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# Board 321: Integrating Design Thinking and Digital Fabrication into Engineering Technology Education through Interdisciplinary Professional Learning

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## Integrating Design Thinking and Digital Fabrication Into Engineering Technology Education Through Interdisciplinary Professional Learning

**Introduction.** Makers by Design is a National Science Foundation(NSF) Advanced Technological Education funded professional learning (PL) fellowship designed to advance participating educators' ability to integrate design thinking into their classroom instruction. Design thinking is a non-linear iterative approach to problem solving using a human-centered approach [1]. 17 educators were recruited to this project from the northern Virginia region, including K-12 teachers, postsecondary faculty, and public librarians. During the project, fellows completed 24 hours of design thinking instruction, practiced teaching at digital fabrication summer camps for elementary and middle school youth, and created a lesson plan that integrated design thinking into their subject area. This paper investigates the extent to which teacher confidence & ability in integration of design thinking principles into classroom instruction were improved by participation in the PL fellowship.

**Project Rationale.** The notion of "making" has shown promise as an active, project-based learning intervention[2]. Integrating digital fabrication into classroom instruction has been shown to improve student attitudes toward the STEM disciplines and increase career interest [3]-[5]. However, studies of classroom implementation of digital fabrication technologies also report that teachers struggle to move beyond "keychain syndrome" – the tendency to fall back to reproducing simple objects, such as a keychain or coaster [6][7]. Teacher PL in digital fabrication has centered on machine operation, and not the pedagogy, cognitive strategies, and processes to situate the technology[8].

Makers by Design (MBD) will use "design thinking" as the central pedagogical model to introduce teachers and students to digital fabrication. Design thinking is a non-linear cognitive strategy used to approach the design of systems and projects, emphasizing collaborative project-based methods to solve real-life problems[1]. Design thinking organizes product creation around building and refining an empathetic understanding of the end-users' needs[1][9]. Rather than moving prescriptively through a rigid series of steps, design thinking fluidly moves between engineering stages (e.g. empathize, define, ideate, prototype, and test) in response to new data throughout the design process (**Figure 1**)[10]. In the classroom, research suggests that design thinking is an effective model for teaching "21st century skills" (e.g., collaboration, creativity, communication) [11]-[14].

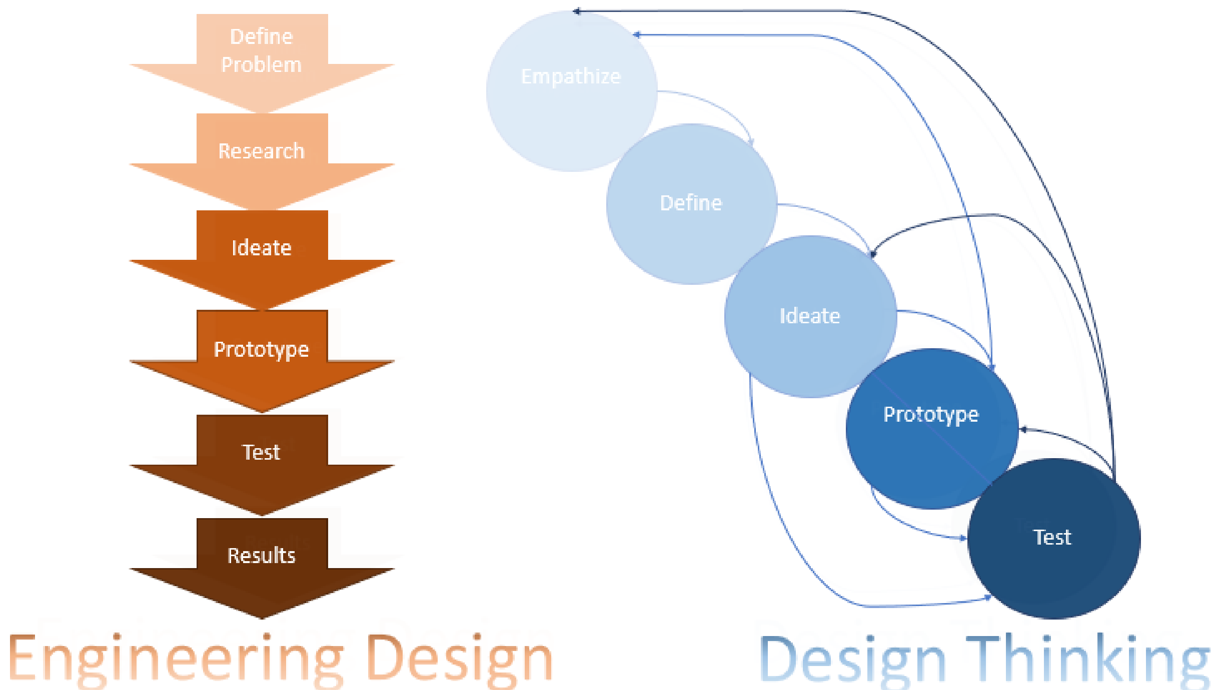


Figure 1: Engineering design is shown as a sequential process(on left) vs design thinking that is non-sequential(on right)

