

The Impact of an Integrated Pre-K STEM Curriculum on Teachers' Engineering Content Knowledge, Self-Efficacy, and Teaching Practices

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Abstract - This paper reports a pilot study to determine the potential impact of an integrated STEM curriculum on Pre-K teachers' engineering content knowledge, self-efficacy and teaching practice. Using a randomized control trial design, researchers examined the impact of the curriculum in 17 Pre-K classrooms (8 intervention classrooms, 9 control classrooms) in central Massachusetts. Questionnaires measuring STEM and engineering content knowledge, self-efficacy and teaching practice were administered to participating Pre-K teachers (N=42; 21 intervention, 21 control) in Fall 2017 and again in Spring 2018. Baseline analysis showed no significant differences in engineering and STEM content knowledge, pedagogical content knowledge, or teaching self-efficacy at the start of the pilot study between intervention and comparison classroom teachers. Fidelity of implementation was measured using an observation instrument developed by the project team based on a published implementation science framework. We hypothesized that teachers who implement the integrated STEM curriculum will have significantly higher engineering pedagogical content knowledge and self-efficacy than teachers in the comparison group. As well the teachers who implement the integrated STEM curriculum will show significant gains in their engineering pedagogical content knowledge and self-efficacy in teaching engineering and STEM as a result of their participation.

Index Terms – early childhood, engineering education, integrated STEM, problem-solving, teacher self-efficacy.

INTRODUCTION

National reports highlight the wide gap in STEM (Science, Technology, Engineering, and Mathematics) literacy between low income and ethnic minority American students and their White, middle-class American peers. These achievement and readiness gaps (in reading, math, science, and approaches to learning) are evident as early as kindergarten, and widen as students advance in school [1].

Early childhood teachers who teach children to solve problems in a systematic way can introduce children to the Engineering Design Process (EDP) and begin to develop their own engineering literacy, which can expose the children to this career field while debunking stereotypes they

may have about engineering as a profession. Studies have found that engineering design projects enabled more positive attitudes towards engineering as a career [2,3]. When teachers engage in the EDP, children showed an increase in their engagement of activities, the number of engineering behaviors displayed, and their persistence in completing activities [4]. Aldemir and Kernami [5] designed and implemented a STEM model to support Pre-K children's skills and knowledge in STEM as well as to improve Pre-K teachers' understanding of how to integrate STEM in the classroom. Their findings suggest that children attending preschool can attain higher levels of understanding in STEM when they are provided with well-planned, stimulating and developmentally appropriate activities.

Despite the evidence that a STEM curriculum and integration of the EDP encourage cognitive development and child curiosity [6-9], there is very little STEM or engineering instruction within pre-kindergarten classrooms [10, 11]. This is due in part to a lack of teacher preparation and shortage of early childhood STEM and engineering curricula [12-15].

For the best teaching practices, it is essential that teachers have a knowledge of the content they teach [16-19] as well as the knowledge of how to teach it to the students i.e., pedagogical content knowledge [20]. Bers et al. [21] reported a statistically significant increase in the early childhood educators' level of knowledge about robotics, engineering and programming, and pedagogies for teaching these topics in the early childhood classroom after participation in a three-day professional development workshop. Their results also indicated significant increases in several aspects of technology self-efficacy and attitudes toward technology. Similarly, Park et al. [22] found the need for professional development that will enhance teachers' understanding of the importance of early childhood STEM education, including their knowledge of STEM disciplines and potential challenges of teaching STEM. Thus, providing professional development to early childhood teachers seems essential to improving integrated STEM content knowledge and pedagogical content knowledge.

In regard to self-efficacy, Pendergast et al. [23] found that although teachers may be more comfortable with integrating science activities and understanding the benefits of science for young children than previously thought, they continue to indicate feelings of inadequacy and anxiety

toward their own science knowledge and ability to support children's scientific thinking. Recently, Gerde et al. [24] reported that domain-specific self-efficacy was highest for literacy, lower for math, and lowest for science. The researchers pointed out that, to enhance science learning opportunities, early childhood teachers can be supported with science content and practices that can also incorporate literacy and math.

Based on these previous findings, the *Seeds of STEM* curriculum was intended to build teachers' engineering knowledge and support their ability to teach young children the EDP. The overarching goal of the project is to support the teaching and learning of STEM practices in early childhood and, as a result, increase students' STEM readiness.

