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Front-end design in middle-school using a web-based collaborative platform: A design-based research approach

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Front-end design in middle-school using a web-based collaborative platform: A design-based research approach (Evaluation)

Abstract

The next generation of young learners face complex challenges ranging from food security to climate change to AI adaptation in the workforce. Challenges like these may be best described as wicked problems owing to their ill structure and multiplicity of competing solutions. Equipping students with experiences and skills from front-end design can help provide new perspectives and toolsets for addressing these challenges. Front-end design deals with the highly open-ended nature of the design process such as problem framing, need finding, and ideation. Given this open-endedness, it can be particularly hard to implement in K-12 settings. This NSF-funded project seeks to support teachers in engaging secondary students in front-end design where they explore and define problems; and then generate and review design ideas that combine scientific, technical engineering, social and contextual considerations. The project takes a design-based research approach in developing curriculum and a web-based platform. The platform enables collaborative content generation, sharing, sketching tools, and scaffolding for idea generation. We present preliminary results of about 30 middle and high school students from the first series of pilots in 3 different classroom contexts (two formal and one informal summer camp). Students were asked to explore and develop solutions to water shortages in their community through a series of 8 activities spanning front-end design processes. We collected post-surveys, interviews, and artifacts from the students, and interviews from the teachers. In this study, we analyze these data streams using quantitative and qualitative approaches to help us understand students' perceptions of engineering, the impact of the project on students' learning, and students' knowledge integration. Teacher interviews also helped guide future iterations of this project. Preliminary findings include an overall positive response by both teachers and students, particularly with respect to aligning the content with issues in the community. Teachers expressed mixed opinions about the technology of the project while student data suggests lack of clarity in what constitutes engineering work. We synthesize these findings to guide our revisions of the learning conjectures and curriculum materials design to illustrate how we use design-based research in this project. We draw out implications for revising the materials, supporting knowledge integration across different areas, and more broadly supporting front-end design in distinct K-12 contexts.

Keywords: front-end design, design-based research, pre-college engineering design

The next generation of working professionals will face complex challenges ranging from food security to climate change to AI adaptation in the workforce. These challenges are particularly "wicked" because of their open-endedness and the potential for solving them using multiple perspectives and approaches. Equipping students with experiences and skills in front-end design can help provide new perspectives and toolsets for addressing these challenges. Front-end design deals with the highly open-ended nature of the earlier phases of a design process such as problem framing, need finding, and ideation [1]. As such, it has been hard to implement in educational settings, particularly in K-12 contexts. While the Next Generation Science Standards (NGSS) have called for an emphasis on engineering design in pre-college settings, back-end design problems, that deal with phases of design after problem-definition, are more common [2], [3], [4]. Only few studies report on the focus of front-end design in K-12 contexts (e.g., [5]).

An ongoing NSF-funded project, MObile Design Studios (MODS), aims to provide late middle and high school educators with a learning environment to support their students in integrating front-end design concepts with Earth Science and Environmental Science challenges. The project is currently in the pilot stage while additional development of the curriculum, learning environment, and teacher support carries on in parallel. This paper describes the findings from the initial pilots focusing on the research methodology guiding the iterative nature of development of the various components of the project. In the following sections, we ground the need for integrating front-end design concepts in pre-college curriculum, followed by a detailed description of the project aims and its various strands. This is followed by the specific contexts of the pilots discussed in this paper including the data collected, findings, and their implications.

Significance of front-end design

Front-end design involves the critical early to middle phases of design work, such as framing problems, identifying impacted and impacting parties on the work, gathering information, defining requirements, and ideating initial solution concepts [6]. Front-end work is essential because many design failures are linked to errors or omissions during these initial stages [7], [8], [9]. Activities in front-end design leverage a combination of sociotechnical and creative abilities to understand people's perspectives and contextual elements, and to develop innovative solutions that align with social values and practical applications. By honing these skills, designers can integrate technical and social dimensions of their work and incorporate stakeholder and community knowledge into their approach to problem-solving and solution creation [6], [10]. Inculcating these skills in pre-college education can help develop an aptitude for structured problem-solving among young learners.

