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Making Inspired by Nature: Engaging Preservice Elementary Teachers and Children in Maker-centered learning and Biomimicry

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Introduction

Makerspaces, innovation labs, and creativity spaces are gaining traction in K-12 schools and community centers. This exploratory project, *Making Inspired by Natur*e, brings together the art of making, the disciplined practices of design thinking, and the creative practices of biomimicry to engage preservice teachers and children in building innovative solutions to real world problems. To achieve this, this project is (a) building and evaluating digital resources and hands-on activities for engaging elementary children in innovation through the application of biomimicry and design thinking in a maker context and (b) evaluating models for deepening preservice teachers' pedagogical knowledge for supporting student learning in maker-centered classrooms. This National Science Foundation (NSF) Improving Undergraduate STEM Education (IUSE) funded project, just ending year 1 of a 2-year project, was in response to an NSF Dear Colleague Letter calling for EAGER proposals to conduct exploratory work with respect to STEM learning and design thinking.

Maker-centered Learning

Maker-centered learning, an infusing of many of the practices and ethos of the maker movement into education, provides a framework for developing in teachers and students the mindsets, habits of mind, and process of innovative that are foundational in all fields of study [8]. In a maker-centered classroom, learning is collaborative, driven by curiosity, includes the act of making through prototyping, is interdisciplinary, and shared [6], [7], [8].

Adopting a maker-centered framework for an elementary classroom provides many opportunities to employ innovative strategies for engaging young learners in engineering. We see shifts in the roles of teachers where students are actively teaching each other, community members provide support in the classroom, and students access online sources for maker instructions. This leads to meaningful pedagogical shifts where students are engaged in collaborative learning to employ effective strategies for innovation.

Biomimicry

Biomimicry provides a unique opportunity for students to investigate how their designs might be inspired by the natural world. Biomimicry, or bio-inspired design fits within the broader field of design-by-analogy [14]. Biomimicry, looking to nature for inspiration, provides an innovative way for engaging children in making, engineering design, and learning about nature. Biomimicry's interdisciplinary nature engages children in a variety of scientific domains such as life science, chemistry, physics, and engineering. Children may find its hopeful orientation empowering since they not only learn about pressing problems facing humanity, but are provided opportunities to apply their own thinking and ingenuity in making solutions.

Design Thinking

Design thinking is a human-centered approach for creative problem solving [8], [10]. There are many variations in processes, activities, and habits of thought that fall under design thinking [9], [10], [11]. This project has adopted the processes and activities promoted at the Institute of Design at Stanford (d.School). Key elements of design thinking are (1) gain insight into the need (i.e. gain empathy), (2) define the problem to be solved, (3) create and consider many options (ideate), (4) create prototypes and (5) test prototypes for gaining feedback [1].

Preservice Teacher Experiences

Preservice teachers starting third year of an undergraduate teacher preparation program in elementary and early childhood education were immersed in a series of maker-centered learning foundations and pedagogy experiences, maker challenges, biomimicry activities, and design thinking projects. These experiences were designed to develop their own identity as a maker and provide concrete strategies for engaging elementary age children in similar experiences.

Maker-centered Learning Foundations and Pedagogy

Preservice teachers began by engaging in several tinkering activities such as Wind Tubes [29] and Marble Machines [29] and learned a simple design process: Think - Make - Improve [19].

Building upon these experiences they employed maker-centered learning thinking routines [8] to develop a level of proficiency in using them with a variety of human made objects and systems. For example, they began with exploring the Parts, Purposes, Complexities [24] of a screw. These were documented through sketches, describing words, and lists. Other thinking routines employed include:

- Parts, People, Interactions [25]: who are the people connected to the system?,
- Think, Feel, Care [30]: explore the point of view of different people that interact with the system, and
- Imagine if… [15]: explore the ways a system might be improved.

At the conclusion of these experiences, they learned how these strategies can be employed in a classroom setting and how these strategies benefit the development of key "habits of mind" in children. Additionally, concepts of maker-centered learning were connected to learning theories and other pedagogical approaches including experiential learning, constructivism [27], constructionism [23], peer learning [33], and project-based learning [17].

Hands-on Maker Challenges and Experiences

Preservice teachers also experienced a series of hands-on challenges that illustrate age appropriate maker activities that teach elementary science concepts including building a small watercraft that can carry weight (buoyancy) and a boat that can power itself with a rubber band (potential energy, kinetic energy).

