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RESEARCH REPORT

Stretch, Dream, and Do - A 21st Century Design Thinking & STEM Journey

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Abstract: *This paper describes the journey of d.Loft STEM Learning, a project of The National Science Foundation ITEST program, which supports building knowledge about approaches, models, and interventions involving K-12 education to increase the nation's capacity and innovation in STEM (science, technology, engineering and mathematics) fields. d.Loft STEM Learning used design thinking as an underlying theoretical and pedagogical approach to enhance STEM learning. Design thinking is a human-centered, prototype-driven innovation process and a series of mindsets that provides a robust scaffold for divergent problem-solving. This paper describes how the design thinking provided a frame within which mentorship and STEM learning thrived, and suggests new ways to conceptualize student learning and teacher practice in 21st century learning contexts.*

Keywords: STEM, Teacher Practice, Middle school, Learning, Design Thinking

This paper describes the journey of d.Loft STEM Learning, a project of The National Science Foundation ITEST program, which supports building knowledge about approaches, models, and interventions involving K-12 education to increase the nation's capacity and innovation in STEM (science, technology, engineering and mathematics) fields. d.Loft STEM Learning used design thinking as an underlying theoretical and pedagogical approach to enhance STEM learning. Design thinking is a human-centered, prototype-driven innovation process and a series of mindsets that provides a robust scaffold for divergent problem solving. This paper describes how design thinking was the theoretical and pedagogical foundation for d.loft STEM learning and how it provided a frame within which mentorship and STEM learning thrived.

The inspiration behind d.loft STEM Project was the "Design for the other 90% movement," which consists of engineers, designers, scientists, architects, and mathematicians engaged in designing low-cost innovative solutions for large portion of the world's population who do not have access to basic services. This movement shaped the National Science Foundation proposal and led to crafting the d.loft STEM Project goals.

These goals included the following:

1. to provide middle school students with pathways into STEM careers by introducing the work of engineers, mathematicians, and scientists and the work of the university student mentors engaged in STEM fields
2. to introduce design thinking as a 21st century learning approach
3. to provide university students with opportunities to create and implement STEM curriculum and design thinking activities for middle school students
4. to foster the development of mentoring relationships

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An Introduction to the Design Thinking Process

Design thinking is an orientation toward learning that encompasses active problem solving and believing in one's ability to create impactful change. Embracing design thinking as an approach to human-centered problem solving leads to the development of creative confidence (Kelley & Kelley, 2013). The key components of design thinking process are that it is (1) human-centered (2) action-oriented, and (3) mindful of process (Hasso Plattner Institute of Design, 2007).

Tim Brown, the chief executive and president of global design consultancy IDEO, describes the design thinking process as "an approach that uses the designer's sensibility and methods for problem solving to meet people's needs in a technologically feasible and commercially viable way. In other words, design thinking is human-centered innovation." David Kelley, founder of design consultancy IDEO and Stanford's Hasso Plattner Institute of Design, says, "My contribution is to teach as many people as I can to use both sides of their brain, so that for every problem, every decision in their lives, they consider creative as well as analytical solutions." This approach, which has energized business innovation, is being applied to K-12 education with considerable impact. With its central emphasis on human needs, it refocuses curriculum and assessment and forefronts solving real-world problems.

Design thinking starts with divergence- the deliberate attempt to expand the range of options rather than narrow them. It is a means to go beyond incremental changes and explore opportunities for breakthrough innovations. Design thinking focuses on asking the right questions, challenging assumptions, generating a range of possibilities, and learning through targeted stages of iterative prototyping. Using ethnographic tools and contextual inquiry, design thinkers learn how to observe, interview, and develop empathetic insights that lead to human-centered ways of solving problems. Figure 1 highlights the five key phases of the design thinking process: empathize, define, ideate, prototype and test.