Introduction to the project and the learning environment

MObile Design Studios (MODS) is an NSF-funded project that aims to support teachers in implementing front-end design concepts with secondary students. The project is driven by targeted modifications to an existing web-based platform, CLUE (Collaborative Learning User Environment), that was originally developed to support collaborative project-based learning in other STEM fields. Concurrently, an Earth Science and Environmental Science focused curriculum is being developed that integrates front-end design approaches with challenges in the community to develop socio-scientific and design skills among 7th - 11th grade students. The project team works in multiple interdisciplinary sub-teams to develop the 1) technology, 2) curriculum, 3) teacher professional development, and 4) research. Members from sub-teams overlap and coordinate with each other on a regular basis.

Technology

The CLUE platform, originally developed by the Concord Consortium, is a collaborative web-based platform intended for STEM project-based learning that allows for the generation of many different kinds of artifacts as well as the ability for students to add, modify and adapt each other's content [11]. This base platform serves as the foundation for project specific platforms, in our case, the MODS platform. MODS supports creating artifacts including texts, sketches, tables, images that can be used in project-based collaborative settings across a variety of STEM content areas (e.g., math, genetics, computing.) It also offers a teacher and student view for project work and detailed data logging to track students' learning process. It focuses heavily on some of the CLUE artifact tools such as sketches, tables, text responses and images, to support front-end design in particular. Most importantly, the project team is working to develop a virtual AI design mentor that is aimed at supporting both students and teachers throughout the lessons by learning from student work and prompting with assistive prompts or feedback such as design heuristics [12], [13] to support convergent and divergent thinking as appropriate. See [14] for images of the platform.

Curriculum

The curriculum team designed the first unit to explore the concept of stakeholder need while addressing the challenge of water conservation in their communities. This exploration of stakeholder need involved knowledge-building in both front-end design and earth science. Subsequent modules will focus on other environmental science challenges while maintaining the integration with front-end design approaches. The unit included nine focal activities, spaced across 8 lessons:

- Stakeholder mapping
- Stakeholder profiling
- Research (on existing solutions in their community)
- Scoping
- Research (on areas identified through scoping)
- Sketching
- Brainwriting
- Design Heuristics
- Presentation

Activities to activate prior knowledge and build relevant content knowledge preceded each focal activity, with the first lesson completely focused on these tasks. Each focal activity was also followed by reflection including an engineer notebook where students could reflect on their experience with front-end design. For example, for a lesson focused on idea generation activities, prompts in the engineer notebook included the question “What parts of today's lesson helped you generate ideas? What worked for you? What didn't work?”

The curriculum employed a backwards design approach [15], planning each lesson to align with the final summative assessment so that students build the necessary knowledge and skills to succeed at this final performance task. The final assessment was a presentation and a written reflection in which students presented key design ideas generated during the series of lessons and evaluated these designs based on their understanding of stakeholder needs. In addition to this summative assessment, the focal activities (listed above) and the engineer notebook served as formative assessments to understand students’ strengths and areas of growth as they worked toward the final assessment. The curriculum team also designed learning activities to leverage several aspects of the CLUE platform, including collaborative features such as the ability for instructors to share student work with the classroom, and a learning log for students to archive and annotate important work.

Research

The research team is supporting the development of curriculum, technology, and teacher professional development using a design-based research approach with multiple iterations of pilot implementations and revision cycles. The research team is formed by several researchers including engineering education faculty, education researchers, and graduate students, some of whom support the curriculum and technology development, too.

