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Empowering Underrepresented Groups to Excel in STEM Through Research Sprints

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Abstract

Learning today is increasingly contextual, embodied, and on-demand. New modes of empowerment through technology are reshaping where, when, and how learning occurs. *Research sprints* are an integrative, fast-paced, active learning experience emphasizing creativity, collaboration, and communication in which teams "sprint" to find the information needed to solve a design or research challenge. The participants must work together to harvest the information and synthesize it through appropriate visuals in presentations and via social media channels (e.g. Mendeley and Twitter).

Two workshops were given during the Summer of 2017 entitled, “Self-Healing Infrastructure,” to a cohort of female underrepresented minority (URM) middle school students participating in Girls Inc and a group of URM high school student participating in the Franklin Institute STEM Scholars program. The session's design created a context for students to (i) actively harvest research information using engineering library databases , such as Compendex on Engineering Village, (ii) gain hands-on experience observing healing of concrete by bacteria, and (iii) synthesize and present their findings via graphical abstracts, all in a compressed timespan of 3-4 hours. The graphical abstracts produced by these cohorts provided visual insights into learners' research pathways from online to laboratory work.

Introduction

The pathways to STEM careers are diverse and varied. It is well known that early exposure to STEM environments can inculcate and reinforce interests in technical fields at key decision points when individuals choose career pathways [1]–[3]. Given the importance of a strong STEM talent-base to global economic competitiveness and prosperity, there exists a need to cultivate a pre-college landscape gives all students broad, authentic exposure to STEM fields earlier in their education [4]. In the framework of cognitive career theory, individuals choose careers based on interests, attitudes, and values [5]. Research in this area indicates that pre-college STEM experiences positively impact participants and steer them toward careers in science and engineering. However, access to STEM programming in the K-12 landscape is unevenly distributed [6], [7]. Furthermore, engineering has historically suffered from an image problem in the eyes of the public, perceived as "not creative", "dry", and "boring" [8]. A 2008 National Academy of Engineering report, *Changing the Conversation: Messages for Improving Public Understanding of Engineering*, highlighted the misperception that engineers do less to save lives, care less about their communities, and are insensitive to societal concerns. Expanding access to pre-college engineering experiences across demographics is certainly a key component of "changing the conversation" [8] on engineering careers to enable a more diverse STEM talent pipeline. Pre-college engineering programs range in scope from one-off demonstrations (often tied to federal funding, dedicated centers within universities [9]. TeachEngineering [10] provides a digital library of pre-college engineering resources to enable K-12 teacher professional development. It is estimated that 85% of jobs that today's learners will fulfill in 2030 do not exist today[11] - making it an imperative to equip learners with persistent learning mindsets and enable them to update their skillsets over the arc of their careers.

Design thinking is a human-centered process for innovation that is well-suited to tackle complex, “wicked”, discipline-defying problems [12] that shape the 21st century. Design thinking and engineering are powerful complements to each other. Whereas engineering emphasizes *feasibility*—applying deductive reasoning to test hypotheses, design thinking emphasizes *desirability*—utilizing inductive reasoning and rapid assumption testing to unmask end user needs. While both emphasize observation, data capture, research, prototyping, and critical thinking, incorporating design thinking elements within engineering education offers an opportunity to shares the conversation on engineering’s societal impacts by creating a linkage between the analytical, feasibility-oriented space of engineering and the human-focused, contextually aware practices of design [12], [13].

To this end, we formed a partnership between Drexel University, Girls Inc., the Franklin Institute, and Elsevier to produce a self-healing infrastructure workshop in the form of a *Research Sprint*, an experience architecture that intertwines design thinking modalities with science and engineering research, to create the context to encourage interactive & collaborative learning behaviors. The theoretical underpinnings for Research Sprints arise from situated learning theory (or contextual learning theory)[14], which emphasizes the importance of learning within authentic contexts to create new knowledge. Research Sprints are designed to provide authentic, technology-aided mechanisms to engage interests of K-12 students in STEM research.

