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Board 394: Supporting Secondary Students' Engineering Front-End Design Skills with the Mobile Design Studio

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Supporting Secondary Students' Engineering Front-End Design Skills with the Mobile Design Studio

Introduction

Today's young learners face a future riddled with challenges, including access to clean water [1], increasing biodiversity loss [2], and climate change[3]. These challenges are particularly thorny because the underlying problems are ill-structured and can be perceived in multiple ways. Front-end design focuses on the early, creative, and highly open-ended stages of design such as problem framing, need finding, and ideation [4]. Projects like these could provide a promising context for learning to approach these wicked challenges, but historically front-end design has been difficult to implement in K-12 settings due in part to student unfamiliarity with design, task complexity (e.g., see [5]) and limited resources and preparation opportunities for teachers[6]. The four-year Mobile Design Studio or MODS 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 targets Earth and Environmental Science challenges for late middle school and high school students. The project team is developing a learning environment in which students can jointly learn socio-scientific reasoning and design thinking skills for approaching these wicked challenges. To facilitate this, the project will extend an existing collaborative project-based learning environment with tools specifically supporting design projects. The platform, called CLUE [7], was originally developed by the Concord Consortium to support collaborative project-based learning in other STEM fields. Our extension of CLUE, which we called the Mobile Design Studio or MODS, will enable students to collaboratively explore, make connections, generate, and evaluate design ideas. Critically, the platform will incorporate a virtual AI design mentor that relies on Design Heuristics [8], [9], an empirically-based creativity tool, to guide students through exploration of ideas. The AI mentor will "learn" from students' design processes to better assist them. This agent will rely both on event-based design process logs (e.g., when a student adds to a team members' sketch or revises their problem statement) generated by the system as well as a tagging typology informed by researcher analysis for distinguishing more convergent or divergent concept generation artifacts.

In conjunction with the development plan and following a design-based research approach [10], the team will research students' learning of and ability to integrate socio-scientific reasoning [11] and design thinking (Li et al., 2019; Razzouk & Shute, 2012), as well as changes in students' perceptions of science and engineering and engineering self-efficacy. For students, we leverage the funds of knowledge framework[12], [13] in our curricular structure to help students make connections between their social and community knowledge or resources and the project. The project team will also develop a robust set of professional development (PD) workshops and aim to investigate how the PD and classroom implementation impacts teachers engineering design self-efficacy, classroom teacher moves, and views of front-end design.

In summary, the main projects objectives are:

1) Conduct fundamental and design-based research with secondary students on design thinking, socio-scientific reasoning and related learning outcomes
2) Develop a series of design challenges and associated K-12 teacher professional development workshops situated in Earth science
3) Develop the Mobile Design Studio to support K-12 front-end engineering design
4) Develop an AI-powered design mentor to support students navigating front-end design

In order to undertake these objectives the project team formed three separate but intertwined strands of work - research, technology development, and curriculum development. This allowed us to proceed with major project tasks relatively simultaneously and to leverage members to advance the strand most closely related to their specific expertise. However, it was also important to have several members who were active in multiple strands to ensure cross-discussion of ideas and insights across strands. At the time of writing of this conference proceeding, the curriculum development is approaching its first major full-draft curriculum, the technology development is finalizing a few smaller issues for the current version, and the research plan is nearly ready for piloting testing, where all strands will merge again. Thus, in the present work we report on the progress on each of these strands and where they are headed as the team approaches pilot studies.

In the remainder of the article, we first review more background on front-end design, engineering design in K-12 settings, and the use of computer supported collaborative learning environments and AI for education. We then briefly outline our major theoretical foundations including situated cognition and funds of knowledge and describe how we situate our focus on design thinking and socio-scientific reasoning within this framing. Following this we introduce each of the strands mentioned above, technology development, curriculum development, and research planning. For each we present the original vision of the strand (as described in our original proposal), the work accomplished on it, and its next steps. Finally, we briefly discuss the mechanisms we have employed to help the project succeed and present fortuitous or serendipitous opportunities that have emerged as part of the project, before concluding.

Background

Front-end Design

Front-end design is focused on early stages of design work, encompassing activities like understanding user needs, gathering information, developing requirements, and generating concepts [14], [15]. The criticality of this phase in engineering design is underscored by studies highlighting that failures often stem from inadequacies or errors during front-end work [16], [17]. Successful front-end design necessitates a deep understanding of user perspectives, incorporation of contextual factors, and creative exploration that aligns with people's values and implementation contexts. As such, front-end engineering design requires sociotechnical and creativity skillsets. Through applying these skillsets to understand design problems and generate solutions, students are set up to make connections across technical and social aspects of science and engineering work [18], as well as to integrate personal and community knowledge into their understanding of the problem and potential solutions.

Numerous frameworks, tools, and methods exist to aid various aspects of front-end design. For instance, in idea generation, Design Heuristics serve as a tool offering prompts that stimulate diverse idea exploration during the design process [8], [9], [19]. These heuristics, arising from empirical studies on idea generation among designers, have been consolidated into a set of 77 cards, enabling novice designers to access and apply these heuristics. They leverage established patterns to inspire idea generation, encouraging consideration of technical, contextual, and stakeholder-related facets in design concepts. Research has evaluated the impact of these cards across expertise levels, from high school students to practitioners, demonstrating their efficacy in fostering more diverse and numerous ideas, achievable even through brief training sessions. Additionally, users find them accessible and beneficial in their idea generation processes [9], [20], [21], [22].

Engineering Design in K-12

The next generation science standards or NGSS, which include an emphasis on science and engineering practices, have led to an increased interest and use of engineering design in K-12 schools [23]. While there has been some research deploying front-end design in K-12 settings (e.g., [24]) historically back-end design, which focuses on design stages after the problem is largely set or defined, have been more common in K-12 settings [25], [26], [27].

AI in Education and Design

Artificial intelligence (AI) can be broadly construed as a field that seeks to create systems and/or algorithms to perform tasks that are thought to require intelligence and not simply brute computation [28]. Some research in AI also aims to develop human-like intelligence or in some measure create an “artificial” cognitive structure and responses in whatever “contains” the AI [29], [30]. AI in education involves the application of AI techniques and methods toward supporting learning or educational goals. There is a long history of AI being used to support learners from intelligent tutoring systems that track students learning through series of problems and provide custom problem delivery and supports[31], [32], [33] to the more recent use of large-language model, such as ChatGPT, to generate content or support for students (e.g., [34]).