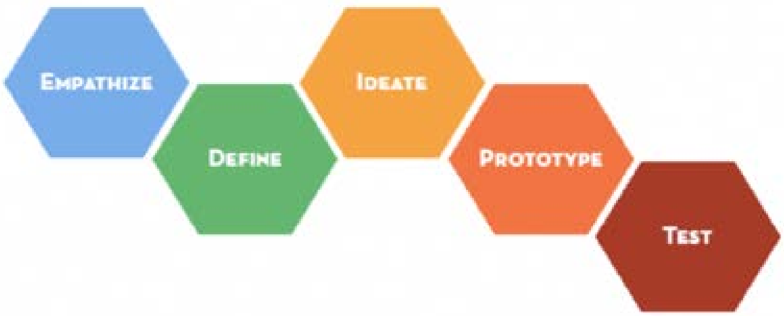

Figure 1. *The Stanford University Hasso Plattner Institute of Design*

Design Thinking Process

<u>Empathy</u>

Empathy is the foundation of the human-centered design thinking process. The following components characterize the empathize mode:

- Observation of user behavior in life contexts
- Engaging, interacting and interviewing users
- Being able to immerse oneself in user's experiences

This sense of empathy provides insights into what people think and feel and is a critical component of the design thinking process.

Define

The second part of the design thinking process is define, which is about analyzing and synthesizing one's empathy findings into compelling needs and insights. Two goals of the define mode are to develop a deep understanding of users and the design space and, based on that understanding, to generate an actionable problem statement. The define mode is critical to the design process because it frames the problem.

Ideate

Ideate is the third step of the design thinking process- it is focused on idea generation. The goal of ideation is to explore a wide solution space – both a large quantity of ideas and diversity among those ideas.

Prototype

The fourth step of the design thinking process is prototyping. A prototype can be anything that takes a physical form that a user can interact with. Prototypes are low-resolution and can be storyboards, role-plays, physical objects or services.

Test

The final step of the design thinking process is testing. Testing is an opportunity to put the prototype into the hands of users so that one can iterate and refine solutions to better meet user's needs.

Design Thinking Mindsets

The design thinking process is supported by a series of mindsets. The mindsets include the following:

- Human-centeredness
- Bias Towards Action
- Radical Collaboration
- Culture of Prototyping
- Show, Don't Tell
- Mindfulness of Process

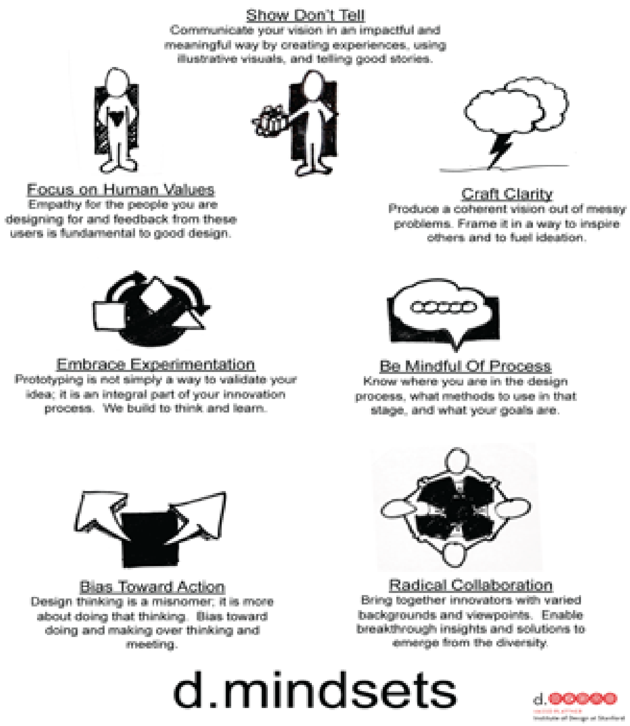

Figure 2. *Design Thinking Mindsets*

Design Thinking in K-12 Education

The need for a design thinking approach is timely. The National Research Council (2009b) states that it takes years or decades to build the capabilities required by societies: "You need to generate the scientists and engineers, starting in elementary school and middle school" (p. 9). Incorporating engineering-based problem solving within students' learning of mathematics, science, and technology is gaining greater attention across many nations, with science, technology, engineering and mathematics (STEM) in K-12 increasingly regarded as an essential component of progressive 21st century education (e.g., Berland, 2013; English & Mousoulides, 2011; National Research Council, 2009a; Zawojewski, Hjalmarson, Bowman, & Lesh, 2008). Today's students will be expected to collectively tackle 21st century problems, yet only 16 percent of teachers reported they are assigning projects that help students develop problem-solving skills (Project Tomorrow, 2009). The Center for Teaching and Learning (2010) report that in California, only 10% of elementary students regularly receive hands-on science lessons and arrive at middle school unprepared for and uninterested in science, In addition, one-third of elementary teachers said they feel prepared to teach science, and 85% said they have not received any training during the last three years. Yet incorporating engineering concepts into middle school curriculum has been found to be an effective way to improve students' problem-solving skills (English, Lyn, Hudson, and Dawes, 2013). Students' engagement in STEM fields can foster innovation, invention, and economic development (Tytler, Osborne, Williams, & Cripps Clark, 2008). It is critical that middle school students engage in challenging learning experiences (Lambert & Stylianou, 2013; Silver, Mesa, Morris, Star & Benken, 2009) as they contribute to building innovative thinking. This is particularly relevant to STEM education, and to the d.loft STEM Learning Project.

