Engineering practices in secondary schools

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INTRODUCTION

The purpose of this study was to investigate secondary school students' competence and self-efficacy in the science and engineering practices. We proposed that engineering education should be started early and integrated with science education to attract students into the science, technology, engineering, and mathematics (STEM) fields. This study targeted middle school age students (grades 6-8 or ages 11-14). Their cognitive development is transitioning from the concrete operational to formal operational stage. Moreover, they are receiving curricula that are very different from the curricula they experienced in primary school grades. Previous studies have pointed out a significant drop in interest and value for schools and science learning among secondary school students [1,2]. Middle school education is crucial for retaining students in STEM fields. The present study would provide educators and researchers with essential tools to identify any gaps in middle school students' expected science practices capabilities and recommendations that support students' development of the respective science and engineering practices during those critical middle school years.

1 SCIENCE AND ENGINEERING PRACTICES

As presented in the newly released science standards documents in the US, A Framework for K-12 Science Education (hereafter the Framework) and Next Generation Science Standards (NGSS) [3], science and engineering practices play a crucial role in situating the learning of crosscutting concepts and disciplinary core ideas in meaningful settings. The Framework identifies eight practices that are essential for learning science and engineering in grades K-12: asking questions and defining problems, developing and using models, planning and carrying out investigations, analysing and interpreting data, using mathematics and computational thinking, constructing explanations and designing solutions, engaging in argument from evidence, and obtaining, evaluating and communicating information. The practices matrix presented in Appendix F of the NGSS [4] lists the capabilities that students are expected to acquire for each practice by the end of each grade band (K-2, 3-5, 6-8, and 9-12). Our discussion of the eight science practices focused on the capabilities that are expected of students in the grade span 6-8. For example, Practice 1 emphasizes the ability to ask good questions (for science) and define problems (for engineering) through observation of a scientific phenomenon or an engineering design and interaction with materials. In grades 6-8, students are expected to be able to ask questions about natural phenomena, models, or unexpected results that they observe, to specify relationships between different dependent and independent variables, and to clarify arguments and models based on K-5 experiences, as well as define problems that can be solved using the available tools.

2 SELF-EFFICACY

Self-efficacy is people's belief about their capabilities to pursue desired levels of accomplishment. An individual's self-efficacy judgments influence his/her personal organization and action used to achieve designated goals [5]. Many research studies have found that students' self-efficacy beliefs are highly correlated with their learning motivation, strategy use, and perceived learning achievements [6-9]. Learners with higher self-efficacy tend to put more efforts into targeted tasks with better strategies, therefore resulting in better learning outcomes [10]. High self-efficacy in science and engineering practices may provoke career choice in STEM fields.

3 RESEARCH QUESTIONS

RQ1. What are the relationships among engineering practices (EP), science practices (SP), engineering practices self-efficacy (EPSE), and science practices self-efficacy (SPSE)?

RQ2. What are middle school students' stereotypical images of engineer at work?

RQ3. How are EPSE related to the stereotypical images?

4 METHODS

4.1 Participants and research procedures

The participants were 48 7th and 25 8th graders from ten middle schools. They completed two scales, which measured their EPSE and SPSE, respectively. We also collected their scores in their science and technology courses in the school, which represented their competence in science and engineering practices. Twenty-four of the participants were invited to draw an engineer at work.

4.2 Instruments

Three instruments were used in this study. The EPSE and SPSE scales were composed of 16 and 40 items, respectively, that covered 8 practices. They were developed based on the practice components for the 6-8th grade band listed in the Appendix F of the NGSS [4]. The EPSE questions were framed in the context: "Imagine that the teacher has given us some materials, based on which each of us have to build an 18 cm long bridge, which is about the size of a pencil box. Please imagine it and answer the following questions." Both scales were anchored with strongly agree/ disagree on a four-point scale. The reliabilities as measured by Cronbach α were both .95, suggesting a high internal consistency. Additionally, we also used the Draw-An-Engineer test [11] along with three open-ended questions [12] for them to provide written descriptions about their drawing.

4.3 Data analyses

The four-point scale was assigned with numerical values 1-4, with 1 point for strongly disagree and 4 points for strongly agree. The mean scores of EPSE and SPSE were used for the correlation analysis for RQ1. Regarding the Draw-An-Engineer test, three stereotypes were identified and coded based on the drawings and written descriptions: computer-engineering, architectural-engineering, others, and unclear. The percentage of each type was calculated for RQ2. Concerning RQ3, students' EPSE and SPSE scores among the three types were compared using ANOVA.

5 RESULTS

5.1 Relationships among EP, SP, EPSE, and SPSE

The participants' EP, as measured by their performance in the technology course, was moderately correlated with EPSE and SPSE, $r=.48$ and .51, $p<.05$ (Table 1). Their SP, as measured by their performance in the science course, was moderately correlated with SPSE, $r=.60$, $p<.05$ but not with EPSE, $r=.25$, $p>.05$. EPSE and EPSE were highly correlated, $r=.73$, $p<.05$.

Table 1. Correlations among EP, SP, EPSE, and SPSE

	SPSE	EP	SP	M(SD)
EPSE	.73**	.48*	.25	2.78(.58)
SPSE		.51**	.60**	2.51(.50)
EP			.63**	88.42(8.16)
SP				81.24(14.83)

*p<.05, **p<.01

5.2 Students' stereotypical images of engineer at work

The drawing and written description showed that 57% of the participants were associated with the computer-engineering stereotype, 22% with the architectural-engineering stereotype, 9% with others including art design and bomb maker, and 13% unclear. The distribution was significantly different from those presented in previous studies [11-13], implying that the wide spread use of computer and Internet had changed students' stereotypical images of engineering.

5.3 EPSE and stereotype

The participants who held different stereotypes differed significantly in EPSE, $F(3,19) = 3.70$, $p < .05$. Those with the architectural-engineering stereotype were significantly lower than those with computer-engineering stereotype and those with unclear stereotype.

6 SUMMARY AND ACKNOWLEDGMENTS

This study has developed two reliable and valid instruments for educators and researchers to assess middle school students' self-efficacy in engineering and science practices. Moreover, it revealed that over half of the middle school students possessed a stereotype associated with computer use. These students also appeared to have higher self-efficacy in engineering practices, compared with their peers who had an architectural-engineering stereotype. The use of ICT in education and daily life may increase students' self-efficacy in engineering practices and, as a result, draw them to engineering fields. This research project was supported by a Grant from the Ministry of Science and Technology, Taiwan (MOST 104-2511-S-011-006-MY3).

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