Background: Architecture of a Research Sprint

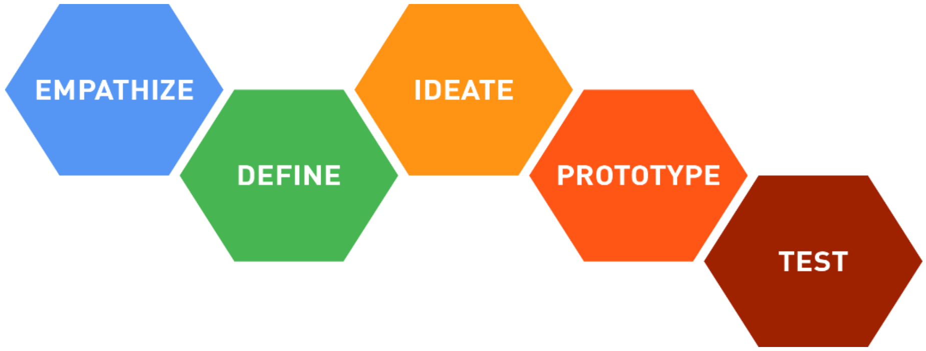

Figure 1: An illustration of the Stanford d.school design thinking process. The steps shown here represent all modes that contribute to a design project, and may occur in parallel or iteratively repeat in an actual design workflow [12].

Design thinking is a highly nonlinear method, meaning that the steps shown in Figure 1 may occur in parallel and can iteratively repeat. Research Sprints are the author's design thinking adaption that interweaves science and engineering knowledge with human-centered design practices into STEM educational activities. In relatively short periods of time, participants in Research Sprints build core research, collaboration & communication skillsets as they work to harvest information from research databases, synthesize this information into knowledge, and build compelling prototypes to support thinking, which can be graphical abstracts, codes, storyboards, or draft research articles to share through social media channels, such as Mendeley[15] or Twitter. This precollege Research Sprint utilized a four-step adaptation of design thinking: "*Expose – Explore – Experience – Express*" (Figure 2).