According to the Carnegie Foundation Commission on Mathematics and Science (2009), the United States needs an educated young citizenry with the capacity to contribute to and gain from the country's future productivity, understand policy choices, and participate in building a sustainable future. The need for knowledge and skills from science, technology, engineering, and mathematics are crucial to virtually every endeavor of individual and community life. In a comprehensive report on STEM education, it is recommended that there is a need to (1) increase America's talent pool by vastly improving K-12 mathematics and science education; (2) sustain and strengthen the nation's commitment to long-term basic research; (3) develop, recruit, and retain top students, scientists, and engineers from both the U.S. and abroad; and (4) ensure that the U.S. is the premier place in the world for innovation. The role of an engineer requires the integration of knowledge, and its application in constantly changing contexts with the goal of using that knowledge to deliver a successful outcome. Vest (2006) described how students are driven by passion, curiosity, engagement, and dreams and the importance of focusing on the environment, forces, ideas, inspirations, and empowering situations to which they are exposed. Design thinking can provide a frame within which students learn how to be mentors, how to create user-centered learning experiences, and how to share their experiences as developing STEM professionals with middle school students (Author, 2012). Design thinking, with its focus on empowerment and agency is a powerful tool to meet the needs of 21st century learners by providing a human-centered scaffold for problem definition and problem solving. Students need to know how to be empathetic towards others, identify problems, and generate creative solutions.

d.Loft STEM Design Thinking Model for Teaching & Learning

Creative confidence is the foundation of the d.Loft STEM Design Thinking model. It develops as one embraces both the design thinking process and underlying mindsets. The diverse stakeholders who were involved in d.Loft STEM Learning provided a lens that informed the model's creation. This paper focuses on two critical components of the model: human-centeredness and prototyping/testing. Embracing these two elements of design thinking had a critical impact on two areas of the d.loft STEM Learning project: the university course and the after school program. This became evident with respect to the university instructors and university students in different ways. Figure 3 highlights the d.Loft STEM Design Thinking Model.

University Course

Development & Planning & Human-Centeredness

The d.loft STEM Learning university researchers/instructors decided that a university course would be an effective structure to meet the project goals. The course would meet two days a week. On Tuesdays, the course would be held at the university. On Thursdays, the course would be held at a local middle school during its afterschool program. The university students would have the opportunity to act as mentors to the middle school students every Thursday. In designing this course, empathy and a mindset of human-centeredness for the needs of both the university students and the middle schoolers was central. The following questions informed the development of the course and course planning:

- What were the best ways to structure the university course to attain the goals of d.loft STEM Learning?
- What did the university students need in order to best learn about STEM topics, design thinking, mentoring and STEM careers?
- What did the middle school students need in order to best learn about STEM topics, design thinking, and STEM careers?
- What were the best ways to structure the afterschool and intercession camp sessions to support the university student's interactions with the middle school students within the course framework?
- What knowledge did the university students have to have about middle schoolers' cognitive and social development in order to both begin their journey and thrive as mentors?
- What were the best ways for the middle school students to gain exposure to and interaction with STEM pre-professionals and professionals and their work and their pathways into the STEM professions?
- What were the best ways to teach the university students how to be mentors?
- What were the best ways to use university in-class sessions to prepare the students for their work in their afterschool program?