Design-based research (DBR)

Education research needs a research design or approach to guide its implementation, and carefully considering the most useful approach is essential given the complexities of learning situated in real-world circumstances. One such approach for investigating learning complexities is Design-based research (DBR) [16]. In discussing DBR, Barab [17] argued for a deeper investigation of specific learning contexts to facilitate the generation and development of new theories of learning, giving more focus to the process of learning over its product. Importantly, design-based research takes an iterative approach, by (1) creating preliminary curricula and sometimes technology prototypes, (2) collecting data of its impact on specific learners in specific contexts, and (3) leveraging that evidence to revise and improve the original learning intervention [18]. A central goal of this iterative process is to improve the learning of the participants [17]. DBR provides opportunities for participants to contribute to the development of curriculum and technology, which then can feed back into the research design. To support this process, Sandoval [19] proposed creating conjectures about interventions such as technologies and curricula, which represent claims about how the specific elements of a learning environment affects students and ultimately their learning outcomes. These conjectures are often used to support the DBR process.

Design-based research (DBR) has many benefits over traditional methods; the primary one is the iterative nature of small-scale tests linked with the research findings in specific contexts, that can generate knowledge to be applied to the ongoing educational practices [16], [20]. Design-based research promotes the interaction between interventions, human psychology, local context, and experiences to improve contextual student outcomes [21].

The benefits of DBR and the complexities of students' learning of socio-scientific reasoning, and design thinking led to our selection of a DBR approach as the research methodology for the present study. The approach calls for learning from contextualized situations, redesigning the curriculum and technology, leading to outcomes grounded in research.

Pilot implementations and current study

During the spring of 2024, the curriculum and technology were implemented in two classrooms with teachers in Kentucky: first with a 6th grade earth science teacher with some experience in engineering design projects; and then, a 9th grade physics teacher who had little experience teaching engineering design. Additionally, the program was also implemented in an informal setting where early high school students participated in a university-organized summer camp at a north-eastern R1 university. The summer camp implementation was run by the PI and a postdoctoral associate, both with experience teaching engineering design in undergraduate settings.

Prior to implementation, both teachers in Kentucky met with the PI to get familiarized with the learning environment and content of the curriculum. Some resources with instructions for navigating the platform were also provided. Due to the timing in the school semester, and limited number of sessions available in the summer, not all of the 8 lessons were implemented. Each teacher made appropriate adjustments to the lesson plan given the time available to them.

Data collection and analysis

All three teachers were interviewed by a member of the research team after their implementation. Interview questions were used to elicit feedback on the program, student reactions as perceived by the teachers, and what resources they believed would be helpful to them and their colleagues in future implementations of the program. Interviews were recorded over a web-conferencing platform (Zoom), transcribed, and then analyzed using a thematic analysis approach to compare and contrast perceptions across the three teachers.

A total of 64 students participated in the program across the three implementations. However, only 24 students provided consent. In one of the Kentucky schools, students were asked to answer a feedback survey administered over Qualtrics. The survey asked students several Likert-scale questions about their experiences with the program and some open-ended questions about how they would describe the program, what activities they considered to be engineering, and what was not engineering. This survey was developed by the project's research team which includes several experienced education researchers. The survey was then reviewed and revised by the project evaluator to establish face validity. Since the survey does not measure a latent construct, statistical methods to investigate the psychometrics were not employed. The second teacher was not able to administer the survey due to time constraints in the class schedule. Lastly, in the university-organized summer camp, students gave feedback on the overall camp which had several more activities beyond the program discussed here. Thus, the student data presented in the findings are only from 11 students in the first Kentucky school. Data were analyzed with descriptive statistics methods and open-coding for text-based items.

Findings

Teacher feedback

Both teachers' experiences suggested that students were engaged with the content and found the activities enjoyable. Both teachers found the connections of the content with real life and their community helpful. For one teacher, students went home and asked parents to take the "water use quiz" (an activity in lesson 1 which uses a website to calculate the daily usage of water) and compared the results with their water bill. For both teachers, teaching using MODS was described as helpful in expanding their own knowledge about teaching. Teachers were able to connect with the structure of the lessons either "as is," or by adapting them to their own teaching preferences.

Some of the challenges faced by the teachers were lack of prolonged exposure to the design process, integrating it into the regular curriculum, and student resistance to design thinking without being given the "correct answer." Other concerns were the need for including some form of assessments with the lessons, making the lessons less text heavy (as students migrate towards videos/simulations), and the need for a structure that would help students to keep up/catch up if they missed a section/entire lesson.