They experienced several digital making activities including coding on Code.org, programming the Sphero robotic ball, and building and programming the LEGO WeDo and LEGO Mindstorms EV3 kits. Preservice teachers also experienced several movie making, digital storytelling and stop motion animation activities.

Creative Team Problem Solving Experiences

To deepen experience with exploring systems thinking and skills in cooperation, communication, and creativity, preservice teachers experienced a series of team problem solving challenges such as:

- Building the tallest tower using 5 sheets of paper [4],
- Stacking cup challenge [28],
- Team talk challenge [13], and
- Draw How To Make Toast [12].

Making Inspired by Nature Experiences

To build a foundation in biomimicry and bio-inspired design preservice teachers completed several readings and watched videos such as Making Stuff Wilder [26] and Biomimicry in Action [2]. Preservice teachers began applying the maker-centered learning thinking routines to the natural world through activities such as Hunting and Gathering for Ideas [3]. Next, they experienced a series of K-5 lessons [18] that bring together making and bio-inspired design. These lessons included:

- Shape and Function (Scallop Shell),
- Keeping Cool (Termite Mound Architecture),
- Aerodynamics (Gliding Seeds), and
- Strong Towers.

All lessons were designed to meet specific Next Generation Science Standards and maker dispositions. As a capstone experience, preservice teachers used two of these lessons with a small group of children in K-5 as part of a 6-hour field experience.

Design Thinking and ChangeMaker K-12

To prepare the preservice teachers to use design thinking with children and to have them apply the principles themselves, they completed several activities including: readings and documentaries on design thinking, application of the design thinking process to simple design problems (e.g. designing a wallet for a partner, designing an eating utensil for a partner), and competing in the ChangeMaker K-12 Faire. The ChangeMaker K-12 faire is a campus-based competition where undergraduate students select an actionable problem in education, work in teams to develop a solution, and share their solution at the ChangeMaker K-12 event.

Methodology

A mixed-methods approach was employed to provide information on the quality of the materials, perceived impacts on preservice teachers, and strengths and challenges associated with implementation of the newly developed materials [5]. Data sources include preservice teacher pre and post surveys (N = 42 at baseline; N = 31 at follow up), preservice teacher interviews (N=20). All preservice teachers taking the project course participated in the baseline survey (N = 40) and 78% (N = 31) completed the follow-up survey; just over half (55%) of students completed both a baseline and follow-up survey (N = 22).

The survey items were developed by the project team and founded on (a) project goals, (b) related research on maker-centered learning [8], (c) innovator competencies [9], [10], [11], [21], [22] , and (d) biomimicry [14]. When possible, valid reliable instruments were used.

Survey data were collected for pre/post analyses on a range of outcome variables: (1) preparedness, value, and utility of core foundational experience topics, (2) teaching efficacy and beliefs related to mathematics problem-solving and biomimicry in science [32], (3) connectedness to nature [20] and (4) resources necessary to support their work as a maker educator in the future.

The survey was made up of six scales: (1) Preparedness on topics of Maker-Centered Learning, Design Thinking, and Biomimicry, (2) Value in Teaching K-12 Children Maker-Centered Learning, Design Thinking, and Biomimicry, (3) Likelyhood to Teach Maker-Centered Learning, Design Thinking, and Biomimicry, 4) STEM Teaching Efficacy and Beliefs for Problem- Solving in Mathematics, (5) STEM Teaching Efficacy and Beliefs for Biomimicry in Science, and (6) Connectedness to Nature.

For the scale *Preparedness on Maker-Centered Learning, Innovator Competencies, and Biomimicry*, participants were asked to reflect to what extent they felt prepared to teach K-12 children maker-centered learning, innovator competencies, and biomimicry. Responses were recorded on a Likert scale from 1 (no emphasis) to 5 (complete emphasis).

For the scale *Value of Maker-Centered Learning, Innovator Competencies, and Biomimicry*, participants were prompted to identify the extent to which they see value in K-12 students engaging with 15 topics related to maker-centered learning, innovator competencies, and biomimicry. Participant responses were recorded on a Likert scale from 1 (no value) to 5 (complete value).

For the scale *Utility of Maker-Centered Learning, Innovator Competencies, and Biomimicry*, participants were prompted to rate the likelihood they would use 15 topics related to maker-centered learning, innovator competencies, and biomimicry when teaching in future classrooms. Responses were recorded on a Likert scale from 1 (extremely unlikely) to 5 (extremely likely).