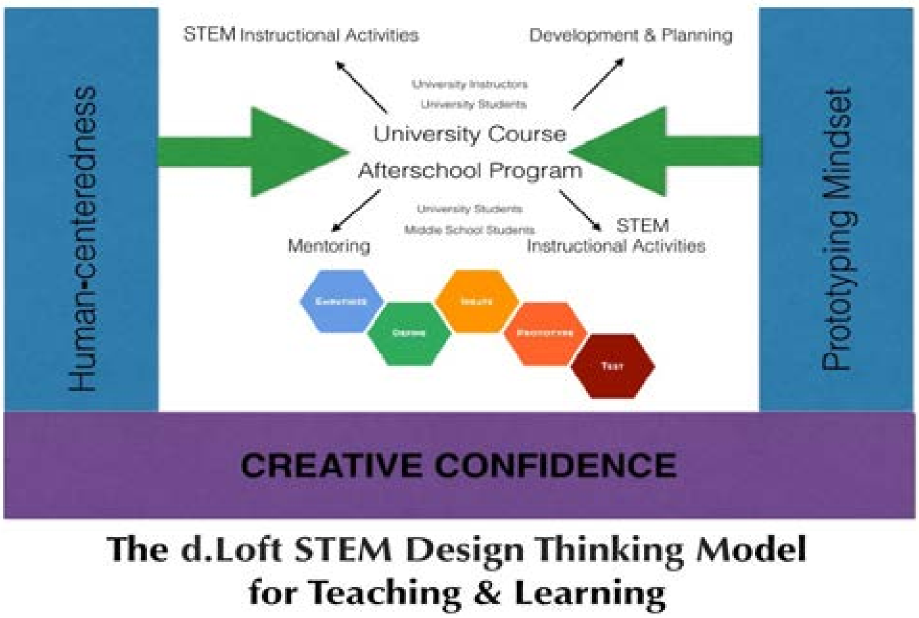

Figure 3. *The d.Loft STEM Design Thinking Model for Teaching & Learning*

Many of these questions might occur in typical course planning, but what distinguished the planning for this course was an explicit emphasis on gaining empathy for the needs and perspectives of the both the university students and the middle school students in the course design. It was a mindset of human-centeredness that drove the development of the university course.

Instructional Activities & Human-Centeredness

With these thoughts in mind, Educating Young STEM Thinkers was created. The ten-week course met twice a week during the university Winter and Spring quarters. For the first two weeks, Tuesdays were spent at the university. In weeks 3-10 the university students traveled to an underserved urban community where they became mentors to middle school youth in an afterschool program. Between the first and second quarter of the course, during their spring break, students had an option to work with a second middle school to deliver a one-week STEM/Design Thinking Camp program.

Students who took the class were undergraduate and graduate students whose majors included Civil Engineering, Environmental Engineering, Mechanical Engineering, Chemical Engineering, Education, Physics, Biology, Learning Design & Technology, Education, as well as those whose majors were undeclared.

The university course gave the students opportunities to deepen their understanding of the role STEM plays in K-12 education. They read literature on STEM pathways issues and the effectiveness that exposure to STEM professional has on K-12students. They also learned about the unique needs of middle school students and read about how to design effective lesson. This background information on middle schoolers helped the university students as they became mentors.

The university students were learning the design thinking process as part of the course, and they were also expected to teach this process to the middle schoolers as they integrated design thinking and STEM-based activities. The university instructors were aware that this would be a difficult task and empathized with the students. One decision that was based on this notion was to invite a small group of middle school students to the university class one week prior to beginning the afterschool program visits. The class session had two components: a hands-on design activity where the middle schoolers were embedded in a team with university students, and an informal interview where the university students asked the middle school students questions about what their lives were like inside and outside of school. After these sessions, many of the university students expressed how much they enjoyed the visit, mentioning how it had been a while since they were middle schoolers themselves, and how they felt they gained more of an understanding of the school they were going to visit and empathy for what the students' lives were like.

Development & Planning & A Prototyping Mindset

The second critical factor for the university researchers/instructors in designing the course was the adoption of a prototyping mindset. Everything was considered a prototype that could be iterated upon and thus improved. The intention was to be metacognitive and mindful and use what did not work as an opportunity to learn what to do the next time. The researchers' goals in year 1 were to prototype the course, and learn from what did and did not work in order to improve the course in year 2 and year 3.

The sense of lingering in ambiguity, which often characterizes the adoption of a prototyping mindset, was a critical part of embracing the design thinking process. This can best be explained by a metaphor of navigating a large ship. A successful course was the destination, but there was an acknowledgment that there would be many course corrections on the journey. The learning was paramount. The university researchers/instructors knew that this first class/afterschool program was the first of a three-year program, and wanted to adopt a prototyping mindset to continually improve the program and meet the needs of the university students and the middle schoolers. More importantly, it was essential that the university students embraced a prototyping mindset as well.