While AI has been used extensively in some education areas such as math [35], [36], [37] and science [38], [39], it has been used relatively less in design education. Most of the work that does focus on using AI to support design education tends to examine highly constrained design problems, such as the design of a gear or shaft (e.g., see [40], [41]). One exception to this is the very recent work by [42] that analyzed students’ design thinking with generative design tools, which leverage AI to search for design solutions. This study uncovered a relationship between students’ ability to employ convergent thinking and generative design reasoning. In contrast to the limited application to design education, AI has seen substantial application in design practice. There is a long history of leveraging AI to support designers by embedding AI-powered assistive tools in design software. A common application for these assistive tools is offsetting some part of the designers search or optimization process to the tool[43], [44], [45]. More recent innovations have focused on having AI algorithms learn from human designers (e.g., [46], [47]) and the advantages and disadvantages of human-AI collaboration in design [48], [49], [50].

Work by [51] sought to synthesize research from both AI applications in education and design. In their work, they identified this hybrid application to design education as *instructional design agents* which can be embedded in learning environments. These agents can take several roles (e.g., teammate or mentor) and can assist novices by embodying good design thinking activities and scaffolding task complexity. They proposed a tripartite framework for developing instructional design agents, which focused on the role or design tasks the agent was responsible for, the role or design tasks the student is responsible for and the agent and students' interactions. See Figure 1.

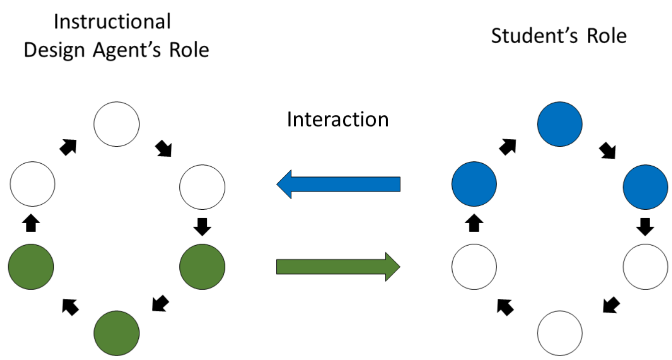

Figure 1 - Tripartite Framework for Creating Instructional Design Agents. Adapted from Schimpf, C., Huang, X., Xie, C., Sha, Z., & Massicotte, J. (2019). Developing instructional design agents to support novice and K-12 Design Education. In ASEE annual conference & exposition.

The present work builds on past research in front-end design, engineering design in K-12 and AI in education and design to analyze how a collaborative learning environment with an AI-powered design mentor can support middle and high school students to engage in the messy, iterative, and open-ended nature of front-end design challenges.

Theoretical Frameworks

The two core frameworks guiding this work are 1) situated cognition, which subsumes design thinking and socio-scientific reasoning and 2) funds of knowledge. We describe each below.

Situated cognition describes learning as the development of knowledge, practices, and ways of thinking tied to specific contexts, such as a particular field of science [52]. As such, learning should ideally occur through experiences engaging in authentic practices in a given context of study. Situated cognition has been used to study how students develop design thinking skills [15] and research describes design expertise as including contextualized skills and knowledge [53], [54]. However, in secondary school contexts, it is unlikely that students will be able to become design experts. We, therefore, draw more specifically on the Informed Designer Matrix [55], which synthesized research on design thinking activities and proposed a new intermediary learning state, the informed designer. For example, whereas a novice designer will often generate only a few design ideas, an informed designer will exhibit idea fluency, generating different ideas through divergent thinking, and using these ideas to identify promising solutions. Three dimensions of the matrix [55]—namely, understanding the challenge, generating ideas, and weighing options and making decisions—are particularly relevant for our front-end design focus.

Situated cognition also grounds our work on socio-scientific reasoning, defined as a mode of thinking that bridges scientific concepts and social contexts, such as students' family or community life (e.g., [56]) or societal issues like climate change [11]. Several studies suggest connecting students' personal or community social contexts to science projects is a potent way for improving learning and interest outcomes [57], [58].

We combine this conceptualization of situated cognition with the Funds of Knowledge (FoK) asset-based framework [59]. Asset-based frameworks contend that students have assets from life outside school that can help them succeed, in contrast to deficit theories, which view education as primarily overcoming student deficits [60], [61]. Asset-based approaches are particularly important for marginalized students in STEM fields, such as low SES and minoritized students, as they help teachers and students recognize the valuable resources students bring to learning. FoK was developed through ethnographic work in students' homes and communities [13], [62], and seeks to uncover and leverage students' resources, in the form of knowledge and practices, in the classroom [61]. FoK has several advantages: it has been frequently leveraged in science and engineering education [12], [59], [63], [64]; key fund types have been identified, including family, community, peers, and popular culture [59], [65]; and explicit and adaptable prompts for eliciting students' key fund types exist [12], [66]. Finally, FoK aligns with the concept of hybrid spaces or spaces that integrate disciplinary knowledge and practices with personal and community knowledge and practices [59]. Hybrid spaces can support creative problem and solution exploration that considers stakeholders and context and integrates personal, community, and disciplinary knowledge, which also aligns with this work's goals of emphasizing science, engineering and community or social-based knowledge.

Project Progress on Major Task Strands

Curriculum Development

Original Vision

Our original vision for the curriculum development strand was to create five front-end design challenges that are grounded in distinct Earth Science concepts and that encompass technical, social or community-based and science aspects of the problem. Each of these challenges would last approximately one week to two weeks of class time and would be crafted to be age-appropriate for middle or high school students, possibly resulting in variations for different populations.

Current Work

While all three strands have been in development concurrently since fall of 2023, the curriculum strand was the first to begin. This is due in large measure to the fact that the other strands were at least partially dependent on curriculum progress. For the technology strand, although we had a broad vision of how to transform CLUE into MODS, a more detailed curriculum would also raise new considerations for how that technology vision could be implemented and highlight aspects of CLUE that may need to be enhanced to support front-end design learning. More directly, without knowing the shape of the curriculum, our research plan could not clearly unfold, as details of the curricular intervention would inform how and what data we collected or where we needed additional research instruments. The curriculum development efforts are led by three members (Giroux, Harmon, and Handley) who have experience in K-12 classrooms, with assistance from other research team members. The primary goal in this effort was to develop a full set of lessons for one Earth Science topical area, which could serve as a prototype for future units.

The curriculum development followed a backwards design approach [67], that started with developing a shared understanding of the purpose of the curriculum and the knowledge and skills students would demonstrate during the final summative assessment. The primary purpose of the curriculum was to engage students in the practices of front-end design [4] supporting students throughout each lesson to develop a strong understanding of stakeholder need while exploring the ill-structured, real-world issue of water conservation. Another central purpose of the curriculum was to help students draw connections between and leverage science, engineering, and social or community knowledge. The curriculum supported students to explore this problem locally, understanding water conservation issues and challenges in their own communities, to allow students to leverage funds of knowledge [12], [13] and their local expertise as they engaged in the process of front-end design. The summative assessment at the end of our series of lessons is an extended reflection task that prompted students to revisit their work throughout the series of lessons. During the reflection task, students would explain how their design solutions met the needs of stakeholders and provide evidence from their work products (such as a stakeholder map, research notes, or scoping table). During the reflection task, students would also reflect on the interesting, surprising, and challenging aspects of their design process.

