2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #37506

Board 234: ChangeMaker K12: A Platform To Support Teacher Candidates in Systems Thinking, Engineering Education, and Change

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Introduction

Professionals with expertise in systems thinking, creative problem solving, and communication are in greater demand on a global scale. This need is acutely felt in K-12 educational institutions that often fail to meet the different needs of teachers, families, and students. Additionally, teacher preparation programs have a hard time producing people who see themselves as innovators with the drive and skill to affect positive change in their careers and communities.

As communities push for rich innovative experiences for K-12 students, some have begun to add maker spaces, robotics clubs, and/or innovation labs. Even though more states have adopted the Next Generation Science Standards (NGSS) [1], far too many school districts deprioritize engineering design experiences in classrooms.

The ChangeMaker K-12 project was developed to create materials for use in teacher education programs that (1) support elementary education undergraduate teacher candidates (TCs) in teaching engineering and human-centered design and (2) engage TCs in employing systems thinking and change processes to improve their own practice. ChangeMaker K-12, accessible at ChangeMakerK12.org, is currently under development with support from the National Science Foundation (NSF), award # 2044358.

Conceptual Framework

The need to address challenges from a systems viewpoint is becoming more and more important as the size and complexity of the problems facing humanity increase. A system is defined as "an interconnected set of elements that is coherently organized in a way that achieves something" [2], [3]. All systems include: elements, interconnections, and a purpose [2]. Systems thinking, mindsets and processes for understanding systems and finding opportunities to improve them, is employed across all domains as a means of innovation. Educational systems are ripe for innovation through a systems perspective.

Research suggests that using a systems perspective in teacher preparation can facilitate the formation of a teacher identity and improve TC capacity for developing solutions to problems that arise in the context of their own practice [4]. Other studies demonstrate effective strategies for enhancing TCs' capacity for systems thinking in environmental science [5], engineering education [6], and biology [7].

Although efforts have been made to integrate the Next Generation Science Standards (NGSS), meaningful implementation has not yet become widespread since many teachers have little to no expertise teaching engineering design. For instance, just 8% of elementary classrooms reported learning about several science/engineering professions, while 16% of kindergarten classrooms placed no emphasis at all on engineering [8]. The majority of instructional minutes in US schools per day are devoted to reading/language arts (89 min) and math (54 min), with science (19 min) and social studies (16 min) lagging behind [8].

But the NGSS are very much in line with what teachers believe. More than 90% of the educators surveyed agree that: 1) science is best learned when it is tied to everyday life, 2) students should learn science by doing, and 3) science should apply phenomena to real-world settings [8]. This disconnect may be attributed to a lack of preparedness of elementary teachers to confidently teach science and engineering. Smith [8] reported 77% of elementary teachers felt well prepared to teach reading/language arts compared to 31% for science and only 3% for engineering. Coppola [9] found engaging teacher candidates (TCs) in engineering mini-units with school-based field experience significantly improved engineering pedagogical content knowledge and dispositional self-efficacy. Web and LoFaro [10] found that TCs' self-efficacy for teaching engineering was increased by including experiences in various courses rather than short-term exposure in a single methods course.

Overview of the ChangeMaker K-12 Model

ChangeMaker K-12 learning path is divided into a series of four progressive stages: design awareness, design for function, design with empathy, and design for change (see Figure 1). The first three stages focus on design fundamentals. The knowledge and practice of these three fundamentals are then brought together in the fourth stage to practice the more complex process of creating change through design.

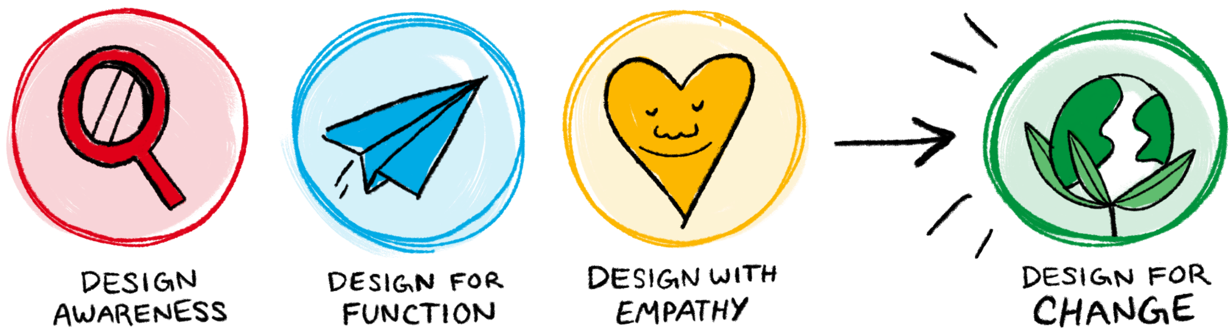

Figure 1: ChangeMaker K-12 Stages

Design Awareness: The Design Awareness section of the pathway provides a collection of activities adapted from the maker-centered learning framework developed by Agency by Design, Harvard Project Zero [11]. A variety of "thinking routines" that emphasize development of systems thinking through looking closely at objects to identify parts, purposes, and how the parts work together to get something done, zoom out to see how people connect to these systems, and then imagine how we can make these systems better. Key activities include:

- Introduction to Design Awareness. View Slidedeck, View Prompt,
- Zoom In, Parts & Purposes. View Slidedeck, Journal Prompt,
- Zoom Out, Parts & People. Slidedeck, Journal Prompt, and

- Wonder: Imagine If… View Slidedeck, Journal Prompt.

Design for Function: Engineering design challenges that guide TCs and students through the engineering design process: define a challenge, ideate, prototype, test and refine solutions. Key activities in the Design for Function stage include:

- Introduction to Design for Function. View Slidedeck, Journal Prompt
- Define Challenge, Create a Bug List. View Slidedeck, Journal Prompt
- Ideate. View Slidedeck, Journal Prompt
- Prototype, Test, and Refine. View Slidedeck, Journal Prompt

Design with Empathy: A set of human-centered design challenges that begin with identifying needs of specific people. Students develop solutions through empathy, defining a challenge, ideating, prototyping, testing and refining. During these activities, students gain experience in developing solutions to real-world problems by first taking the point-of-view of the individuals for whom they are designing. Key activities include:

- Introduction to Design with Empathy. Slidedeck, Journal Prompt
- Empathize & Define, Design for a Spy Fairy. Slidedeck, Journal Prompt,
- Prototype, Test and Refine, Desk Design Challenge. Slidedeck, Journal Prompt.

Design for Change: Now that students have developed some skill in systems thinking (design awareness), have experience in designing for function (i.e. engineering design process), and have experience in human-centered design, students are guided through developing a solution to a real-world problem. Key activities include:

- Introduction to Design for Change. Slide Deck, Journal Prompt
- Wonder. Slidedeck, Journal Prompt,
- Empathize & Learn. Slidedeck, Poster, Journal Prompt,
- Define Problem + Ideate Slidedeck, Poster, Journal Prompt,
- Prototype, Test, & Refine Slidedeck, and
- Communicate Solution. Slidedeck, Poster.

A ChangeMaker journal, along with prompts for each activity, is used to help support students and as an assessment component for teachers to track progress.

Methodology

This mixed-methods study collects and analyzes both qualitative and quantitative data to learn more about the effectiveness of the materials, design iterations, perceived effects on TCs, and the benefits and drawbacks of using the newly developed materials. Data sources include TC interviews and pre- and post-surveys.

Qualitative Methods

TCs who were enrolled in the *Becoming a Changemaker* engineering education course in fall 2021 (Cohort 1) and those enrolled in spring 2022 (Cohort 2) were invited to participate in a focus groups in December 2021 (2 focus groups, N = 21 TCs) and April 2022 (1 focus group, N

= 9), respectively. TCs were questioned regarding their use of project materials and curricula, their involvement in the Design and Innovation camps, their participation in the Becoming Changemaker coursework, their perceptions of the project's successes and challenges, and their perceptions of their own and their potential students' outcomes.

Quantitative Methods

Baseline and followup surveys were administered to all TCs enrolled in the *Becoming a Changemaker* course in either Fall 2021 (N=23) or Spring 2022 (N=10) at the beginning and end of the semester. A second follow up survey was administered following participation in the summer camps in June and July 2022.

Surveys were developed through adapting or adopting existing reliable and valid measures where possible. All TCs who had participated in the *Becoming a Changemaker* coursework and camps were invited to complete the survey. The survey included five scales:

- Confidence for teaching engineering design, systems thinking / design awareness, and human-centered design;
- Value of engineering design, systems thinking / design awareness, and human-centered design;
- Utility of engineering design, systems thinking / design awareness, and human-centered design;
- STEM Teaching Efficacy and Beliefs for Problem-Solving; and
- STEM Teaching Efficacy and Beliefs for Engineering Design.

The Teacher Efficacy and Beliefs in Problem Solving and Engineering Design scales were adapted from the Personal STEM Teacher Efficacy and Beliefs (PSTEBS) scale. The PSTEBS has demonstrated reliability and validity [12] and consists of 11 items which prompted 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. The scale was revised to include 10 items targeting two subject areas relevant to the current project: problem solving and engineering design. For example, participants indicated their agreement with the statement "I am continually improving my problem-solving teaching practice."