This was explicitly acknowledged by the researchers/instructors with the notion that perfection was not expected, but learning from failure was. Dweck (2007) states that students are often praised for being smart rather than being willing to take chances: "...we tell them that this is the name of the game: Look smart, don't risk making mistakes." She describes a "growth mindset" which purports that intelligence is not fixed, but can be developed. Diener (2007) describes this idea: "Failure is information—we label it failure, but it's more like, 'This didn't work, I'm a problem solver, and I'll try something else.'" The idea of a growth mindset is a perfect complement to the design thinking process of prototyping and testing.

Instructional Activities & A Prototyping Mindset

During the first quarter of the class, the university instructors tried to find a balance between mentorship, design thinking, and STEM. In the subsequent Winter quarter, many instructional changes were made. These included changing the readings based on the class discussions to give students a more nuanced understanding of what middle schoolers were like socially, emotionally and cognitively. In the spring quarter of the first year of the course, the university instructors worked with students in two groups: a curriculum group and a research group. The curriculum group was responsible for planning activities for both groups to implement each week with the middle school students. This was changed in the subsequent quarter, as the instructors realized that it was important for both groups to be able to design activities for their particular middle school students. The curriculum group also shifted to be more inclusive of students' input into the curriculum in the subsequent quarter. In the spirit of a prototyping mindset, giving students more responsibility for the final curriculum proved to be a more rigorous learning experience.

With respect to the learning from students' journals, the university instructors decided to bring the university students to the middle school students one week earlier than had been done in previous quarters. This was done to give the university students additional time to build the mentoring relationship. What was most important with respect to all these changes was the idea that the entire course was a prototype, and how instruction was conceived and developed needed to change in order to continuously improve. This became evident through the focus on empathy, the adoption of a prototyping mind set, and the course content which integrated STEM and design thinking.

Afterschool Program

In order to achieve the program goals the university researchers reached out to a local afterschool program and asked if they would be willing to partner. Both human-centeredness and a prototyping mindset were key in the creation of the Milagra Academy afterschool program. Milagra Academy is a college preparatory secondary school dedicated to preparing all students for acceptance and success at the 4-year college or university of their choice. Their mission is to equip their students with the academic skills, behaviors, habits, and qualities of character necessary to successfully complete college so that they have the opportunity to earn a family-sustaining income and make a positive impact on their community. The school was founded in 2006 in a community where 10% of the residents have a Bachelor's degree and the high school drop out rate is over 70%. There are approximately 300 students in the school, and 97% of the students participate in the federal free/reduced lunch program. 90% of the students speak English as a second language and 97% of the students are first-generation college students. The ethnic background of the students is 86% Latino (a), 11% African American, 3% Asian/Pacific Islander, 1% White/Other.

One of the university researchers/instructors had a long-term relationship with the middle school that was selected for the afterschool program. She had delivered design thinking workshops to the school faculty, and worked with the students on end-of-school extension courses. There was a sense of trust that had developed, and this created a willingness on the part of the school principal to try the new program at the middle school. Two months prior to the beginning of the course, the university researchers met with the Afterschool

Program Coordinator to determine the best days/times for the program. The existing program met each day from the end of the school day at 4 until 6, and she felt the d.loft STEM Project would be a welcome addition. The university students created carpools to drive to the middle school each week.

STEM Activities in the University Course & The Afterschool Program

The content for the university course, which was inspired by the Design for the Other 90% movement, focused on three STEM-based topics. In year 1, the topic was water; in year 2, energy; and in year 3; shelter. The university students were required to design activities for the middle schoolers that integrated STEM concepts from each topic and design thinking.

At the end of each quarter a curriculum was created that contained the university students' activities that were used in the middle school afterschool program. Each year a curriculum was developed:

- Year 1: Dive In! An Integrated Design Thinking/STEM Curriculum
- Year 2: IGNITE! Redesigning Energy Conservation
- Year 3: BUILT TO LEARN! Redesigning Shelter: An Integrated Design Thinking/STEM Curriculum

In Year 1, *Dive In! An Integrated Design Thinking/STEM Curriculum* provided an integrated approach to building science, technology, engineering and math knowledge and skills while engaging students in both identifying and solving problems in their communities and the larger world using a design thinking approach. The activities focused on water conservation, drought, purification, recycling, patterns of use, products that have been designed for those in developing countries and global water usage. All the learning was integrated with a human-centered design thinking approach. The design thinking process activities included conducting interviews, synthesizing data to uncover deep user needs and insights, brainstorming, prototyping and testing. A companion Teacher Guide was created that provided an overview of the project goals, background information on design thinking, teaching tips, a curriculum calendar overview, descriptions of materials, lesson plans, and material lists and resources.

