concepts related to investigating innovations that we have found instructive for our STEM-ID implementation research. First is the idea that innovations vary in the number and type of components and the extent to which components are more explicit or implicit. Thus, innovations may focus more on structural components or prioritize interactional components. As evident in our list of STEM-ID components (Table 1), while we attended to essential structural components, we focus primarily on interactional components, which vary somewhat in their explicitness within and across the sixth-, seventh-, and eighth-grade STEM-ID courses. Second, Century et al. highlight that “full implementation of all critical components is not necessarily optimal, noting that appropriate enactment varies depending on contexts and conditions [2].” Similarly, Century and Cassata [1] distinguish between investigations of implementation fidelity, which compares actual implementation to a theoretical ideal, and investigations focused on innovation *use*. Given the broad consensus that innovations are rarely if ever implemented exactly as intended, Century and colleagues encourage measuring how components of innovation are used rather than a focus on strict fidelity of an innovation as a whole. This strategy of investigating *innovation use* over strict fidelity characterizes our approach to studying STEM-ID implementation.

Data Collection

During the current reporting period, the project utilized classroom observations, teacher interviews, and implementation surveys to explore STEM-ID implementation. Each of these data sources are summarized in Table 2 below.

Table 2
Data Sources for ***** Implementation Research

Data Source	Instrument	Data Collected
Classroom Observations	Semi-structured observation protocol Checklist items and field notes aligned to each critical component	103 STEM-ID class sessions total in 4 schools.
Individual Teacher Interviews	Semi-structured interview protocol including questions/prompts	45-60 minute interviews each semester. 11 interviews total.
Group PLC Discussions (Online "check-ins")	Open-ended discussion questions prompting teachers to share updates, challenges, lessons learned with STEM-ID PLC in online group discussion.	45-60 minute discussions 7 monthly PLC check-ins
Implementation Surveys	Online surveys completed by teachers following implementation of each challenge. Surveys include checklist items for key student/teacher actions in the curricula and open-ended items for teachers to describe challenges and adaptations	29 surveys

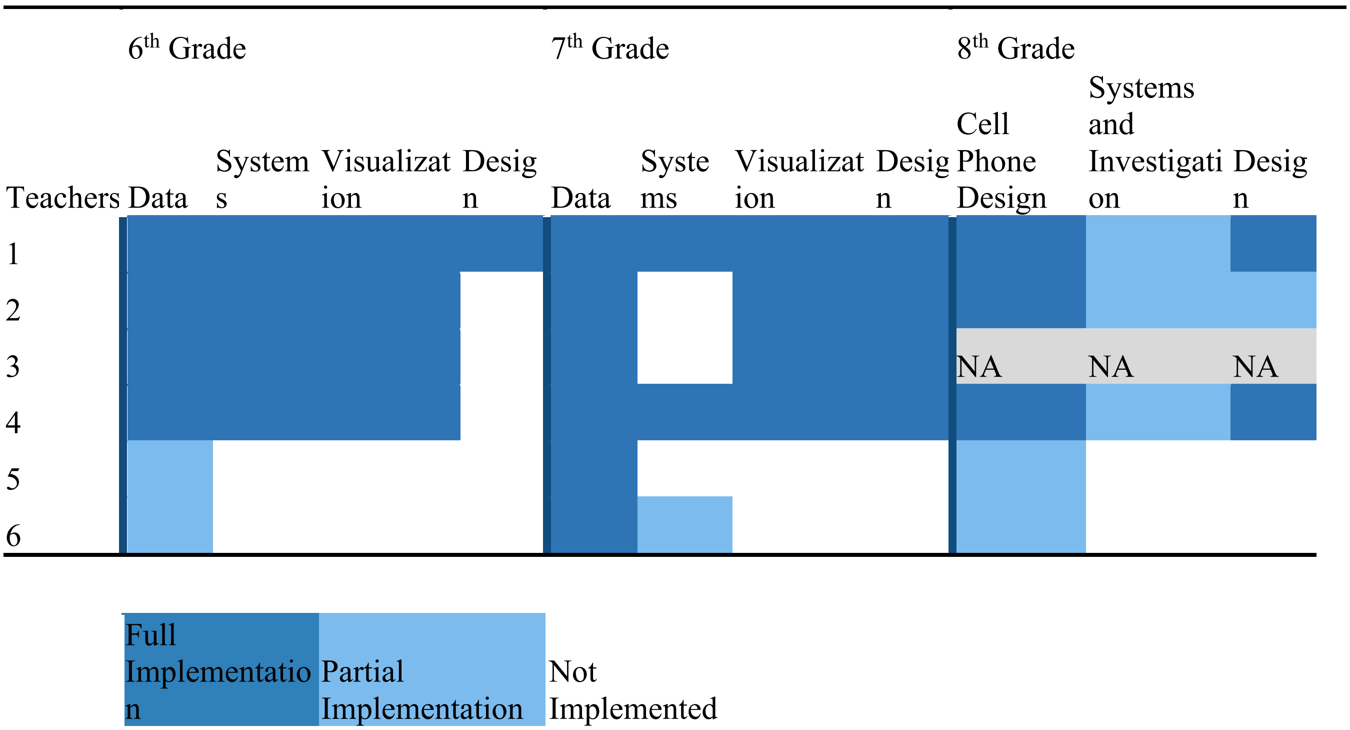
Findings

Illustrative findings from our implementation research highlighted presented below. First, we present analysis of data pertaining to the overall implementation of STEM-ID, followed by an overview of findings for each critical component.