Reliability analyses were conducted on the TC 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 for Pre (N=23)	Cronbach's Alpha for Post (N=17)
Level of Confidence to Teach Engineering Design, Systems Thinking, Human-centered Design	15	.923	.911
Value of Engineering Design, Maker- Centered Learning, Human-Centered Design	15	.936	.971
Utility of Engineering Design, Maker- Centered Learning, Human-Centered Design	15	.912	.945
Teacher Efficacy for Teaching Problem Solving	10	.709	.788
Teacher Efficacy for Teaching Engineering	10	.801	.880

Table 1. Teacher Candidate Survey Composite Scales Internal Reliability

Participants in the TC focus groups were chosen at random. They were questioned regarding their use of the project's resources, curricula, and website; their involvement in student camps (i.e. field experience); their perceptions of the outcomes for themselves and their future students; and the project's advantages and disadvantages.

Analysis

Qualitative data collected through interviews and focus groups were analyzed using an approach explicated by Miles, Huberman, and Saldaña [13]. This approach emphasizes well defined study variables to ensure the comparability of data and reduction of data to common themes. Issues examined using qualitative data included factors that facilitate or impede progress, factors associated with sustainability, and program impacts that are less likely to be documented using survey data.

Paired-samples t-tests were conducted to assess change in outcomes for those who complete both a baseline and a followup survey. A Bonferroni adjustment was used to account for multiple statistical tests.

Findings and Discussion

Confidence For Teaching Engineering Design, Systems Thinking / Design Awareness, And Human-Centered Design

Confidence was rated on a Likert scale from 1 (not at all confident) to 4 (very confident). For Cohort 1, survey data shows significantly higher confidence in teaching engineering design, $t(14) = 2.80$, $p < .05$, and systems thinking, $t(14) = 2.24$, $p < .05$. Confidence in teaching human-centered design increased, but not significantly, $t(14) = 0.94$. Cohort 2 similarly shows significantly higher confidence in teaching engineering design, systems thinking, and human-centered design.

Focus group interviews with TCs reported that the course material and associated experiences piqued students' interest in engineering. The majority of TCs stated that the ChangeMaker K-12 project shifted the way they perceived the world because they began to consider how commonplace objects might be improved upon. The ChangeMaker K-12 curriculum, according to some TCs, demonstrated to them that you don't need to be a genius to think and create like an engineer. All TCs stated that taking part in the ChangeMaker K–12 initiative helped them better grasp design thinking. Several TCs noted that the human-centered problem-solving process empowers students because it teaches them that these types of activities are easier to approach as a group rather than working independently.

Value and Utility Of Engineering Design, Systems Thinking / Design Awareness, and Human-Centered Design

TCs rated their perceptions of the value of teaching these concepts on a Likert scale from 1 (no value) to 4 (high value). TCs for Cohort 1 indicated that they placed between moderate value and high value on students engaging with engineering design, maker-centered learning, and human-centered design topics. Overall, Cohort 1 TCs reported a slight decrease in value after participation in the Becoming a Changemaker course, though the change was not significant, $t(13) = -0.56$, $p = .59$. The value scale for Cohort 2 showed very little variability with almost all of TCs indicating that they placed value on engineering design, maker-centered learning, human-centered design, and other related topics prior to taking the Becoming a Changemaker course. After taking the course, TCs reported a slight decrease in ratings of value, but the changes were not significant.

Participant responses for the Utility (i.e. how likely are TCs to teach these topics in their future classrooms) were recorded on a Likert scale from 1 (very unlikely) to 4 (very likely). TCs in Cohort 1 reported a slight decrease in the likelihood they would use the topics after completing the Becoming a Changemaker course, though the change was not significant, $t(13) = -1.13$, $p = .28$. Cohort 2 ratings of utility were overwhelmingly positive before course completion with between 90% and 100% of TCs indicating that they were likely or very likely to use 14 of the 15 targeted topics. A significant increase in the likelihood of use was observed for engineering design and maker-centered learning following course completion.

To better illuminate how TCs viewed value and utility of engineering design, systems thinking / design awareness, and human-centered design, frequency of value ratings over time for engineering design, systems thinking, and human-centered design were calculated showing that over 90% of TCs rated topics as being of moderate or high value at both baseline and follow up. And over 94% of TCs indicated they were likely or very likely to engage in engineering design, systems thinking / design awareness, and human-centered design. Only a small number indicated that they were unlikely or very unlikely to use engineering design, human-centered design, in their future classroom. After completing the Becoming a Changemaker course only 6% were unlikely to teach engineering design in their future classroom.

Teacher Candidate Efficacy and Beliefs: Problem Solving and Engineering Design.