Views about technology differed between the teachers even though both found several aspects easy to use and favorable. One teacher enjoyed using the technology even though they did not prefer technology over books in their classroom typically. While signing up on the web-platform was easy, one teacher experienced the need for training for student-selected groups and expressed that assigning groups by teacher may be easier. Using the teacher dashboard was helpful for one teacher and their students, but was not used by the second teacher because switching between the student view and the dashboard while projecting on the classroom screen was cumbersome. Using the learning journal was complicated for one teacher. Encouraging dual modes of sketching where students can use digital sketching but also paper and pencil in regular science journals was also discussed by one teacher. Lastly, the sketching tool was hard to use on chromebooks and would be easier with a touchpad.

Student survey

The students were asked how strongly they agreed with 13 statements about their perceptions of and experiences with MODS. The statements covered various aspects of the project, such as its effectiveness in promoting learning, enjoyment, understanding of engineering design processes, and the value of specific activities like research and stakeholder mapping. Table 1 shows the number and percentage of students selecting each agreement level for each statement, as well as the weighted average score. Overall, the students responded positively. Most students either somewhat agreed or strongly agreed with each statement. Most students disagreed that the activity was confusing. This question, as a reverse-coded item, provides additional evidence that the students were reading and reflecting on the questions.

When asked to identify the top three things (from a list provided on the survey) they enjoyed the most about the project, nine students (81%) chose *Lesson 1: Importance of water conservation* and nine (81%) chose *Lesson 6: Drawing ideas*. Additionally, more than half of the students selected *Lesson 2: Stakeholder building* and/or *Lesson 3: Scoping*. The topics that the students least frequently selected were *Lesson 5: Research, Lesson 7: Idea generation,* and *Lesson 8: Presentation and reflection,* with only one or two students indicating each**.**

The students were also asked to identify which three things they found most confusing. The largest number of students (7, 63%) reported that they were most confused about *Lesson 8: Presentation and Reflection.* It is to be noted that lesson 8 was not implemented in any of the pilots due to time constraints. Since the survey was not edited to maintain consistency across the implementations, this option was not removed before administering. Thus, students selecting this option as most confusing can be attributed to the survey itself. Clarity in the lesson will be evaluated in future pilots. Over half the students noted they were confused about *Lesson 4: Stakeholder interviews* and/or *Lesson 5: Research,* suggesting that these are the two topics that students enjoyed the least. In addition, one student selected *Lesson 1: Importance of water conservation,* as confusing.

Students were also asked how they would describe MODS to a friend. Their responses were sorted by theme, many of which were sorted into multiple categories. Five students responded with enthusiasm, describing it as *fun, awesome or great*. Five students described the experience as *helpful.* Four students also noted it was *easy and/or fast.* Two students noted they learned about *water conservation.* One student's response was coded as neutral.

The survey asked students to describe (open-ended narrative response) four things that they did during the project that were related to engineering. Coding of the responses revealed that the most frequently mentioned engineering activities were *designing*, *mapping*, *sketching*, *researching*, and *scoping*. *Identifying stakeholders*, *water conservation*, *working together*, *building ideas,* and *general engineering* were also mentioned, but less frequently.

The students were also asked to identify four things they did that they felt were **not engineering**. Responses such as "sketches", "identifying stakeholders", and "thinking of designs" were mentioned. It is noteworthy that some students provided similar answers for both engineering and non-engineering work. The data suggest some confusion between engineering and non-engineering work. For example, *identifying stakeholders*, *sketching*, and *designing* were mentioned in both categories. "Drawing or sketching" was identified as engineering work by seven students and as NOT engineering work by six students. Of those, four students reported it as both engineering work and non-engineering work. Similar results were found for *making a design*: of the eight students who reported making a design was not engineering work, three also reported it was the work of an engineer. This overlap suggests that there may have been confusion about the question or a lack of clarity regarding what constitutes engineering work.