Following a backwards design approach, the team then developed a sequence of 8 lessons that would leverage students' background knowledge and funds of knowledge and scaffold their learning to prepare them for the final reflection. Each lesson followed the general structure of lesson introduction, activities, and reflection prompts. Learning activities emphasized front-end design methods and included stakeholder mapping, creating stakeholder profiles, scoping, research, and multiple idea generation activities. The curriculum team used the collaborative features of MODS to include opportunities to discuss and share student work in each lesson. The curriculum also included opportunities for formative assessment in each lesson using the learning log in MODS and the engineer notebook. In the learning log, students can add content from their workspace into a log that they can access across lessons. Students can also annotate their work in the learning log. In the engineer notebook, students reflect on their learning in each lesson (i.e., the third part of every lesson) through typing or sketching guided by a question prompt related to the lesson objectives. Through collaborative learning activities and ongoing formative assessment, students will be well prepared to experience the front-end design process, explore issues of water conservation, and propose design solutions that meet stakeholder needs.

Next Steps

The next step in curriculum development is to collect pilot data on the implementation of the curriculum with middle school students to identify areas of improvement through an analysis of student work, open-ended questions, observational data and/or interviews. An analysis of student work collected in the MODS platform will identify any challenges or difficulties students face in achieving the learning objectives and observational and interview data taken from the classroom during the curriculum implementation will identify any aspects of the curriculum, for example the clarity of instructions and the usability of the MODS interface, that can be improved so that the curriculum supports all students to achieve our learning outcomes.

Piloting the curriculum will also provide opportunities to provide professional development for educators and receive feedback. Currently, the team is developing professional development activities that will engage educators in the same activities that students will experience in the curriculum combined with opportunities to reflect on the experience. Our activities will allow for teachers to reflect on pedagogical approaches to implementing the curriculum but will also engage educators in reflection on the process of engaging in front-end design, building engineering content knowledge for educators who may have had little exposure to the subject matter.

Technology Development

Original vision

Our original vision for the technology development strand was to extend the Concord's Consortium's CLUE environment to the Mobile Design Studio or MODS and to develop an AI design mentor that would share design heuristics with students when they were struggling with front-end design. CLUE is a web-based platform that supports student collaboration in project-based learning by enabling a broad array of artifact generation (e.g., text, sketches, graphs), has a robust action-logging system for tracking student use of the platform, and allows teachers and students to share and adapt their work [7]. Our initial vision for the design mentor was to follow the framework put forth by [51] and specifically have the mentor support students when sketching by providing customized design heuristic prompts based on activity in the CLUE event logger (e.g., if they are not creating many sketches).

Current work

The technology strand started after sufficient progress had been made on the curriculum strand. This allowed insights from curriculum development and newly discovered needs to inform the technology development, while the technology development itself could inform how research may be conducted. The technology strand is led by Concord Consortium, specifically team member Bondaryk who is the chief technology officer at Concord and her team of software developers and project managers. PI's Schimpf and Daly likewise provided expertise on the content (e.g., front-end design and supporting design learning with technology) which informed development goals. The primary goals of this effort was to expand the CLUE platform to support student engagement with front-end engineering design projects and to create an AI-powered design mentor that can support student learning in these open-ended challenges.

As with all work done at The Concord Consortium, an iterative, agile development process is used to identify the technology features that will most impact a project's ability to implement and measure a desired intervention. A series of design discussions around the curriculum and the supports for students design sketching informed both the upgrade of the drawing tool and the facilities for introducing additional AI mentor content. We are now building features in two-week sprints so that the project team can review progress and provide feedback on direction as we go. New versions of the software appear on test branches so they can be reviewed and adjusted long before they ever make it a class test. New features are also made available in an authoring system - CLUE documents are used both by students and curriculum developers - so their utility and future specifications come from a steady stream of feedback from real use cases.

The CLUE platform upon which MODS is based already had a number of important facilities to support the development of a collaborative, generative front-end design curriculum. An initial gap analysis revealed the need for additional features in our sketching tools, so our early focus was on making the sketch tool far more robust, accessible, and functional on touch/tablet devices to make the drawing process as easy for students as working on paper, but in a digital environment that allows for easy revision, sharing and iteration. We added a number of new sketching tools and created an interface that would allow students to work with shapes, have multiple drawing layers, and group objects in their drawings:

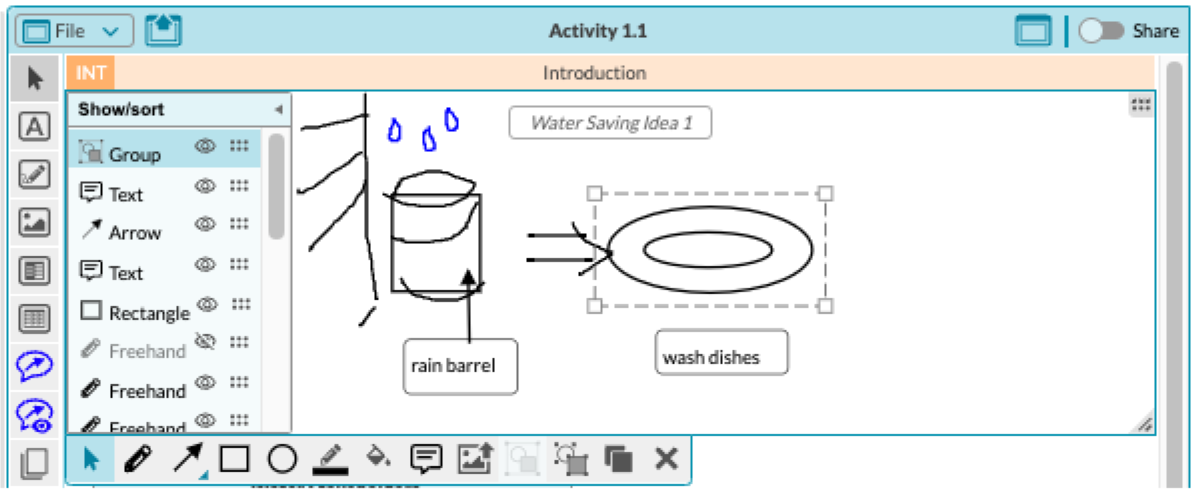

Figure 2 -MODS Sketching Tool Example

The tools added were geared towards making quick, communicative drawings that are easy to revise, and include arrows, text labeling, resizing, grouping, ordering, and visibility. These tools were developed to work as far as possible with both digital pen, mouse, keyboard and touch for the greatest number of modalities and accessibility.