TCs rated their confidence in their teaching skills based on a series of statements on a Likert scale from 1 (strongly disagree) to 4 (strongly agree). TCs' efficacy for problem solving increased slightly after their completion of the Becoming a Changemaker course, though the change was not significant, $t\ (11) = 0.58$, ns. Over 80% of TCs rated their efficacy in problem solving positively for 9 of 10 items before and after completing the Becoming Changemaker course.

For TCs in Cohort 2, a significant increase in teacher efficacy for problem solving was observed after completing the Becoming a Changemaker course. Specifically, TCs reported a significant increase in their level of agreement with the statement that they know what to do to increase student interest in engineering design. About two thirds of TCs reported that they agreed with 5 of the 9 items targeting problem solving efficacy prior to completing the Becoming a Changemaker course. By the end of the semester, the majority of TCs indicated they agreed with 8 of the 9 items.

TCs were also asked to indicate their level of agreement with statements related to engineering design. Cohort 1 TCs efficacy for engineering design increased, however, this increase was not statistically significant, $t\ (11) = 2.14$, $p = .06$. A majority of TCs reported low levels of efficacy across all items at baseline. Following their completion of the Becoming a Changemaker course, a majority of the TCs indicated that they agreed with 8 of the 9 items targeting efficacy for teaching engineering design. TCs in Cohort 2 reported a significant increase in efficacy for teaching engineering design after completing the Becoming a Changemaker course.

Conclusion

The quantitative and qualitative data suggests that teacher candidate engagement with the ChangeMaker K12 materials and associated field experiences results in high confidence in teaching engineering design and systems thinking. There was no change in TCs value and likelihood of use in future classrooms, though the lack of change may be attributed to high ratings at the start of the study, thus there was little room for growth. On the measure of efficacy for teaching problem solving, both Cohort 1 and 2 increased, though only Cohort 2 increased significantly. On the measure of efficacy for engineering design, both Cohort 1 and 2 increased, though only Cohort 2 increased significantly. The difference in Cohort 1 and 2 may be the result of improved ChangeMaker K12 materials and experiences. Overall, results suggest the materials can have a positive impact on TC capacity for teaching systems thinking and engineering design.

References

[1] NGSS Lead States. 2013. *Next Generation Science Standards: For States, By State*s. Washington, DC: The National Academies Press.

[2] Meadows, D. H. (2008). Thinking in systems: A primer. White River Junction, VT: Chelsea Green

[3] Senge, P., Cambron-McCabe, N., Lucas, T., Smith, B., Dutton, J., and Kleiner, A. (2012). Schools that Learn: A Fifth Discipline Fieldbook for Educators, Parents, and Everyone Who Cares About Education. New York, NY: Crown Business.

[4] Astaíza-Martínez, A.F., Mazorco-Salas, J.E. & Castillo-Bohórquez, M.I. Teacher-Researcher Training in Higher Education: a Systems Thinking Approach. *Syst Pract Action Res* 34, 187–201 (2021). https://doi.org/10.1007/s11213-020-09532-x

[5] Güliz Karaarslan Semiz & Gaye Teksöz (2019): Developing the systems thinking skills of pre-service science teachers through an outdoor ESD course, Journal of Adventure Education and Outdoor Learning, DOI: 10.1080/14729679.2019.1686038

[6] Rea Lavi & Yehudit Judy Dori (2019) Systems thinking of pre- and in-service science and engineering teachers, International Journal of Science Education, 41:2, 248-279, DOI: 10.1080/09500693.2018.1548788

[7] Streiling, S., Hörsch, C., & Rieß, W. (2021). Effects of Teacher Training in Systems Thinking on Biology Students—An Intervention Study. *Sustainability*, *13*(14), 7631. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su13147631

[8] Smith, S. (2020). Obstacles to and progress toward the vision of the NGSS. Horizon Research, Inc.

[9] Coppola, P. (2019) Preparing preservice elementary teachers to teach engineering: Impact on self‐efficacy and outcome expectancy. School Science and Mathematics;.119: 161– 170. https://doi.org/10.1111/ssm.12327

[10] Webb, D, LoFaro, K. (2020). Sources of engineering teaching self‐efficacy in a STEAM methods course for elementary preservice teachers. School Science and Mathematics. 120: 209– 219. https://doi.org/10.1111/ssm.12403.

[11] Clapp, E. P., Ross, J., Ryan, J. O., & Tishman, S. (2016). Maker-centered learning: Empowering young people to shape their worlds. San Francisco, CA: Jossey-Bass.

[12] Streiling, S., Hörsch, C., & Rieß, W. (2021). Effects of Teacher Training in Systems Thinking on Biology Students—An Intervention Study. *Sustainability*, *13*(14), 7631. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su13147631

[13] Miles MB, Huberman AM, Saldana J. (2014). Qualitative Data Analysis, A Methods Sourcebook, Edition 3. USA: Sage Publications.