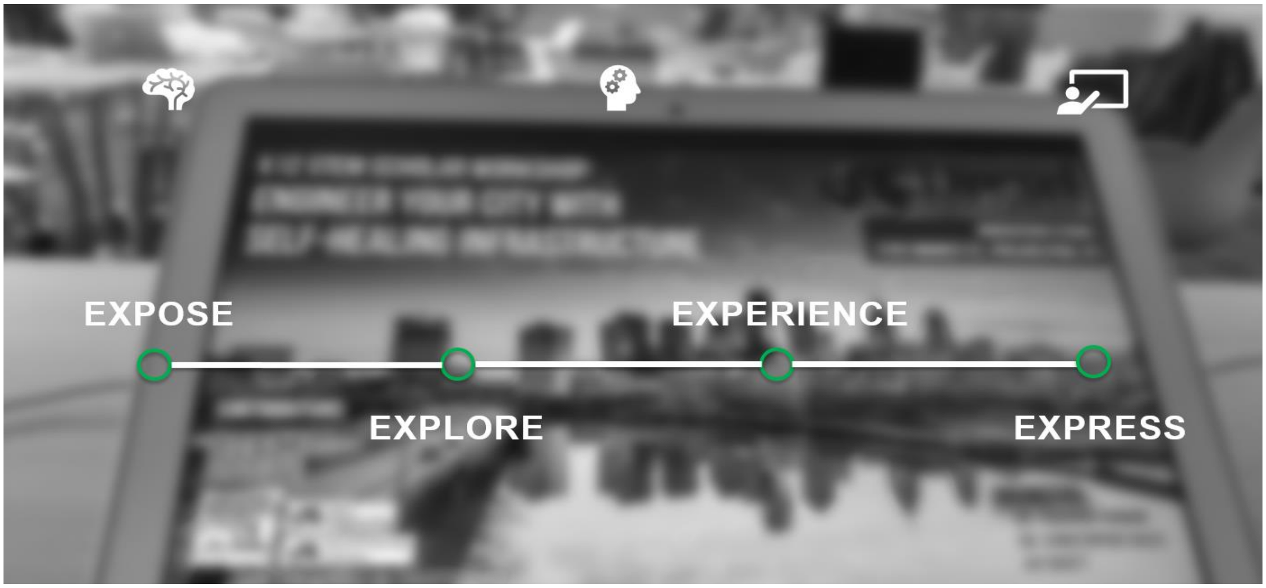

Figure 2: A high-level illustration of the research sprint experience. Beginning with a design challenge, teams harness Elsevier research toolsets to discover relevant interdisciplinary information, synthesize, and mobilize that knowledge into solutions with short periods of time

At the onset of a sprint (*Expose*), the facilitators distribute a brief introducing the challenge to all teams. This launches the *Explore* phase, where the teams launch a literature search and (if applicable) stakeholder interviews to quickly build understanding of the problem space, through relevant knowledge and contextual data. The goal of this step is to harvest information from diverse streams to arrive at a crisp problem definition that can inform the ideation stage. During ideation, teams generate ideas to remix, combine, and prototype into a proposed solution. "Prototype" in this context applies manifestation of an idea that helps expose and test assumptions, quickly and cheaply, with the emphasis on "building to think" rather than "thinking to build" (*Experience*). A prototype may be a cause-effect diagram, a syllabus, user journey map, an experimental demonstration, or a physical mockup. In research sprints, participants *Express* their ideas through graphical abstracts produced on whiteboards or sketchpads representing the team's shared information space. Graphical abstracts are a growing form of scholarly communication that provide a "concise, visual summary of the main findings" to quickly deliver the "take-home" message of a research article [16], and lower communication barriers across knowledge disciplines[17]. They are also ideal outputs for workshop groups, as they allow multiple individuals to contribute through auditory and visual channels and enable the facilitators to—at a glance assess—the progress of a given group. Each team shares a graphical abstract with the group at-large and can upload a snapshot to social channels (e.g. Mendeley, Twitter) for broader reach and digital archiving.

It is well-known that university students tend to over-rely on superficial Google search [18], while underutilizing specialized discovery tools available through institutional library subscriptions such as Engineering Village [19] and Knovel [20] that can be harnessed to discover deep insights from vetted external knowledge sources. Information discovery solutions are evolving away from being static literature repositories, to dynamic, generative workflow solutions that can learn their users, and even deliver probabilistic recommendations for course of action to solve a given engineering challenge. The questions **i) "**What knowledge do I need", and **ii)** "what contextually relevant data do I need?" become ever more prescient in a day and age when collective experiences of humans and machines (e.g. encapsulated in onboard sensor data) are increasingly available and discoverable.

Piloting Research Sprints: Self-healing infrastructure

Research sprints can be developed around any STEM topic. We chose to pilot our first pre-college series of research sprints on the cutting-edge and multi-disciplinary concept of self-healing infrastructure. To "expose" the participants to this research concept and establish context for the activity, a sprint brief was distributed to all participants just before the start time, which included an introduction to the theme, and an outline of the activity. An excerpt from the brief is presented below:

> "*Every day that we commute in our city, we see cracks, fractures, potholes in our infrastructure (e.g., buildings, roads, bridges, and tunnels) that may affect their use or our safety. We pay taxes, so the crumbling infrastructure can be fixed and we can*

*com/mute safer and more comfortable. However, as buildings, roads, bridges, and tunnels age, repairs become more costly and we often have to destroy the existing structures. The question of the day? "Do we have to keep using traditional ways of fixing or rebuilding our infrastructure, or are there new scientific approaches we can use?"***.**

Researchers and engineers have been studying nature for many years, inspiring new approaches to fix crumbling infrastructure. Many animals, including humans, can heal wounds or cracks to their bones. In nature, organisms show a healing strategy or response to damage. When damage occurs, living units (e.g., cells) become active and begin to produce suitable chemicals that can heal the damage. This concept will be followed in this workshop to create a self-healing solution containing bacteria that can be used to heal cracks in concrete samples.