Note that, like all tools in the CLUE system, the student is encouraged to label their drawings. Recording notes within the drawing and titling is critical for keeping track of different kinds of design attempts, versions, and general intent. These features will be important as the teachers and eventually the AI mentor attempt to evaluate and categorize student work as we will see in the next section. This work on a tagging system that the AI mentor could tap into fortuitously emerged as part of CLUE's larger development cycle. We originally intended the AI mentor to rely primarily on action logs, but expanding to tagging artifacts, such as different sketches students produced, may allow us to have the agent offer customized design heuristic suggestions based on ideas they have expressed less in their sketches.

Related to above, the other piece of work to begin early in this project is a system for categorizing student work in a way that allows feedback. The categories must be specific enough that helpful feedback can be given that is relevant to each piece of student work, but general enough that they cover common cases and have meaning for the student journey in the curriculum. Selecting these categories is the work of the curriculum designers, and these are expected to evolve over the duration of the project. That requires a system in CLUE for exposing and applying these tags that is similarly flexible and updateable. A system was developed for applying tags defined in the curriculum. These can be applied to any piece of student work by the teacher or the researcher as more data is generated in the system. Eventually we expect to train the AI system to recognize these different categories reflected in student work, but for now we need more tagged training data. The existing teacher comment system was co-opted for this work, allowing teachers to annotate why they chose the tag they did as well as apply tags to documents or specific sketches, and apply multiple tags as the work evolves.

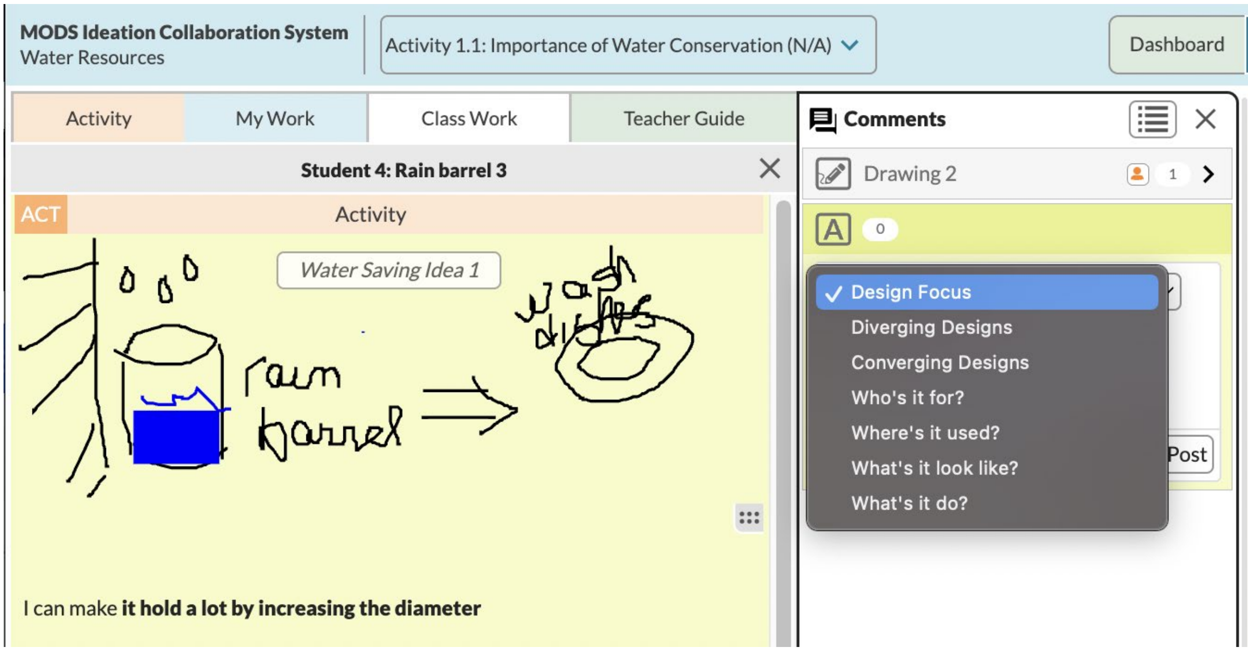

Figure 3 - MODS Tagging System Example

These tags will be presented to teachers and students through new views in CLUE that allow all the work in the class to be sorted by strategy, along with other relevant sorts such as by collaboration Group or by Student or Bookmarks. These sorts will both encourage teachers to apply tags to help their students know what directions to take their sketches, and help students to discover potential strategies. If all of a student's documents fall in a single strategy or two, they may wish to explore alternatives. Part of our work this spring will be to also supply examples of design heuristic strategies as part of the curriculum, so that the AI mentor can guide students to alternative content as part of these views.

Website Development

Finally, outside of the main development at the Concord Consortium, UB has led the creation of the website for the MODS project. Team member Fan created the website using basic HTML, CSS and Javascript. HTML constructs the basic structure of the website, CSS enhances the pages to make them more appealing and engaging to users, and Javascript allows users to interact with the site. The website is for anyone interested in learning more about the MODS research project and our work throughout its project timeline. It also serves as a resource for teachers to gain teaching insights about the project and for them to acquire curriculum and teaching resources to use in their own classrooms. The website includes a landing page with a general introduction to the research, a curriculum page, a teacher resources page, the ideas behind the project, related publications and presentations, a team page introducing everyone involved, as well as a contact page to send us any questions or suggestions.