The second year curriculum was entitled *IGNITE! Redesigning Energy Conservation*. Again, the focus was on providing an integrated approach to building science, technology, engineering and math knowledge and skills while engaging students in both identifying and solving problems in their communities and the larger world using a design thinking approach. The activities focused on potential and kinetic energy, exploring concepts of non-renewable energy sources, hydroelectric energy, building water wheels, gaining empathy for someone cooking without electricity or living without lights, building a solar oven, simulating techniques used for extraction of natural resources, investigating and evaluating hydraulic fracking, and learning about technologies used in energy-efficient houses.

The third year curriculum, *BUILT TO LEARN! Redesigning Shelter: An Integrated Design Thinking/STEM Curriculum,* provided an integrated approach to building STEM knowledge and skills while engaging students in both identifying and solving real-world problems using a design thinking approach. Students engaged in integrated STEM and design thinking activities focused on shelter. The foundation of the curriculum was an enduring understanding: *students will develop the creative confidence to fail forward by building successful shelters using both STEM concepts and the empathy-driven design thinking process*. The first module, *The Personal Shelter Design Challenge,* began with an introductory design challenge. This challenge gave students a brief overview of the design thinking process. Subsequent activities provided students with the opportunity to learn and practice the nuances of the design thinking process. In the second module, *The Global Shelter Design Challenge: Redesigning the Shelter Experience for Refugees in the Developing World*, students learned to empathize with children who lived in refugee camps in the developing world. The activities provided an opportunity for the middle schoolers to employ the knowledge and skills they gained from the first module, which included design thinking and STEM concepts. The third module, *The Local Shelter Design Challenge: Redesigning the*

School Shelter Space, gave the middle school students an opportunity to apply their skills to working on a project to benefit their own community and school. They used design thinking and their STEM knowledge and skills gained throughout the curriculum to design a school shelter for a specific user.

In addition to the three design challenge modules, there were seven STEM-based units focused around different shelter topics: building principles, architecture, sustainability, structure and building materials, global shelter, biodiversity, and STEM careers. These units complemented the design challenges by providing the background STEM knowledge and skills needed to create the best design solutions for a variety of users. The seven content areas were chosen because they captured the variety of different considerations that engineers, architects, ecologists, and designers have to consider when thinking about shelter.

Through the creation of STEM-based integrated design thinking curriculum, the university students had the opportunity to not only impact the middle schoolers they worked with, but provided a valuable resource for the larger educational community.

Mentoring & Human-Centeredness

Mentoring and human-centeredness were critical components of the d.loft STEM Design Thinking Model for Teaching & Learning. The expectation was that the university students would learn how to become mentors to the middle school students as they engaged in teaching them about STEM, STEM careers, and design thinking. For many of the students, the notion of what it meant to be a mentor was unclear. Many came from a place of humility and felt that they would learn from the middle schoolers as they were teaching them. The mentors thought deeply about their growing relationships with their students. In their initial visits to the middle school, they were often tentative and tried different approaches to get the middle school students to open up. They planned improvisation warm-ups and unstructured "getting to know you" time so that they could focus on building relationships with the middle schoolers. They realized that they had to get to know those they mentored as people and they realized that they needed to empathize with the middle schoolers. This human-centered mindset permeated their interactions. This awareness was crucial, because adopting a human-centered mindset impacted the development of the mentoring relationships. Fostering empathy was a constant, ongoing topic of conversation among the mentors.

STEM Instructional Activities & Human-Centeredness

Designing and implementing STEM activities for middle school students was challenging, and the university students realized the importance of getting to know the middle schoolers was essential. As part of the course, the university students were required to keep journals reflecting on their weekly work with the middle school students. The mentors used what they learned about connecting with the middle school students as they designed activities. Below are journal excerpts highlighting this understanding.

> "I learned that working with students is all about connecting with them at the level they're at – whether that's their interests or their energy level for that day or whatever else might be influencing their ability to learn. If you can't listen and try to make the activities or mentorship about the relevance of this education to their lives, then it becomes difficult to have the students empower themselves."
>
> "In terms of mentoring, when talking to the students some of them said they would rather be texting their friends or on Facebook than at our afterschool program. This was an important insight because it helped me understand what types of activities this age group enjoys. I am now wondering how to better incorporate social media into a STEM activity."
>
> "I learned to be particularly sensitive to middle school students' need to "maintain [their] reputation"! More generally, I became much more aware of the way they handle the social pressures of middle school and tried to be hyper-cognizant of this while developing activities."