**Effective Professional Learning.** Research on PL suggests that interventions that foster sustainable changes in teaching practice include (a) modeling, (b) lesson plan development, (c) practice teaching, (d) coaching, and (e) building a community of practice. Modeling desirable instructional practices provide teachers with examples of exemplary, authentic instruction [15]. Modeling has shown utility in several areas of STEM education including engineering instruction, digital technology use and reform-based science instruction [16]-[19]. Lesson planning allows teachers to revisit and apply what they learn in an active way; and integrate it into their own instructional context[15][20]. PL can support teachers integrating new strategies into lessons that address standards-based concepts, and mitigate time-related concerns by allowing teachers to develop their own lesson plans [17]. Teachers value opportunities to practice using new instructional strategies in conditions where there are no repercussions if a lesson does not go as planned [21]. Individualized coaching allows PL implementers to differentiate support based upon teachers' needs [22].

**Program Design.** In line with the above, fellows first practiced design thinking through a series of PL workshops in the spring of 2022. Throughout the spring PL, fellows worked in interdisciplinary groups on a design challenge. Specifically, fellows developed a storage and sorting solution for a fictional LEGO hobbyist. During each session, fellows were introduced to a concept or strategy in design thinking, applied that strategy to their project, then observed a guest teacher delivering a model lesson using the strategy in a particular educational context (e.g., middle school science, introductory college engineering). Each session roughly corresponded to one of the 5 steps of the design thinking cycle (**Table 1**).

| DT Step | Description | Model Lesson |
|---|---|---|
| Empathize *Virtual, 2 hours* | Broadly introduce fellows to design thinking. Provide an overview of the LEGO design challenge. In groups, fellows develop an interview protocol for their users. | N/A |
| Empathize *Virtual, 2 hours* | Fellows use their interview protocols to flesh out their users, building out their bio and describing their experiences with LEGO. | Build-A-Bridge: adds users to an engineering bridge-building exercise. |
| Define *Virtual, 2 hours* | Fellows formulate a specific and actionable statement of their users problem. | Citizen Science: challenge students to identify the problems with a failed science outreach project. |
| Ideate *In-person, 8 hours* | Groups develop a journey map that follows their user's experiences. Using their map as a guide, fellows ideate a number of potential solutions to their user's problem. | Board Game Design: play a prototype board game, then propose new rules and test them. |
| Ideate *Async, 2 hours* | Fellows meet with their groups asynchronously and evaluate their solutions using a rubric. | N/A |
| Prototype & Test *In-person, 8 hours* | Fellows develop a physical rough prototype using paper, cardboard, and glue. Then, groups switch prototypes and gather testing data. | Camp Practice: rapidly prototype a LEGO transport method for Suresh, an elementary school student. |

Table 1: 6 PL workshops connected to the 5 steps of Design Thinking

After completing the spring PL, fellows practiced teaching design thinking at one-week digital fabrication summer camps run by Norther Virginia Community College(NOVA). Morning sessions focused on introducing digital fabrication technologies (e.g., 3D printer, laser cutter) and design software (e.g., TinkerCAD, Inkscape). Afternoons were devoted to design thinking using papercraft and rough prototyping materials. Fellows were provided with user bios and a rough outline detailing how to structure the afternoons. During fellows' practice, PL facilitators observed and provided feedback.

For the last stage of their fellowship, fellows developed a lesson plan integrating design thinking into their classroom instruction. After testing out lessons in their own classrooms, fellows provided NOVA with a copy of their lesson plans and a brief reflection explaining how their lesson went and what advice they would give another educator who wanted to use their ideas.

**Results.** Fellows completed a presurvey asking them whether they have past experience integrating design thinking / digital fabrication and to rate their confidence with that integration using Likert-scale responses. Fellows were also asked to provide narrative responses explaining a past time they attempted to teach design thinking and how they helped a student who was struggling. Initial responses showed a low level of confidence with all the digital fabrication tools (mean: 1.1). Educators reported higher confidence with design thinking (mean: 3.0).

Despite this level of confidence, however, fellows' narrative responses frequently belied an unfamiliarity with the practice of design thinking. Fellows confused design thinking (which has a specific focus on empathy) with engineering design and more broadly with project or problem-based learning(**Figure 2**).