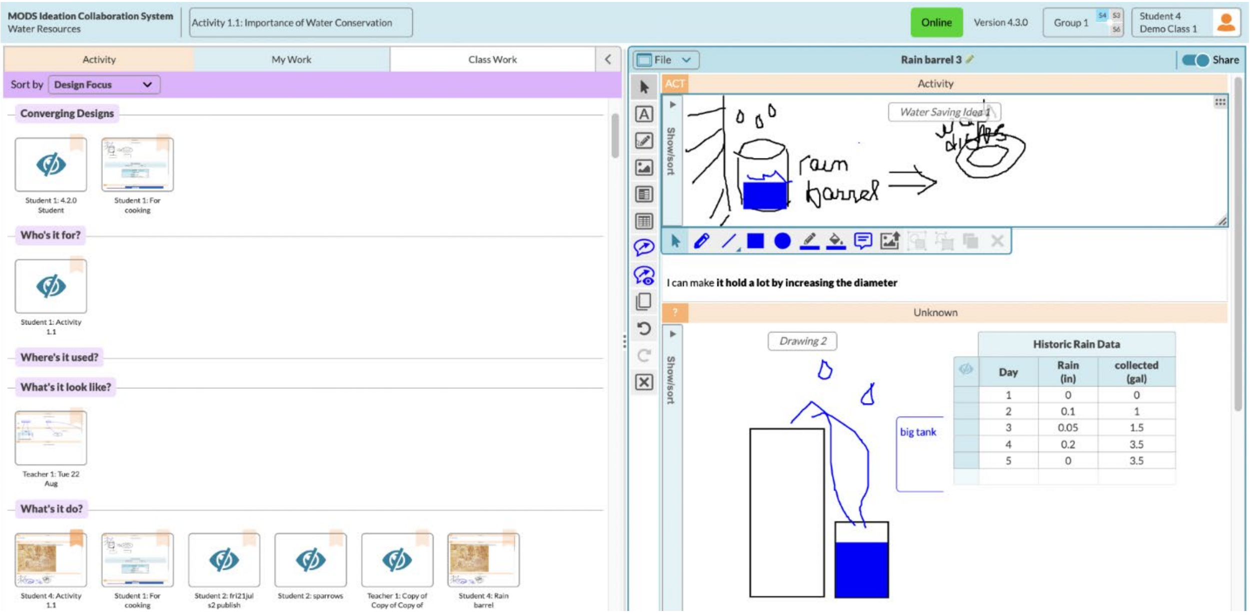

Figure 4 - MODS Sorting

Next Steps

The late spring will provide opportunities for this new UI work to be tested in classrooms with teachers and students both for usability of the sketch and collaboration tools, and for the educational enhancement effects of the heuristic support files. While we are vetting the software and the curriculum, the tagged student data that we gather during these class tests will also form the basis of our training set for future AI determination of strategy. These files as well as other examples drawn from the literature will be used to train a model that can tag student work for the teacher and can guide the student to particular files - either from the exemplar heuristics or from peer work. We will also analyze the workflow data to see when students begin to seek examples from their classmates or the curriculum, so we know when to trigger the AI mentor to offer help.

Research Plan

Original vision

Our original research plan sought to investigate how our front-end design intervention might impact middle and high school students' design thinking and socio-scientific reasoning abilities, as well as their ability to draw connections between science, engineering, and community or social knowledge. We also sought to conduct design-based examinations of different versions of the curriculum and technology to better understand how changes did or did not impact these learning outcomes. We planned to collect both quantitative and qualitative data including student artifacts, pre/post surveys, and interviews.

Current work

Of the three strands, research planning started last, as it depended on notable progress in the curriculum and technology strands, as described above. The research team was led by the PI's at University at Buffalo and University of Michigan and their research teams, with some of those on the curriculum development team also joining as researchers, as well as a researcher from the Concord Consortium. The primary goal of this group in this period was to plan the research design for pilots of the initial curriculum and prepare any research instruments, experiments, or other protocols needed to support this effort.

The research team started by outlining the broad topics of investigation each team member thought would be important to this study. It became evident that to gain an in-depth understanding of introducing front-end design using a web-based platform, perceptions and lived experiences of multiple stakeholders would be necessary. While student experiences and behaviors would be valuable, teacher perceptions would also be key to creating appropriate scaffolding tools to support them. This represented a shift from the original vision as written in the grant, where students were the primary subject of inquiry. In regular meetings, potential research questions were discussed, and relevant data sources identified to support those investigations. Initial discussions provided a framework for planning the research endeavor with several stakeholders. Research would be conducted at multiple stages including the pilot implementations that would support the iterative improvement and subsequent implementation of the succeeding full-scale implementations. Since the study involves a large number of stakeholders, a project-management approach to the planning was essential. A structure for organizing research questions, appropriate data sources, and potential scholarly venues was created using collaborative spreadsheets. Research and its various components took an important place in the Gantt chart that was developed to graph out the timeline of the project.

The research team also tasked itself with collaboratively deploying a front-end design process to shape the development of the agent including its purpose, underlying philosophy and scope of actions that it will take with students or teachers This would be key to supporting the technology development by outlining the tasks and behaviors the agent would be able to perform. Questions like for who, what, how, and why will need to be answered. In discussions that ensued on this, the research team found that their approach in the planning of research was also very design-oriented. Important questions in the context of the agent have been identified by the team which will guide discussions on creating criteria for the development of the agent. The team will collaboratively brainstorm different possibilities for several aspects of the agent's interactions with the stakeholders. Facets like agency of the agent, agency of students, and how the agent will support the teachers will be discussed. The result of the brainstorming sessions will be a set of guidelines or requirements for the technology development team which will be further developed in an iterative cycle using stakeholder artifacts from the interactions with the platform.

Next Steps

At the end of the spring academic semester, we will be running pilot tests of our initial curriculum with students, as mentioned in the curriculum development section. Data collection at this stage will focus on student perceptions of front-end design, engineering, and how it is situated in societal contexts. Research findings from the curriculum pilot tests will drive curriculum revisions and guide future implementations as described earlier. Teacher's feedback will also be documented to inform both curriculum revisions and professional development practices. Brainstorming sessions to identify agent characteristics are ongoing. The immediate next steps also involve planning the research design for the curriculum implementation post-pilots and requesting IRB approval for further research.

Mechanisms of Success

Given the size and scope of this project there are several ways it may prove difficult in terms of logistics, our diversity of academic and applied perspectives, and technical feasibility. We have employed several mechanisms to try to provide checks on our process and to better ensure our voices and insights are incorporated into project progress. There are three major mechanisms we have relied on. First, our evaluator and broader evaluation plan. Our evaluator has over thirty years of experience with federally funded programs, including DRK12 projects like this one. More importantly, our evaluator has been embedded on several of the sub-teams and employs an evaluation approach that involves micro-testing of research and curricular prototypes iteratively, which aligns well with our design-based research focus on iterative testing and contextualized development [10]. Given the size and volume of materials being generated for curriculum and research purposes, this approach enables us to provide checks at multiple levels of scale and across contexts. Coupled with our evaluator's regular feedback, potential issues or possible new opportunities can be identified earlier before the project has progressed too far.

Second, although we have three separate strands of work, members from other teams frequently participate in other strands. For example, several of our research team members reviewed each curriculum lesson draft and met with the curriculum team to provide feedback and suggestions for revisions. Additionally, several of the curriculum team members join the technology team meetings to provide suggestions on possible revisions or additions to the MODS platform based on the curriculum development. In this way we ensure the project is truly interdisciplinary (e.g., see [68]) across the diverse expertise of our team members and strands are not operating in isolated silos. Third, and related to above, our teams embrace the philosophy of using prototypes as communication devices across group boundaries [69]. From jamboards created by the research team, to sketches from the technology team and scope and sequence tables by the curriculum team, these artifacts help us communicate ideas across the strands and allow others to react and build upon each other's ideas. In lieu of not being able to participate in meetings across all groups, these prototypes facilitate transmission of ideas across teams asynchronously.