Overall STEM-ID implementation

Figure 1 illustrates the degree of implementation for each STEM-ID challenge by teacher. Degree of implementation tended to be quite similar each semester. Where there were differences in the degree of implementation, the semester with the most complete implementation is represented. Implementation was considered partial when teachers either didn't get to the end of the challenge or did not implement major elements of the challenge (e.g., not having students do presentations at the end of the challenge).

Figure 1. STEM-ID Implementation by Grade Level Challenge and Teacher



Notes: Teacher 6 only participated in the project during the first semester. Teachers 3 and 4 co-teach a year-round schedule and thus implemented STEM-ID once. Teacher 3 only teaches 6th and 7th grade.

STEM-ID implementation varied considerably across teachers, with some teachers completing nearly all of the curricula and others making significantly less progress. Design challenges, particularly at the 6th and 8th grade levels, were the most commonly skipped or partially implemented type of challenge. Partial implementation of the 8th grade systems and investigation challenge can be primarily explained by technical issue that prevented teachers from engaging students in the data-logging part of that challenge. Notably, prior teaching experience and prior experience teaching STEM-ID did not always translate into a higher degree of completion. In fact, the teacher who implemented STEM-ID most fully (T1) was teaching engineering and STEM-ID for the first time during the 2022-23 school year. Conversely, one of the teachers who struggled most to complete the curricula (T5) is a veteran teacher with 28 years teaching experience and three years teaching engineering with STEM-ID. Other teacher characteristics influencing STEM-ID implementation will be further discussed in the Implementation Factors section of this report.

Implementation of STEM-ID critical components

Implementation data provide clear evidence that each of the critical components of STEM-ID were evident as STEM-ID was enacted in participating schools. As would be expected, Implementation of critical components mirrored overall implementation patterns, with teachers who completed more of the curricula tending to implement the critical components more fully than those who did not complete the curricula. Variations in implementation of critical components are illustrated in Figure 2 and illustrative examples related to each critical component are presented in Table 3 below.