Concrete is the most used construction material on Earth, and the second most utilized material after water. This will be a fast-paced, intense, and collaborative workshop in which you research, design and create self-healing concrete. It will get chaotic at times – that's OK. Embrace the chaos, and have fun!"

In addition to the brief, the university professors and graduate students, guiding the Research Sprint activity, briefly introduced the concept of self-healing infrastructure through a short, interactive presentation. After exposing the participants to the topic, they broke out into groups of 3-4 students and were encouraged to "explore" the topic using Engineering Village to disocer the latest research regarding self-healing infrastructure. Questions to spawn their exploration included:

*"**Self-healing mechanisms in nature:** How do natural materials achieve self-healing properties?*

***How does self-healing concrete work?** What are the ways that we can enable self-healing in concrete?*

***What agencies in our communities may benefit from using self-healing materials in infrastructure?** Local agencies, federal agencies, private companies? And why? Bring some statistics if possible.*

***Strategic Partnerships:** Who are some subject matter experts around the world that we might contact? Are there any researchers, engineers, or companies we might approach for commercialization opportunities?*

***How might we make self-healing concrete at industrially relevant scales?** What are the steps that we need to take?"*

After exploring the topic online, the participants performed hands-on experiments using cracked concrete specimens that could be healed in real-time (a few hours) with application of specialized bacterial and nutrient solutions. These experiments provide the learner to "experience" the STEM concept by allowing them to use microscopes to monitor and observe self-healing concrete in action.

Following the experiments, the participants were then asked to synthesize information from published literature with the observations they made from their experiments in graphical abstracts, to present to their peers. In groups, the participants were given the freedom to share and "express" what they had learned during their Research Sprint on white boards or canvasses that each team was provided. Each session was self-contained within a single three to four hour span.

In order to effectively implement interactive workshops, space is an important consideration. When chosen well, physical space encourages interaction and collaboration. When chosen poorly (e.g. most lecture halls and computer labs with immovable furniture), the space itself will work against the desired behaviors. The middle school session was held in a new "active learning studio", outfitted with ample whiteboard space, reconfigurable furniture, and audio/visual capability. The high school version was held in the university makerspace, also equipped with reconfigurable furniture and large canvasses used in place of whiteboards. Both spaces are ideal configurations for research sprints.

Targeted Cohorts

Table 1: Demographic breakdown of the high school and middle school participants

	High School Cohort	Middle School Cohort
Gender		
Male	9	0
Female	7	24
Self-Reported Ethnicity		
African-American	7	22
Asian	4	1
Hispanic	3	1
Other	2	0
Total	16	24

The organizers partnered with two community groups enhance their existing onramps for K-12 STEM education experiences. The middle school cohort was affiliated with the Philadelphia/Camden chapter of Girls, Inc. a national non-profit with a mission of encouraging all girls to be "strong, smart, and bold". The Franklin Institute is among the nation's oldest science museums, and runs the STEM Scholars outreach program [21] for underserved high school students to gain science & engineering experience over the duration of their high school careers, through afterschool and summer programming. Graduate students from the Chemical & Biological and Civil, Architectural & Environmental Engineering departments served as mentors for each team, in addition to the authors of this manuscript (two civil engineering faculty members, an engineering liaison librarian, and an Elsevier Engineering representative).