Serendipitous Opportunities in Project Execution

Although our initial grant proposal set out the vision for this project as we have progressed on the project goals there have been times new ideas or opportunities emerged serendipitously. In a designerly spirit we have embraced these fortuitous happenings. Two major examples have appeared so far. First, in the original vision of the design mentor, we thought it would primarily support students while sketching, which is lessons six and seven of the current curriculum unit. However, as the research team began discussing the design mentor and reviewing the curriculum thus far, we felt only focusing on the sketching lessons may be too narrow of a support system. Moreover, given the wide range of experiences our team brings to the research including science education, engineering education, mechanical engineering, data science, literacy education, teacher education, educational technology, K-12 education we felt that leveraging our unique insights and perspectives could help us design a more robust design mentor. As such, we have begun a series of brainstorming sessions to collectively redefine the envelope of what the agent or design mentor may do.

The CLUE software developed by the Concord Consortium is a general platform and set of features that supports a variety of project-based learning curricula including biology, computer science, and math. Many of these development projects run concurrent with the MODS project, which focuses on front-end design. One of the other strands of CLUE has begun development of a student artifact tagging system that would allow teachers or researchers to tag student artifacts to classify them as examples of key learning outcomes or challenges. A sufficiently large pool of examples could then be analyzed by a classification algorithm which would allow the system to automatically recognize aspects of a student's work and offer more specific feedback. In light of the fact that the team already planned on using the event or action logger of CLUE to help identify where students are struggling in front-end design and how to support them, we saw the tagging systems as another opportunity to better capture students activities in the platform, not only through their actions but also through the artifacts they generated. The team is currently working on a categorization schema that could be used to classify student front-end design artifacts that may give us additional insight into what students have completed or understood and serve as another basis for specialized feedback or support. Since MODS is built from CLUE, we can simply bring these new features into MODS without having to begin any separate development cycles. We are hopeful this will help us better understand how students navigate the complex landscape of front-end design.

Conclusions

As part of the NSF Grantees Session, on our key objectives our progress thus far has resulted in a prototype of our curriculum, a quickly approaching pilot of our research design, MODS has emerged as a modified version of CLUE for front-end design and we have begun the project of envisioning a much more robust design mentor. In this work we have also highlighted our next steps for each of the strands of the project. Front-end engineering design is an underemphasized project area and can be used as means to encourage interests in and improve perceptions of STEM fields especially when grounded in socio-cultural contexts. Prior research suggests that integrating community concerns with engineering and science can encourage women and persons from minortized groups who often place greater emphasis on community impact of their work but find engineering detached from their experiences (Colvin et al., 2012; Smith et al., 2014). We combine Earth and environmental science contexts with front-end design process, an initiative not implemented before to further embed engineering within secondary science curricula. These design projects are aimed at providing both students and teachers with exposure to engineering and implemented with research-based scaffolding strategies and a design mentor. In this paper on our project, we describe how three different, but interconnected strands are following a design-based approach to leverage the strengths of professional development, AI and data science, and project-based learning to build a model for implementing front-end design in secondary school under different domains. Building on our experiences so far and following a planned approach that includes interdisciplinary collaboration and strategic and iterative evaluations, we aspire to add to the knowledge-base of NSF’s 10 Big Ideas, the human-technology frontier.

[1] “Grand Challenges for Engineering,” National Academy of Engineering, Washington D.C., 2017.
[2] G. M. Mace *et al.*, “Aiming higher to bend the curve of biodiversity loss.,” *Nature Sustainability*, vol. 1, no. 9, pp. 448–451, 2018.
[3] S. Fawzy, A. I. Osman, J. Doran, and D. W. Rooney, “Strategies for mitigation of climate change: a review,” *Environmenal Chemistry Letters*, pp. 1–26, 2020.

[4] I. Mohedas, S. R. Daly, and K. H. Sienko, "Requirements Development: Approaches and Behaviors of Novice Designers," *Journal of Mechanical Design*, vol. 137, no. 7, p. 071407, Jul. 2015, doi: 10.1115/1.4030058.

[5] Nguyen-Thinh Le, F. Loll, and N. Pinkwart, "Operationalizing the Continuum between Well-Defined and Ill-Defined Problems for Educational Technology," *IEEE Trans. Learning Technol.*, vol. 6, no. 3, pp. 258–270, Jul. 2013, doi: 10.1109/TLT.2013.16.

[6] J. Utley, T. Ivey, R. Hammack, and K. High, "Enhancing engineering education in the elementary school," *School Sci & Mathematics*, vol. 119, no. 4, pp. 203–212, Apr. 2019, doi: 10.1111/ssm.12332.

[7] C. Dorsey and L. G. Bondaryk, "Real-Time WYSIWIS System for Shared Artifact Construction in Student Groups Collaborating on Mathematical Inscriptional Learning," presented at the Digitally-Mediated Team Learning, Washington D.C.

[8] S. Yilmaz, C. Seifert, S. R. Daly, and R. Gonzalez, "Design Heuristics in Innovative Products," *Journal of Mechanical Design*, vol. 138, no. 7, p. 071102, Jul. 2016, doi: 10.1115/1.4032219.

[9] S. R. Daly, S. Yilmaz, J. L. Christian, C. M. Seifert, and R. Gonzalez, "Design Heuristics in Engineering Concept Generation," *Journal of Engineering Education*, vol. 101, no. 4, pp. 601–629, Oct. 2012, doi: 10.1002/j.2168-9830.2012.tb01121.x.

[10] S. Barab and K. Squire, "Design-Based Research: Putting a Stake in the Ground," *Journal of the Learning Sciences*, vol. 13, no. 1, pp. 1–14, Jan. 2004, doi: 10.1207/s15327809jls1301_1.

[11] V. Dawson and K. Carson, "Introducing Argumentation About Climate Change Socioscientific Issues in a Disadvantaged School," *Res Sci Educ*, vol. 50, no. 3, pp. 863–883, Jun. 2020, doi: 10.1007/s11165-018-9715-x.

[12] A. Wilson-Lopez, J. A. Mejia, I. M. Hasbún, and G. S. Kasun, "Latina/o Adolescents' Funds of Knowledge Related to Engineering: Latina/o Adolescents' Funds of Knowledge Related to Engineering," *J. Eng. Educ.*, vol. 105, no. 2, pp. 278–311, Apr. 2016, doi: 10.1002/jee.20117.

[13] N. Gonzalez, L. C. Moll, and C. Amanti, Eds., *Funds of Knowledge: Theorizing Practices in Households, Communities, and Classrooms*. New York, NY: Routledge, 2005.

[14] Y. Li *et al.*, "Design and Design Thinking in STEM Education," *Journal for STEM Educ Res*, vol. 2, no. 2, pp. 93–104, Dec. 2019, doi: 10.1007/s41979-019-00020-z.

[15] R. Razzouk and V. Shute, "What Is Design Thinking and Why Is It Important?," *Review of Educational Research*, vol. 82, no. 3, pp. 330–348, Sep. 2012, doi: 10.3102/0034654312457429.

[16] A. M. Davis, *Software Requirements - Objects, Functions, and States*. Upper Saddle River, NJ: Prentice Hall, 1993.