Table 1: Descriptive statistics of student responses to Likert-scale items

**Highest response for each statement is marked in bold*

Statement About MODS	Level of Agreement				Mean
	Strongly Disagree (1)	Somewhat Disagree (2)	Somewhat Agree (3)	Strongly Agree (4)	
I believe the activities in this project was helpful for me to learn	0 (0.00%)	2 (18.18%)	3 (27.27%)	**6 (54.54%)**	3.36
I believe the technology in this project was helpful for me to learn	1 (9.09%)	0 (0.00%)	4 (36.36%)	**6 (54.54%)**	3.36
I really enjoyed the activities in this project	1 (9.09%)	1 (9.09%)	**7 (63.63%)**	2 (18.18%)	2.91
I found the activities in this project were confusing	1 (9.09%)	**6 (54.54%)**	4 (36.36%)	0 (0.00%)	2.27
I believe this project helped me understand the engineering design process	0 (0.00%)	2 (18.18%)	**5 (45.45%)**	4 (36.36%)	3.18
I believe this project helped me learn about water conservation	0 (0.00%)	0 (0.00%)	4 (36.36%)	**7 (63.63%)**	3.64
I believe the activities in this project helped me connect classroom knowledge to concerns in my community	0 (0.00%)	0 (0.00%)	**8 (72.72%)**	3 (27.27%)	3.27
After completing this project, I want to do more engineering activities	1 (9.09%)	2 (18.18%)	**5 (45.45%)**	3 (27.27%)	2.91
After completing this project, I want to learn more about what engineers do	0 (0.00%)	3 (27.27%)	**6 (54.54%)**	2 (18.18%)	2.91
After completing this project, I see the value of engineering in my community	0 (0.00%)	2 (18.18%)	**5 (45.45%)**	4 (36.36%)	3.18
After completing this project, I see the value in working with others to design solutions	0 (0.00%)	0 (0.00%)	**6 (54.54%)**	5 (45.45%)	3.45
After completing this project, I see the value of research before designing solutions	0 (0.00%)	1 (9.09%)	4 (36.36%)	**6 (54.54%)**	3.45
After completing this project, I see the value in stakeholder mapping before designing solutions	0 (0.00%)	0 (0.00%)	**7 (63.63%)**	4 (36.36%)	3.36

Discussion

Summary of Findings

This paper outlined the technology and curriculum developed for middle and high school teachers to support them in implementing front-end design concepts in their classrooms. A web-based learning environment is being adapted to provide collaborative sketching affordances in this effort. Pilots were conducted in three different settings using water conservation as a challenge to practice front-end design approaches in tandem with Earth science topics. Findings from the data collected in pilot implementations have been discussed.

Using teacher feedback, it was noted that aligning the content with day-to-day issues in the students' and teachers' community was received well. While the curriculum was easily adaptable by teachers, a need for more structured assessments was expressed. Challenges with technology and suggestions for improvements were discussed even though the overall feedback on the platform was positive. Student feedback in the survey suggests an overall positive response to different aspects of the project including enthusiastic perceptions when describing to a friend. Responses however suggest a lack of clarity in what is understood to be engineering work and what is not. The research team is using this data to iteratively revise the curriculum and modify the web-based platform using a design-based research methodology.

Next Steps

The biggest change planned in the next round of the pilots is the development and implementation of a teacher professional development (PD) program before the teachers implement the program in the classroom. In the pilots, only an informal one-on-one orientation to the curriculum and the learning environment was provided to the teachers. The pilots are being used as a means to identify the bottlenecks in front-end design for teachers and students. These bottlenecks have become the foci of the PD program. The PD will include multiple asynchronous and synchronous sessions to allow teachers to engage with topics of front-end design, preparing for the lesson plan as guided by the curriculum of water conservation challenge, and science and engineering pedagogies for K-12 classrooms. The PD program is being developed by team members who have experience in K-12 science teaching and in front-end design teaching. The sessions will allow teachers to find a community and engage in interactions with facilitators who have designed the curriculum and have experience with the learning environment. The PD implementation will follow a similar DBR based approach where it will be piloted with a few teachers to get feedback and iteratively revised to meet their needs. For example, in the first round of pilots without the PD program, both the Kentucky teachers provided feedback about the types of professional development that are needed to successfully implement MODS. Teacher 1 recommended specific training about how to use the technology. Teacher 2 recommended that the professional development include opportunities for teachers to engage with the lessons in the same way that their students will experience the lessons. Using this feedback, one of the PD sessions will require teacher participants to wear their "student hat" and go through one or more lessons like their students would.