DESCRIPTION OF THE INTERVENTION

The *Seeds of STEM (SoS)* 8-unit curriculum was developed by a team of engineers, STEM pedagogy experts, a cognitive developmental psychologist, a social psychologist, and six Head Start classroom teachers. The integrated STEM units were designed based on a Pre-K teacher needs assessment and edited through continuous feedback from approximately 20 participating teachers over a 10-week period during the first two years of the project.

The researchers adapted the Dayton Regional STEM Center's Quality STEM Framework [25] and defined eight principles for high-quality early childhood STEM experiences, to guide the development of the curriculum: developmental appropriateness; cultural responsiveness; applications of the EDP; integrity of academic content; quality of technology integration; connections to non-STEM disciplines; real world connections; and nature of assessment. Specifically, in regards to developmental appropriateness, the developers relied on the National Head Start Child Development and Early Learning Framework [26] and the Massachusetts Framework for Science, Technology, and Engineering for Pre-K [27] to define the learning outcomes of the curriculum. In regards to assessment, the curriculum includes formative and summative authentic embedded assessments. The variety of assessment activities allows children to demonstrate their understanding in different ways and allows teachers to record children's mastery of learning outcomes.

In the next section, we elaborate on how each STEM area was integrated into the curriculum.

Science. The developer teachers and researchers designed the curriculum around the learning and exploration of science concepts, such as light and shadow, solids and liquids, and animal habitats. The first week of each unit emphasized the vocabulary and hands-on activities around these science concepts.

Technology. According to Barron et al. [28], technologies that benefit early learners the best are those that are interactive and allow children to develop their curiosity, problem solving, and independent thinking. Towards this

end, the curriculum included learning centers that allow children to tinker with objects to create innovative solutions to problem using a variety of tools and materials to solve problems (e.g., scissors, scales, computers, rulers, hand lenses).

Engineering. Through adapted use of the engineering design process (EDP), children are taught the steps to solve design problems encountered by the curriculum's main character, Problem Panda. Specifically, during the second week of each unit, the teacher introduced a problem and the children apply the problem-solving process based on the EDP to solve simplified versions of real-world problems.

Mathematics. The development team incorporated mathematical concepts, such as sorting, counting, and one-to-one correspondence, into the unit activities to enhance children's math learning. For instance, in one activity, each child chose one of two solutions presented by using a rock to represent their vote. The class then counted the number of blocks for each solution, while the teacher wrote the number of blocks on a piece of paper and asked the class which solution has more blocks, or more votes.

Table I provides an example of the integrated STEM components at the unit level.

TABLE I
SEEDS OF STEM UNIT 6 ACTIVITIES

Unit Topic	Science	Technology	Engineering	Math
Matter	Children explore the property of absorbency and the main groups of materials: plastic, wood, glass, fabric, paper, rubber, and metal.	Children design a container to send cookies to a friend across the river without the cookies getting wet.	Teacher facilitates children through the engineering design cycle (i.e., identify the problem, research, plan, and create a solution) to solve Panda's problem.	Children sort different materials based on a characteristic or property. Children compare different quantities of materials.

PRESENT STUDY

A randomized control trial conducted during the 2017-2018 academic year explored the potential curriculum impacts on each of the following: 1) teacher knowledge of the engineering design process (EDP); 2) teacher pedagogical content knowledge of the EDP for pre-K students; and 3) teacher self-efficacy in teaching STEM and engineering. We hypothesized that:

a) teachers who implement the *SoS* curriculum will report significantly higher engineering pedagogical content knowledge and self-efficacy than teachers in the comparison group;

b) teachers who implement the *SoS* curriculum will show significant gains in their engineering pedagogical content

knowledge and self-efficacy in teaching engineering and STEM from pre- to post.

I. Measures

A teacher questionnaire was created to gather individual teacher data before and after the intervention. The survey included demographic and background information as well as the first three instruments below to measure the variables of interest:

Engineering Instruction. This scale included 14 items from the Teacher Efficacy and Attitudes Towards STEM Survey (T-STEM) [28]. Responses are rated on a 5-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). Reliability for elementary version of T-STEM is Cronbach's alpha = .95.