[17] A. Khurana and S. R. Rosenthal, "Towards Holistic 'Front Ends' in New Product Development," *Journal of Product Innovation Management*, vol. 15, no. 1, pp. 57–74, 1998.

[18] I. Mohedas, S. Daly, and K. Sienko, "Gathering and Synthesizing Information During the Development of User Requirements and Engineering Specifications," in *2014 ASEE Annual Conference & Exposition Proceedings*, Indianapolis, Indiana: ASEE Conferences, Jun. 2014, p. 24.639.1-24.639.9. doi: 10.18260/1-2--20530.

[19] S. Yilmaz and C. Seifert, "Creativity through design heuristics: a case study of expert product design," *Design Studies*, vol. 32, no. 4, 2011.

[20] S. R. Daly, C. M. Seifert, S. Yilmaz, and R. Gonzalez, "Comparing Ideation Techniques for Beginning Designers," *Journal of Mechanical Design*, vol. 138, no. 10, p. 101108, Oct. 2016, doi: 10.1115/1.4034087.

[21] C. M. Gray, C. M. Seifert, S. Yilmaz, S. R. Daly, and R. Gonzalez, "What is the Content of '"Design Thinking"'? Design Heuristics as Conceptual Repertoire".

[22] J. Kramer, S. R. Daly, S. Yilmaz, C. M. Seifert, and R. Gonzalez, "Investigating the impact of Design Heuristics on idea initiation and development," *Advances in Engineering Education*, vol. 4, no. 4, 2015.

[23] NGSS Lead States, "The Next Generation Science Standards: For States, By States," The National Academies Press, Washington D.C., 2013.

[24] J. Handley, "Reframing the Problem and Reworking the Design: Learning from Youth Engineering Design Experiences," Dissertation, University of Michigan, 2021. [Online]. Available: https://hdl.handle.net/2027.42/169641
[25] A. J. Magana *et al.*, "Classroom orchestration of computer simulations for science and engineering learning: a multiple-case study approach," *null*, pp. 1–32, Apr. 2021, doi: 10.1080/09500693.2021.1902589.
[26] C. M. Cunningham, "Engineering Seltzer Rockets," *Science Scope*, vol. 39, no. 9, pp. 42–52, 2016.
[27] C. Johnstone, "Teaching Electricity and Engineering with LEDs," *The Science Teacher*, vol. 81, no. 2, pp. 27–35, 2014.
[28] S. J. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*, 3rd ed. UK: Pearson, 2015.
[29] J. Hernández-Orallo, *The Measure of All Minds: Evaluating Natural and Artificial Intelligence*. UK: Cambridge University Press, 2017.
[30] P. Langley, "The cognitive systems paradigm," *Advancies in Cogntive Systems*, vol. 1, pp. 3–13, 2012.
[31] T. Murray, "Authoring Intelligent Tutoring Systems: An analysis of the state of the art," *International Journal of Artificial Intelligence in Education*, vol. 10, pp. 98–129, 1999.
[32] S. Bull, "Negotiated learner modelling to maintain today's learner models," *Research and Practice in Technology Enhanced Learning*, vol. 11, no. 1, 2016.
[33] M. Abdelshiheed, T. Barnes, and M. Chi, "How and When: The Impact of Metacognitive Knowledge Instruction and Motivation on Transfer Across Intelligent Tutoring Systems," *International Journal of Artificial Intelligence in Education*, Sep. 2023, doi: 10.1007/s40593-023-00371-0.
[34] S. Elkins, E. Kochmar, I. Serban, and J. C. K. Cheung, "How Useful Are Educational Questions Generated by Large Language Models?," in *Artificial Intelligence in Education. Posters and Late Breaking Results, Workshops and Tutorials, Industry and Innovation Tracks, Practitioners, Doctoral Consortium and Blue Sky*, vol. 1831, N. Wang, G. Rebolledo-Mendez, V. Dimitrova, N. Matsuda, and O. C. Santos, Eds., in Communications in Computer and Information Science, vol. 1831. , Cham: Springer Nature Switzerland, 2023, pp. 536–542. doi: 10.1007/978-3-031-36336-8_83.
[35] K. VanLehn, F. Milner, C. Banerjee, and J. Wetzel, "A Step-Based Tutoring System to Teach Underachieving Students How to Construct Algebraic Models," *International Journal of Artificial Intelligence in Education*, Jan. 2023, doi: 10.1007/s40593-023-00328-3.
[36] X. Huang, S. D. Craig, J. Xie, A. Graesser, and X. Hu, "Intelligent tutoring systems work as a math gap reducer in 6th grade after-school program," *Learning and Individual Differences*, vol. 47, pp. 258–265, Apr. 2016, doi: 10.1016/j.lindif.2016.01.012.
[37] S. Steenbergen-Hu and H. Cooper, "A meta-analysis of the effectiveness of intelligent tutoring systems on K–12 students' mathematical learning.," *Journal of Educational Psychology*, vol. 105, no. 4, pp. 970–987, 2013, doi: 10.1037/a0032447.
[38] A. C. Graesser, "Learning science principles and technologies with agents that promote deep learning," *Learning science: theory, research, and practice*, pp. 2–33, 2020.
[39] L. S. Myneni and N. H. Narayanan, "An Intelligent Tutoring and Interactive Simulation Environment for Physics Learning," in *Intelligent Tutoring Systems*, vol. 7315, S. A. Cerri, W. J. Clancey, G. Papadourakis, and K. Panourgia, Eds., in Lecture Notes in Computer Science, vol. 7315. , Berlin, Heidelberg: Springer Berlin Heidelberg, 2012, pp. 250–255. doi: 10.1007/978-3-642-30950-2_31.
[40] L. V. Hoppe, S. Plappert, P. C. Gembarski, and R. Lachmayer, "DEVELOPMENT OF AN INTELLIGENT TUTORING SYSTEM FOR DESIGN EDUCATION," in *Proceedings of the 22nd International Conference on Engineering and Product Design Education*, The Design Society, 2020. doi: 10.35199/EPDE.2020.46.