Outcomes

The self-healing infrastructure Research Sprint series prompted students to think about various forms of infrastructure (e.g., transport, communication) and the central role that engineers play in enabling society's daily functions through several STEM fields (i.e., microbiology, chemistry, physics, civil engineering). The compressed time frame of the Research Sprint created a sense of urgency for students to rapidly explore a topic and gain actionable insights to leverage against an engineering challenge. In the process, this builds exposure to scientific journal and conference content for the first time. A hands-on component further complemented the online research in the Compendex database on Engineering Village. Furthermore, the students gained experience of working on teams to understand an engineering concept and express what they learned in front of an audience of their peers and faculty mentors.

Although no formal assessments were performed during the piloting of the Research Sprints, the high school groups' graphical abstracts were observed to be qualitatively more sophisticated than the middle school groups (i.e., the use of higher-level science and engineering concepts and terminology), as shown in Figure 3. However, while the middle school cohort had comparatively less science background knowledge than the high school group, they undoubtedly asked more questions and offered up more creative ideas than the high school students (i.e., use of "milk" or "magic juice" to feed bacteria and sensors to detect cracks vs. manual injections of chemicals into visible cracks). In the facilitators' observations, it was also easier to focus the middle school group than the high school group on task because the former seemed to be more curiosity-driven, while the older students were more task-oriented and became more easily distracted. When working with older audiences, the facilitators can design challenges that give each member in a group individualized tasks or specific roles (e.g., note-taker, presenter) that keeps them engaged throughout.

Figure 3: Graphical abstracts produced by the (top row) middle school and (bottom) high school students

The requirement to produce a drawing on a large canvas or whiteboard enables the facilitators nonverbally assess a group’s progress and intervene if deemed necessary. The injection of drawing as a communication mode also allowed less talkative students a chance to express themselves.

Figure 4: Graphical abstracts have the added benefit of enabling the facilitators to non-verbally check the progress of a group at a glance. The students work together to express their findings on large canvasses or whiteboards and present them in front of their peers.

Research sprints are an extensible format for students to rapidly explore a topic in-depth, gain hands-on research experience, and express their learnings. Most pre-college outreach activities emphasize the hands-on component but tend not to emphasize scientific knowledge creation & communication. Science fair competitions such as Intel International Science & Engineering Fair (ISEF) affiliated competitions do emphasize these elements and are highly impactful experiences but run over the course of an entire school year, demanding sustained support from parents and educators. By contrast, research sprints are high intensity, short duration experiences that can be adapted to a wide range of audiences and challenges. Sprints may feed into longer term commitments such as a competitive entry to a regional science fair. In future cohorts, surveys and other formative and summative assessments of the effectiveness of Research Sprints will be evaluated. It is our goal to empower expand access to authentic research-based learning experiences to inculcate mindsets for students to seek relevant knowledge and datapoints to leverage against engineering challenges. Incorporating research toolsets that enable independent literature exploration such as Knovel or Engineering Village within design or research-based experiences reduce the need for unidirectional content delivery and allow facilitators to place greater emphasis on learning experience design to inculcate desired skillsets, such as communication, collaboration, and systems thinking.

Concluding Remarks

Research Sprints are a learner-centered pedagogical approach that is adaptable across the spectrum from middle school to working professionals. In this example, Research Sprints served as a gateway for underserved pre-college groups to gain exposure to a contemporary civil engineering topic of self-healing infrastructure, explore contextually relevant knowledge, synthesize actual self-healing concrete samples, and synthesize online and offline findings to present in front of a peer audience. They are also well-suited to project-based courses and "unconference" sessions that inculcate greater interaction and collaboration between participants. For instance, at the time of writing, Elsevier's Engineering team has partnered with a series of AiChE Regional Student Conferences to launch similar sessions having as many as 100 participants, to provide a professional development experience around real industry corrosion mitigation and asset management challenges. The format is agnostic to the particular challenge or toolsets used and provides a creative way to inculcate mindsets and skillsets for future engineers to seek contextually relevant knowledge and data, in order to create new knowledge.

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