STEM and Engineering Knowledge Assessment. This assessment included 18 open-ended questions that were created by the research team to assess a Pre-K teacher's content knowledge and pedagogical content knowledge of engineering and STEM. The assessment was scored by a trained research assistant.

Engineering Teaching Self-Efficacy. This scale included 11 items from the T-STEM Survey [29]. Example item: "I am continually improving my engineering teaching practice." Responses are rated on a 5-point Likert-type scale ranging from 1 (strongly disagree) through 5 (strongly agree). Reliability for elementary version of T-STEM is Cronbach's alpha = .905 (Sci) and .939 (Math).

Fidelity of Classroom Implementation. A project-created observation tool was used to measure the extent to which the teacher and students experienced the SoS curriculum activities as intended. The tool included 13 items representing implementation indicators on 4 critical component areas created by the researchers and based on Century et al.'s [30] framework. Using classroom videorecordings, fidelity was scored on a 4-point scale ranging from 0 (no evidence) through 3 (high evidence). Higher scores reflected a higher degree fidelity. Inter-rater reliability was reported using Krippendorff's alpha.

Student outcomes were measured as part of the project but are not reported in this paper.

II. Participants

In Fall 2017, 42 teachers enrolled in the pilot study across 17 classrooms at 5 preschools in central Massachusetts. Seventy-three percent of teachers reported White/Caucasian (not Hispanic) as their ethnicity, 17% Hispanic/Latino, 5% Black/African-American, 2.4% multi-racial/multi-ethnic, and 2.4% other. Approximately 95.2% of teachers self-identified as female, 2.4% as male, 2.4% preferred not to identify. Using teacher baseline measures for each classroom, the 17 classrooms were divided into two groups: 8 intervention classrooms (n=21 teachers) and 9 comparison classrooms (n= 21 teachers). No significant differences were found between intervention and control group classrooms in terms of teacher age, Pre-K teaching

experience, knowledge of STEM/engineering, self-efficacy, or Engineering/STEM instruction practices (see Table II).

III. Procedure

After providing informed consent, teachers completed a questionnaire to gather demographic information and baseline measures of the variables of interest. Using the classroom teacher averages of the measures, matched pairs of classrooms were created and randomly assigned to one of two groups: intervention (8 classrooms) and comparison (9

TABLE II
TEACHER PARTICIPANTS AT BASELINE

Measure	Intervention (M (SD))	Control (M(SD))
STEM/Eng Knowledge Assessment (0= low knowledge; 7 = high)	1.5 (1.0)	1.5 (.8)
Engineering Instruction (0 = no STEM/Eng practices used; 8 = use STEM/Eng practices often)	5.0 (1.2)	5.5 (1.0)
Engineering Teaching Self-Efficacy (1 = low confidence; 5 = high confidence)	3.1 (.4)	3.3 (.6)
Pre-K Teaching Experience (1 = 1 year; 4 = 4 years; 5 = 5-10 years)	4.8 (1.7)	5.3 (1.2)
Age Range (1 = 18-24 yo; 2= 25-34; 3 = 35-44 yo; 4= 45-54; 5 = 55-64 yo)	3.5 (1.2)	3.6 (1.1)

classrooms). All intervention teachers received two 2.5-hour professional development sessions to provide background information about the EDP and a challenge that demonstrated the approach of teaching integrated STEM problem solving. After the sessions, intervention teachers received separate units of the curriculum in sequence according to a predetermined schedule. The intervention teachers then recorded each unit activity they implemented using a video camera provided by the research team. After each unit, the research team collected and coded a random sample of the recordings to examine fidelity. The comparison group teachers continued to use their current (teacher-developed) STEM activities (i.e., business-as-usual); however, both intervention and comparison groups will implement Unit 8 of the curriculum with their students to gather learning outcomes data to compare between groups. All intervention and comparison teachers completed assessments of STEM and engineering content knowledge, pedagogical content knowledge and self-efficacy at the beginning of the study and again at the end of the study.

IV. Analysis Plan

A general random effects regression model was used to analyze the data post-intervention (about June 2018). The matching variables served as covariates, and teacher self-efficacy, practices, and engineering content knowledge as outcomes.

SIGNIFICANCE

The findings from this study contribute to our understanding about the effects of implementing an integrated STEM

curriculum on Pre-K teacher content knowledge, pedagogical content knowledge, and self-efficacy in STEM and engineering.

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