[41] B. Aberšek and V. Popov, "Intelligent tutoring system for training in design and manufacturing," *Advances in Engineering Software*, vol. 35, no. 7, pp. 461–471, Jul. 2004, doi: 10.1016/j.advengsoft.2004.04.003.
[42] A. Brown, M. H. Goldstein, J. Clay, H. O. Demirel, X. Li, and Z. Sha, "A Study on Generative Design Reasoning and Students' Divergent and Convergent Thinking," *Journal of Mechanical Design*, vol. 146, no. 3, p. 031405, Mar. 2024, doi: 10.1115/1.4064564.
[43] J. Wang and J. Terpenny, "Interactive evolutionary solution synthesis in fuzzy set-based preliminary engineering design," *Journal of Intelligent Manufacturing*, vol. 14, no. 2, pp. 153–167, 2003, doi: 10.1023/A:1022947329200.
[44] D. Cvetković and I. Parmee, "Agent-based support within an interactive evolutionary design system," *AIEDAM*, vol. 16, no. 5, pp. 331–342, Nov. 2002, doi: 10.1017/S0890060402165012.
[45] M. I. Campbell, J. Cagan, and K. Kotovsky, "A-Design: An Agent-Based Approach to Conceptual Design in a Dynamic Environment," *Research in Engineering Design*, vol. 11, no. 3, pp. 172–192, Oct. 1999, doi: 10.1007/s001630050013.
[46] A. Raina, C. McComb, and J. Cagan, "Learning to Design From Humans: Imitating Human Designers Through Deep Learning," *Journal of Mechanical Design*, vol. 141, no. 11, p. 111102, Nov. 2019, doi: 10.1115/1.4044256.
[47] C. McComb, J. Cagan, and K. Kotovsky, "Capturing Human Sequence-Learning Abilities in Configuration Design Tasks Through Markov Chains," *Journal of Mechanical Design*, vol. 139, no. 9, Art. no. 9, Jul. 2017, doi: 10.1115/1.4037185.
[48] Z. Xu *et al.*, "Adaptation Through Communication: Assessing Human–Artificial Intelligence Partnership for the Design of Complex Engineering Systems," *Journal of Mechanical Design*, vol. 146, no. 8, p. 081401, Aug. 2024, doi: 10.1115/1.4064490.
[49] B. Song *et al.*, "Decoding the agility of artificial intelligence-assisted human design teams," *Design Studies*, vol. 79, p. 101094, Mar. 2022, doi: 10.1016/j.destud.2022.101094.
[50] G. Zhang, A. Raina, J. Cagan, and C. McComb, "A cautionary tale about the impact of AI on human design teams," *Design Studies*, vol. 72, p. 100990, Jan. 2021, doi: 10.1016/j.destud.2021.100990.
[51] C. Schimpf, X. Huang, C. Xie, Z. Sha, and J. Massicotte, "Developing Instructional Design Agents to Support Novice and K-12 Design Education," in *2019 ASEE Annual Conference & Exposition Proceedings*, Tampa, Florida: ASEE Conferences, Jun. 2019, p. 32640. doi: 10.18260/1-2--32640.
[52] J. Lave and E. Wenger, *Situated Learning: Legitimate peripheral participation*. Cambridge UK: Cambridge University Press, 1991.
[53] C. J. Atman, R. S. Adams, M. E. Cardella, J. Turns, S. Mosborg, and J. Saleem, "Engineering Design Processes: A Comparison of Students and Expert Practitioners," *Journal of Engineering Education*, vol. 96, no. 4, Art. no. 4, Oct. 2007, doi: 10.1002/j.2168-9830.2007.tb00945.x.
[54] N. Cross, "Expertise in design: an overview," *Design Studies*, vol. 25, no. 5, Art. no. 5, Sep. 2004, doi: 10.1016/j.destud.2004.06.002.
[55] D. P. Crismond and R. S. Adams, "The Informed Design Teaching and Learning Matrix," *Journal of Engineering Education*, vol. 101, no. 4, Art. no. 4, Oct. 2012, doi: 10.1002/j.2168-9830.2012.tb01127.x.
[56] S. O. Yager, R. E. Yager, and G. Lim, "The Advantages of an STS Approach Over a Typical Textbook Dominated Approach in Middle School Science," *School Science and Mathematics*, vol. 106, no. 5, pp. 248–260, May 2006, doi: 10.1111/j.1949-8594.2006.tb18083.x.
[57] L. M. Bouillion and L. M. Gomez, "Connecting school and community with science learning: Real world problems and school-community partnerships as contextual scaffolds," *J. Res. Sci. Teach.*, vol. 38, no. 8, pp. 878–898, Oct. 2001, doi: 10.1002/tea.1037.
[58] T. D. Sadler and V. M. Dawson, "Socioscientific issues in science education: Contexts for the promotion of key learning outcomes," in *The second international handbook of science education*, B. J. Fraser, K. Tobin, and C. McRobbie, Eds., Dordrecth: The Netherlands: Springer, 2012, pp. 799–809.

[59] A. C. Barton and E. Tan, "Funds of knowledge and discourses and hybrid space," *J. Res. Sci. Teach.*, vol. 46, no. 1, pp. 50–73, Jan. 2009, doi: 10.1002/tea.20269.
[60] S. Celedón-Pattichis *et al.*, "Asset-Based Approaches to Equitable Mathematics Education Research and Practice," *JRME*, vol. 49, no. 4, pp. 373–389, Jul. 2018, doi: 10.5951/jresematheduc.49.4.0373.
[61] L. Hogg, "Funds of Knowledge: An investigation of coherence within the literature," *Teaching and Teacher Education*, vol. 27, no. 3, pp. 666–677, Apr. 2011, doi: 10.1016/j.tate.2010.11.005.
[62] L. C. Moll, C. Amanti, D. Neff, and N. Gonzalez, "Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms," *Theory Into Practice*, vol. 31, no. 2, pp. 132–141, Mar. 1992, doi: 10.1080/00405849209543534.
[63] M. Denton, M. Borrego, and A. Boklage, "Community cultural wealth in science, technology, engineering, and mathematics education: A systematic review," *J. Eng. Educ.*, vol. 109, no. 3, pp. 556–580, Jul. 2020, doi: 10.1002/jee.20322.
[64] D. S. McLaughlin and A. Calabrese Barton, "Preservice Teachers' Uptake and Understanding of Funds of Knowledge in Elementary Science," *Journal of Science Teacher Education*, vol. 24, no. 1, pp. 13–36, Feb. 2013, doi: 10.1007/s10972-012-9284-1.
[65] E. B. Moje, K. M. Ciechanowski, K. Kramer, L. Ellis, R. Carrillo, and T. Collazo, "Working toward third space in content area literacy: An examination of everyday funds of knowledge and Discourse," *Reading Research Quarterly*, vol. 39, no. 1, pp. 38–70, Jan. 2004, doi: 10.1598/RRQ.39.1.4.
[66] C. Sias, A. Wilson-Lopez, and J. Meijia, "Connecting Students Background Experiences to Engineering Design," *Technology and Engineering Teacher*, pp. 30–35, 2016.
[67] G. Wiggins and J. McTighe, *Understanding by design*. Alexandria, VA: ASCD, 2005.
[68] J. T. Klein, "A taxonomy of interdisciplinarity," in *The Oxford handbook of interdisciplinarity*, R. Frodeman, Ed., Oxford, UK: Oxford University Press, 2010.
[69] C. A. Lauff, D. Knight, D. Kotys-Schwartz, and M. E. Rentschler, "The role of prototypes in communication between stakeholders," *Design Studies*, vol. 66, pp. 1–34, Jan. 2020, doi: 10.1016/j.destud.2019.11.007.