The university students paid close attention what engaged and intrigued the middle school students and used this information to design activities. They saw how different approaches, such as hands-on activities, had an impact on students. As the weeks progressed, they adapted their activities as they learned more about the middle schoolers. The role of empathy was central as the university students were able to base their activities on putting themselves in the middle schoolers' shoes.

Mentoring & A Prototyping Mindset

The adoption of a prototyping mindset in design thinking allows one to learn from failure. Ideas are implemented and evaluated, and then changes are made when needed. This was an essential part of the students' journey as mentors for the middle school students. It began with adopting a prototyping mindset themselves. This was not an easy task, because often as a university student, the notion of failing forward was a new concept. Different students had different comfort levels with failure. The emphasis was on learning from failure as a way to improve, and as students began to understand that, their comfort and ability to embrace a prototyping mindset began to permeate their interactions as mentors. This was reflected in excerpts from their journals.

> "I think I managed to strike a balance between guiding and challenging students in their thought process. Being forced to lead students even when I felt uncomfortable or unsure was a pivotal part of this process for me."

> "Though both students and adults respond to failure with varying degrees of fear, I hope that I will be able to develop some activities that will help Milagra students let go of some of the fear associated with failure. Failing forward is one of my favorite design thinking mindsets and I think it is very important for students to be exposed to."

STEM Instructional Activities & A Prototyping Mindset

Once the university students were able to embrace a prototyping mindset, they modeled this in their interactions with the students. When things did not go exactly according to plan in the activities they designed, they explicitly acknowledged that they would move forward and learn from what did not work.

> "I also learned that embracing that inevitability, instead of freaking out about it or getting upset about it, usually makes everything work itself out. For example, when we were working with the students on the boat-building activity and it turned out to be much easier than we expected, we all looked at each other and said "oh well," thought on our feet about how to change it and then tried the change out. The activity worked out fantastically! The students knew that we had misjudged the challenge, but I think that seeing us react to our mistake in a positive way helped them realize that we were human and helped us to make huge steps as mentors. Finally in light of all this, I learned to not be afraid of making mistakes. It's not only part of the design process, but it can actually bring you closer to your students."

Modeling how to learn from what doesn't work is an essential life skill in a 21st century world. In sum, the focus on empathy and the adoption of a prototyping mindset were critical components of the afterschool program design and implementation.

Implications for Practice

Throughout the three years of d.loft STEM Learning much was learned. This section highlights implications for practice. The first implication for practice is that developing a more facilitative stance as an educator/ mentor can foster the development of empathy. This happens with a willingness to create a learning climate where questions are important and finding answers is a mutual journey. It is important to embrace this within any forward thinking 21st century community that is looking to be more innovative and more human-centered.

Sharing authority empowers students and helps them become more self-directed learners. Design thinking is often based around challenges where one is designing solutions for another person. When teams of student mentors and middle schoolers collaborated and shared authority this led to a greater sense of agency. This agency is a hallmark of becoming a design thinker.

Personal connections are critical to learning. Design thinking provides that opportunity. Learning flourished through the relationships that were built among educators and students.

Being a life-long learner can be a powerful inspiration for students as they confront the challenges and possibilities of the 21st century. That means being willing to always learn new things, learn from and with each other, stretch the boundaries of creativity, and communicate meaningfully. Empathy and prototyping are inextricably linked. Being able to uncover others' needs demands empathy. Once that happens, there must be a willingness to adopt a culture of prototyping to find solutions. If these mindsets are separated, one is simply conducting interviews and building objects. Explicitly acknowledging mistakes can have both cognitive and social/emotional benefits. Students see that learning happens when one examines and reflects on mistakes. They develop increasing comfort with making mistakes, and begin to embrace a fail-forward, prototyping mindset. This enables them to take risks as learners and to be more metacognitive. Developing a culture that supports risk-taking is essential to creating thriving 21st century learning communities.