Figure 2. Implementation of STEM-ID Critical Components by Teacher

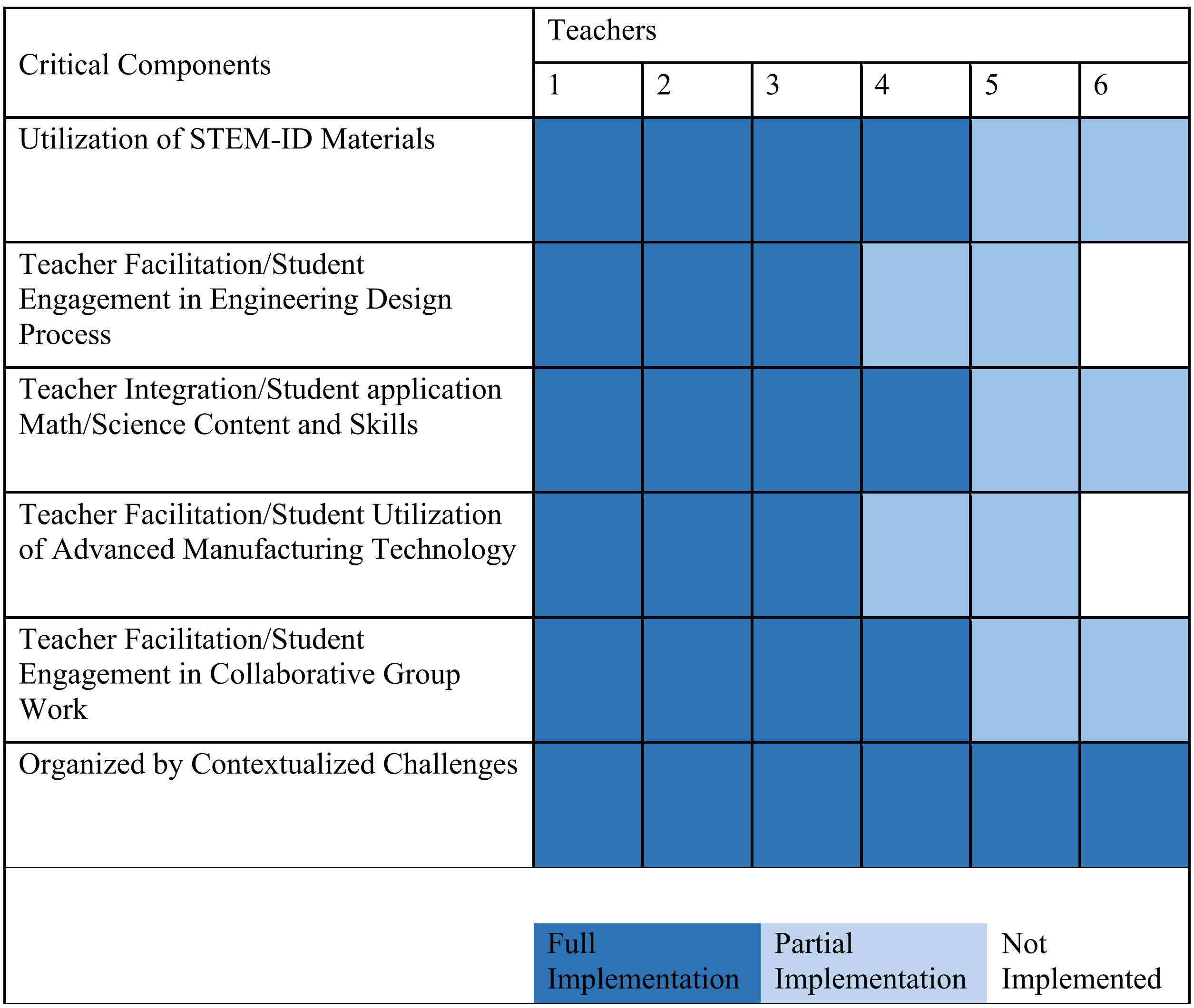


Table 3
Illustrative Examples of Implementation Data by Critical Component

Critical Component	Illustrative Example
Utilization of STEM-ID Materials	Observation data indicate consistent use of digital Engineering Design Process Log (EDPL) during implementation of 8th grade curricula, as suggested. Several teachers also observed using the EDPL with 6th and/or 7th grade classes as well.
Teacher Facilitation/Student Engagement in Engineering Design Process	Interviews document teacher reflections on which stages of the EDP they found most challenging to facilitate. Challenges related to the Ideate and Evaluate stages were most common. For example, Teacher 1 described students' reluctance ideate and the challenge of facilitating iteration: "The biggest thing that they struggled with is the ideate portion and understanding that you should have more than one idea. They all wanted to come up with one idea, make the prototype, and then go on. And then I also wish I had more time with iteration, um, and going back, but overall, they, they got it by the end of the semester."
Teacher Integration/Student application Math/Science Content and Skills	Observation data indicate consistent integration of math and science, as indicated in the curricula. For example, in the 8th grade Robot Rescue Systems and Investigation and Design Challenges, both teachers and students commented on relevant force and motion concepts (e.g., friction, velocity, torque) as they designed and tested robot foot designs. Observations also included instances where teachers referenced relevant science concepts not included in the curricula. For example, during the 7th grade Flight of Fancy Data Challenge, Teacher 3 added a short description of Bernoulli's Principle in a discussion of how an aircraft achieves lift.
Teacher Facilitation/Student Utilization of Advanced Manufacturing Technology	Interview data indicate that partial implementation of this component was most often due to technical challenges (3D printer issues, LEGO robotics software issues). Over 50% of observed class sessions rated as having high student engagement involved students either working in CAD modeling software or testing their 3D printed designs using LEGO robotics. Additionally, observation field notes suggest that within class sessions, students were often particularly engaged when using CAD software.
Teacher Facilitation/Student Engagement in Collaborative Group Work	With very few exceptions, teachers followed curricula guidance when it came to whether activities were best suited for group versus individual work. Instructional strategies, such as assigning roles within groups and conducting progress checks with groups, were reported and observed in these teachers' classrooms. In reflecting on collaborative group work in their classrooms, several STEM-ID teachers affirmed the importance of this component for middle school students. For example, Teacher 4 shared her view that "group work is essential, especially in middle school, right? They need to practice those communication and those social skills."
Organized by Contextualized Challenges	Observation data indicate that instances of students spontaneously referencing the challenge context were rare; however, teachers continually returned to challenge contexts by posting and reviewing challenge requirements in the classroom, periodically reviewing the RFPs provided at the beginning of design challenges, explicitly discussing whether student designs met challenge requirements during the Prototype and Test stage of the EDP, and encouraging students to reference the challenge context in their final presentations.

Conclusion

Data collection during Year 2 of the project provide insight into the degree to which each of the critical components of STEM-ID were implemented and the various factors influencing STEM-ID implementation. Knowing which components of STEM-ID were implemented as intended and which proved more challenging for teachers to implement will inform the project's continued. refinement of STEM-ID materials and its professional development model. These data will also inform future research, including the investigation of connections between teacher outcomes, such as increased self-efficacy and the development of PCK, and successful implementation of STEM-ID. As the scope of the project expands in Year 3 to include new teachers and schools, we will continue to collect data exploring how STEM-ID unfolds in diverse classrooms and the array of factors that may account for variations in implementation patterns across teachers and school settings.

References

[1] J. Century and A. Cassata, A. "Implementation research: Finding common ground on what, how, why, where, and who," *Review of Research in Education*, vol. 40, no. 1, pp. 169-215, 2016.
[2] J. Century, A. Cassatta., M. Rudnick, and C. Freeman. "Measuring enactment of innovations and the factors that affect implementation and sustainability: Moving toward common language and shared conceptual understanding." *The Journal of Behavioral Health Services & Research*, vol. 39, pp. 343-361, 2012.