The next big upcoming change in the project is related to the learning environment and the virtual AI design mentor. Initial plans for the mentor included capabilities of supporting divergent thinking during the ideation process using design heuristics. After the pilots and looking at student artifacts, it was observed that students needed more scaffolding with the concept and identification of stakeholders. The research team is currently in the process of identifying prompts that the design mentor can present to students to help them engage in both convergent and divergent thinking as they move through the process of identifying stakeholders and addressing the needs of specific stakeholders in their design process.

In parallel, the research team is collaborating with the curriculum developers to identify threshold concepts in front-end design and add more scaffolding during specific activities. Although over 70% of the students agreed with statements related to enjoyment, interest in further engineering activities, and understanding what engineers do, the findings also suggest these are areas for potential additional gains. In particular, including explicit discussion about engineering and the work of engineers might help more students to understand how the activities are related to engineering and its relevance to their lives. The confusion between what is and is not an engineering or non-engineering activity highlights the need for clearer communication and education about the nature of engineering activities. It may be beneficial to provide students with more explicit examples and explanations of what is considered engineering work to help them better distinguish between the two categories. Another change to the curriculum will involve revisions to the activities to promote more collaborative work where students share their work in teams and build on each other's ideas. The pilots showed a lack of such collaboration among the students.

Lastly, the research instruments will also get more elaborate as the project progresses. Instruments to assess students' self-efficacy in engineering, their attitude towards engineering and science, teachers' self-efficacy in teaching engineering, and attitude towards AI in education are currently being identified and adapted.

These plans and this approach to revisions present a unique way of approaching curriculum design and implementation using design-based research. In particular, the complex integration of earth science socio-scientific skills, open-ended front-end design, and a virtual AI mentor is being addressed using a process that mirrors the front-end design of the program itself.

Limitations

While there are important directions suggested by the preliminary findings of the pilot implementations, there are limits to the generalizability of these conclusions. This is foremost owed to the small sample size in the analysis of the data. While the pilots were implemented with a larger number of students, the number of participants consenting to the research was much smaller. Furthermore, the differences in contexts of the pilots (e.g., formal/informal settings, specific teacher expertise, time available for implementation) undoubtedly influenced the experiences of both students and teachers participating in the module. Additionally, none of the pilot implementations was able to accommodate all lessons developed for the water conservation module in their respective settings. Thus, a complete understanding of the impact of the project is still ongoing. However, the early feedback and findings are crucial in the long-term development and revision goals of such projects.

Implications

The findings from this project provide important insights for educators seeking to implement front-end design in secondary education. Teachers found the real-life and community-based connections engaging for students, suggesting that anchoring design challenges in local or personally relevant issues can enhance student motivation. However, limited time and exposure to the design process made it difficult for students to fully engage with its iterative nature. This finding highlights the need for structured yet flexible implementation strategies that allow students to practice front-end design thinking over an extended period. Additionally, teachers had mixed views on the technology used in the project, indicating that while digital tools can support collaboration and idea generation, their effectiveness depends on ease of integration and teacher familiarity. Design education platforms should prioritize accessible, user-friendly platforms and provide teachers with sufficient training and support to maximize their effectiveness in guiding students through the front-end design process. The study also found that some students struggled with the lack of a "correct answer" and had overlapping or unclear distinctions between engineering and non-engineering work. These findings suggest a need for emphasis in secondary school curricula on the breadth of engineering skills, particularly that successful engineering work incorporates people and contextual considerations into their decision-making. For educators and curriculum developers, ensuring that students see engineering as a field that blends creativity, technical knowledge, and problem-solving within real-world contexts is crucial to fostering a more comprehensive understanding of the discipline.

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