Conclusions

Kelley and Kelley (2013) describe creative confidence as the belief in one's ability to create change in the world. Creative confidence is the ability to come up with new ideas and the courage to try them out. It is built upon generating new approaches and solutions. This notion was the theoretical foundation that undergirded the d.loft STEM Learning project, which focused on the integration of design thinking, STEM learning and mentorship.

Embracing the human-centered and prototyping mindsets impacted how the university course was designed, how the university instructors interacted with the university students, how the university students designed activities for the middle schoolers, how the university students interacted with the middle schoolers, and how the university students interacted with the university instructors. Everyone grew in his or her ability to put themselves in another's shoes and there was willingness to both acknowledge, embrace and learn from failure that permeated the program. Most importantly, this enhanced the relationships. The typical notion that the teacher/mentor is the all knowing and immune to failure was reconceptualized. In this more equal learning relationship, relationships thrived amongst the university instructors and the university students and the university students and the middle school students. The most important learning was the importance of caring, engaging, taking risks, and trusting as relationships are built. There must then be a willingness to be vulnerable, to fail, and learn from what doesn't work. This leads to being resilient, optimistic, and ultimately, empowered. The d.loft STEM Learning journey was colored with the optimism, hope and resiliency of 21st century learners.

References

Berland, L. K. (2013). Designing for STEM integration. *Journal of Pre-College Engineering Education Research, 3*(1), 22–31.

Carroll, M., Goldman, S., Britos, L., Koh, J., & Royalty, A. (2010). Destination, Imagination & The Fires Within: Design Thinking in a Middle School Classroom. *International Journal of Art & Design Education*. 29(1), 37-53.

Center for the Future of Teaching and Learning at WestEd. (2012). Lost opportunities: The status of science education in California middle schools. Retrieved December 4, 2012 from http://www.cftl.org/ centerviews/march12.pdf.

English, Lyn D.; Hudson, Peter; and Dawes, Les.(2013). “Engineering-Based Problem Solving in the Middle School: Design and Construction with Simple Machines,” *Journal of Pre-College Engineering Education Research (J-PEER): 3*(2), Article 5. http://dx.doi.org/10.7771/2157-9288.1081

English, L. D., & Mousoulides, N. (2011). Engineering-based modeling experiences in the elementary and middle classroom. In M. S. Khine, & I. M. Saleh (Eds.), *Models and modeling: Cognitive tools for scientific enquiry (pp. 173–194)*. Dordrecht: Springer.

Fast Company (2009). “A Designer Takes on His Biggest Challenge”

1 http://www.fastcompany.com/magazine/132/a-designer-takes-on-his-biggest-challenge-ever.html Retrieved 6/15/15

Lambert, R., & Stylianou, D. A. (2013). Posing cognitively demanding tasks to all students. *Mathematics Teaching in the Middle School,18* (8), 500–506.

National Research Council. (2009a). *Engineering in K-12 education: Understanding the status and improving the prospects.* Washington, DC: The National Academies Press.

National Research Council. (2009b). *Rising above the gathering storm two years later: Accelerating progress towards a brighter economic future*. Washington, DC: The National Academies Press. http://www.nap.educ/catalog/12537

Project Tomorrow. (2009). Project Tomorrow: STEM Education & Technology Use in K-12 Schools. Retrieved December 20, 2010 from http://www.debaird.net/blendededunet/2009/02/project-tomorrow- stem-education-technology-use-in-k12-schools.html

Silver, E. A., Mesa, V. M., Morris, K. A., Star, J. R., & Benken, B. M. (2009). Teaching Mathematics for understanding: An analysis of lessons submitted by teachers seeking NBPTS certification. American Educational Research Journal, 46(2), 501–531.

Tytler, R., Osborne, J., Williams, G., & Cripps Clark, J. (2008). Opening up pathways: Engagement in STEM across the primary-secondary school transition. Canberra, Australia: Department of Education, Employment and Workplace Relations. http://pandora.nla.gov.au/tep/ 88047

Vest, C.M. (2006). Educating Engineers for 2020 and Beyond. The Bridge Linking Engineering and Society. National Academy of Engineering. Retrieved 6/15/15 http://www.nae.edu/File.aspx?id=7396

Zawojewski, J. S., Hjalmarson, J. S., Bowman, K., & Lesh, R. (2008). A modeling perspective on learning and teaching in engineering education. In J. Zawojewski, H. Diefes-Dux, & K. Bowman (Eds.), *Models and modeling in engineering education: Designing experiences for all students (pp.1–16).* Rotterdam: Sense Publications.

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