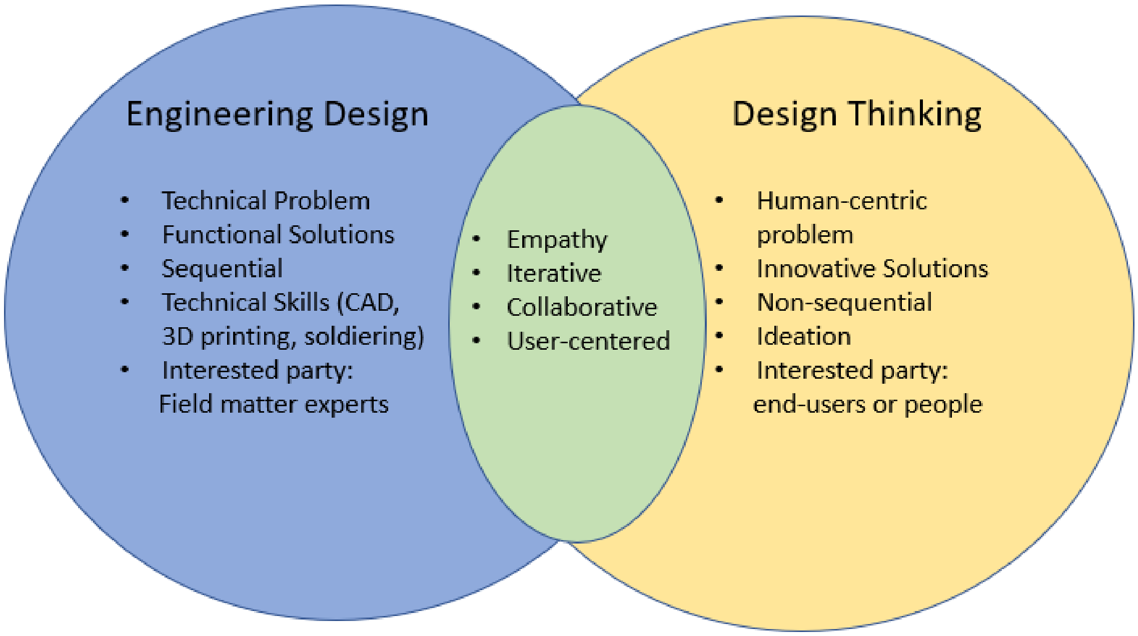


Figure 2: Comparison of engineering design and design thinking

During the PL, fellows demonstrated comfort and fluency with practicing design thinking themselves. In response to the confusion mentioned above, facilitators spent extra time introducing tools to practice empathizing with users and explicitly contrasted engineering design with design thinking practice. After completing the spring PL, fellows reported a significant increase in confidence integrating design thinking into their classroom instruction (mean: 4.6)(**Table 2**). After the PL, fellows ranked their technical knowledge and pedagogical confidence as insignificant barriers to classroom integration, ranking time as the largest barrier.

| Pre Survey Results (Mean value) | Post Survey Results (Mean Value) |
|---|---|
| Digital Fabrication: 1.1<br>Design Thinking: 3.0 | Digital Fabrication: 4.2<br>Design Thinking: 4.6 |

Table 2: Pre-survey and Post-survey results for confidence levels of participants in PL

Camp observations of teaching practice identified several key characteristics of successful design thinking instruction for K-12 audiences. First, younger students struggled with open-ended empathy exercises lasting longer than 10-15 minutes. Fellows had difficulty helping students move beyond initial "I don't know" responses to user dossiers, especially if those users were fictional. Fellows who successfully navigated this challenge deployed several tactics in response to student apathy, including moving empathy exercise to after an initial prototype had been constructed and roleplaying as users to provide direct responses to student questions. In fellows' post-camp reflections, physical prototyping and testing was regarded as significantly easier than the other aspects of the design thinking process. When comparing the pre and post survey results, majority of the fellows deemed the fellowship as helpful, planned on implementing design thinking in their classrooms, and felt more confident about their overall implementation.

Fellows' lesson plans reflect the emphasis on empathy discussed above. Teachers often relied on colleagues or students themselves to act as live users, so that students could have multiple opportunities to ask questions. In one successful lesson for a middle school tech ed setting, students were assigned to design a custom classroom nameplate for a teacher "client." Students were required to interact with their client for multiple iterations of their product, documenting their results in a design journal. In another lesson plan situated in a high school makerspace, students identified a problem at their institution and determined which people were most affected by that problem. Only after interviewing at least two stakeholders who experienced that problem were students permitted to propose potential solutions.

**Conclusions and Future Iterations.** The Makers by Design (MBD) PL fellowship program was largely successful at improving participant confidence and intentions to integrate design thinking into classroom instruction. Participants also reported broadened professional networks and intentions to continue collaborations between fellows and with NOVA.

However, while the PL structure did help educators deepen their pedagogical knowledge of design thinking as a problem-solving strategy, the program did not make sufficient connections between design thinking as a cognitive strategy and digital fabrication technologies. Part of the reason for this disconnect is logistical – fabrication technologies are rapid from an industrial perspective, but when students are prototyping over the course of one or two instructional periods time is even more limited. Additionally, educators lack the time to troubleshoot temperamental machinery (e.g., 3D printers) if they even have access to them.

While these barriers are to some extent endemic, future iterations of the camp program will attempt to bridge the gap by developing a fabrication pipeline that accompanies iterations of the design thinking process. As students move through the process of refining a prototyped solution to a user's problem, they will be introduced to more sophisticated methods of fabricating that solution. In this schema, students begin making rough, unmeasured prototypes using paper, then add accurate dimensions, and finally use precision machinery to fabricate a final version. Educator fellows facilitating these camps as part of their PL can extract and adapt this "pipeline" as would be appropriate given the limitations of their environments.