Personal STEM Teacher Efficacy and Beliefs (PSTEBS) had demonstrated reliability and validity [32] and comprises 11 items which prompt participants to rate their confidence in their teaching skills based on a series of statements on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). One item on each scale was reverse coded. Higher scores indicated greater efficacy in teaching the subject area. Two subject areas relevant to the current project were covered: problem-solving for mathematics and biomimicry in science. For example, participants indicate their agreement with the statement "I am continually improving my mathematics (problem-solving) teaching practice."

Connectedness to Nature had demonstrated reliability and validity [20] and comprises 14 items on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). Participants were prompted to answer each question in terms of the way they generally feel. Three items were reverse coded. The survey was designed to examine respondents' relationship with the natural world; higher scores indicated greater feelings of connectedness to nature. An example item is: I often feel a sense of oneness with the natural world around me."

Reliability analyses were conducted on the preservice teacher baseline data to identify clusters of similar items to form composite scales, which are more robust and reliable than single survey items. As shown in Table 1, composite scales at baseline had acceptable internal reliability (alpha coefficient greater than .700).

Scale	**Number of Survey Items**	**Cronbach's Alpha (N =42)**
Preparedness on Topics of Maker-Centered Learning, Design Thinking, and Biomimicry	16	.976
Value of Maker-Centered Learning, Design Thinking, and Biomimicry	15	.939
Utility of Maker-Centered Learning, Design Thinking, and Biomimicry	15	.931
STEM Teacher Efficacy and Beliefs (PSTEBS): Problem-Solving for Mathematics	11	.856
STEM Teacher Efficacy and Beliefs (PSTEBS): Biomimicry in Science	11	.872
Connectedness to Nature	14	.739

Table 1. Preservice Teacher Survey Composite Scales Internal Reliability

Preservice teacher focus group participants were randomly selected. They were asked about: their experience with project materials, curricula, and the website; participation in Science and Innovation Saturday Program student camps; perceived outcomes for themselves and their potential students; and strengths and challenges of the project.

Analysis

Qualitative data collected through interviews and focus groups were analyzed using an approach that closely follows methods explicated by Miles, Huberman, and Saldaña [21]. This approach emphasizes well defined study variables to ensure the comparability of data and reduction of data using data displays and matrices so that the common themes can be identified. The qualitative data was analyzed for trends, and were used to validate and extend understanding of survey data, probing complex issues in greater depth.

Quantitative data collected from participant surveys were analyzed and presented using descriptive statistics (e.g., frequencies, means, and standard deviations). Frequencies of response categories were calculated for three scales at post-test: Emphasis on, value of, and utility of maker-centered learning, design thinking, and biomimicry. Means and standard deviations were calculated for all preservice teachers who completed both a baseline and follow-up survey to assess change in outcomes during participation in camp.

Mean differences were examined between sample of students who took both the baseline and follow-up surveys and those who took just one survey, using an independent samples t-test with a Bonferroni adjustment for multiple comparisons. No differences between outcomes were found, suggesting preservice teachers who took only one survey (either baseline or follow-up) did not differ from those who took both surveys. Change over time was documented using paired-sample t-tests and a Bonferroni adjustment.

Findings and Discussion

Preparedness On Topics Related to Core Foundational Experiences: Maker-Centered Learning, Design Thinking, and Biomimicry.

Preservice teachers indicated that the Making Inspired by Nature Core Foundational Experiences emphasized all intended topics to at least a moderate amount. Most respondents indicated that their experiences placed much emphasis or complete emphasis on each topic. Overall, the combined score indicated that the core foundational experiences placed much to complete emphasis on maker-centered learning, design thinking, and biomimicry topics ($M = 4.67$, $SD = .45$). This finding seems to indicate that participates feel they were engaged in maker-centered learning, design thinking, and biomimicry.

Value and Utility of Topics Related to Core Foundational Experiences: Maker-Centered Learning, Design Thinking, and Biomimicry

Participant responses for the value scale were recorded on a Likert scale from 1 (no value) to 5 (complete value). Preservice teachers initiated core foundational experiences with a relatively high level of value in teaching K-12 children maker-centered learning, design thinking, and biomimicry, with ratings of topics related to these falling between much value and complete value. They increased slightly over the course of their engagement with Making Inspired by Nature activities, though the change was not significant after correcting for multiple comparisons, $t\ (21) = -\ .12$, $p = .0468$ Ceiling effects due to high baseline scores may conceal significant changes. It appears that, at least for this group of participants, preservice teachers entered the project already valuing the importance of engaging children in these innovative practices.

Participant responses for the Utility scale were recorded on a Likert scale from 1 (extremely unlikely) to 5 (extremely likely). Preservice teachers initiated core foundational experiences with a relatively high level of belief that they are likely to use maker-centered learning, design thinking, and biomimicry in their future classrooms, with ratings of topics falling between somewhat likely and extremely likely. They were fairly stable over the course of their engagement with Making Inspired by Nature activities, with a very slight increase that did not reach significance, $t(21) = -0.97$, $p=.341$. Ceiling effects due to high baseline scores may conceal significant changes. This finding indicates that participants entered the program with high value for these types of activities and and belief that they would likely use these activities in their future classrooms.

Preservice STEM Teacher Efficacy and Beliefs: Mathematics and Science.

Respondents rated their confidence in their teaching skills based on a series of statements on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). Preservice teacher efficacy and beliefs grew over the course of their experience with Making Inspired by Nature. They rated most statements about agreement with items related to efficacy and beliefs for problem-solving for mathematics as between neither agree nor disagree and agree at baseline and at follow-up increased slightly closer to agree for the same statements on average. This change was not significant, $t(20) = -2.06$, $p = .053$. Preservice teachers increased their efficacy and beliefs for biomimicry for science, rating statements at follow-up, on average, as neither agree nor disagree at baseline and agree at follow-up. This change was significant, $t(19) = -3.68$, $p = .002$.

Preservice Teacher Connectedness to Nature.

Respondents indicated their agreement with statements about connectedness to nature on a scale from 1 (strongly disagree) to 5 (strongly agree). Preservice teacher connectedness to nature grew slightly over the course of their experience with Making Inspired by Nature, though this change was not significant. They rated most statements about agreement with items related to efficacy and beliefs for problem-solving for mathematics as between neither agree nor disagree and agree at baseline, and at follow-up increased slightly. This change was not significant, $t(20) = -1.49$, $p = .153$.

Preservice Teacher Focus Group Responses Related To Impact

All respondents agreed that the Making Inspired by Nature project increased their understanding of biomimicry and design thinking in a maker context and enlarged their pedagogical knowledge for supporting student learning in maker-centered classrooms. Several teachers said they had never heard of biomimicry before their association with the project and now viewed it as an important concept to utilize in classes. They believed that had acquired skills for translating concepts into classroom practice and utilizing more experiential approaches in their instruction.

In terms of pedagogical knowledge for supporting learning in maker-centered classrooms, teachers expressed the vital importance of helping students believe they could be makers and thought that if students perceived of themselves as makers in one class, they could then carry that understanding with them to other classes. Teachers reiterated that their pedagogy would be informed by greater creativity and stated that the teaching strategies they learned would help them make class content more developmentally appropriate. They said they planned to use more hands-on activities to increase student engagement and foster resiliency and persistence.

Teachers suggested multiple ways they would use their learning from the project to create positive change. They said that they would use knowledge from the project to inspire students to attend college and consider degree programs related to mathematics and science. They also said the program would allow them to appreciate their own capacity for making lasting change in students' lives, increase student engagement and creativity in their classrooms, enable students to become more independent learners, and facilitate students becoming better citizens as they recognized their capacity to help solve problems.

The Making Inspired by Nature project clearly impacted teachers' interest in biomimicry and ability to help students apply biomimicry to solving real-world problems. One teacher said that the project encouraged students to think about problems in their community and build prototypes to decrease river pollution. Several teachers described using the knowledge of biomimicry to help students recognize the extensive use of this concept in engineering and design applications. Others said they planned to make biomimicry a fundamental way to teach problem-solving skills by turning to nature for solutions.

There was strong agreement among most teachers that involvement in the Making Inspired by Nature project would foster changes in their classroom curriculum instruction and/or assessment practices. The majority of teachers indicated that they would use more hands-on activities, forge connections between making and being inspired by nature, and integrate biomimicry concepts into lesson plans. Some teachers said they recognized the importance of letting students struggle with a problem and find their own solutions rather than telling them how to solve it. Other teachers said they wanted to create a maker center in their classroom in which students could examine different objects and create whatever they wanted.

Conclusion

Both survey and interview data suggest that the experiences provided to preservice teachers (i.e. foundings in maker-centered learning and pedagogy, hands-on maker challenges, creative team problem solving experiences, making inspired by nature experiences, design thinking projects and ChangeMaker K-12 Faire, and hands-on field experience with children) left them feeling well prepared and likely to use maker-centered learning and biomimicry in future classrooms.

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