JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

STUDENTS' REFLECTIONS ON THEIR SCIENTIST- OR ENGINEER-LIKE PRACTICES IN STEM PROJECT-BASED LEARNING

Tian Luo,
Jiayue Zhao,
Winnie Wing Mui So,
Wencong Zhan

Abstract. *Students build up their STEM career interest based on their experiences. However, it remains unclear how students reflect on their STEM experiences in light of their understanding of STEM careers. This study aimed to explore how students relate their practices in STEM project-based learning (PBL) with their perceptions of scientists' and engineers' work. A randomly selected sample of students (n =142) participating in a STEM event participated in structured interviews regarding the resemblance between their months-long STEM PBL and scientists' and engineers' work. The data were coded using content analysis mostly by adopting a bottom-up approach followed by statistical analysis. Results showed that the majority of students claimed that their group had done things like scientists, while only about half of the students acknowledged doing things like engineers. The number and aspects of the students' mentioned practices were generally limited, with engineer-like practices more divergent and reflecting their stereotype of engineers working as manual laborers. The results also suggest that students tend to neglect the minds-on but hands-off scientist- or engineer-like practices such as raising a question/problem. The findings address the research gap regarding how students reflect on their STEM PBL experiences in light of career development.*

Keywords: *project-based learning, STEM education, STEM practices, structured interviews*

Tian Luo, Jiayue Zhao
Capital Normal University, P.R. China
Winnie Wing Mui So
The Education University of Hong Kong, P.R. China
Wencong Zhan
Beijing Zhaodengyu School, P.R. China

Introduction

STEM (the acronym for Science, Technology, Engineering, and Mathematics) education is not only the aggregation of the four disciplines but also an integrated way of teaching and learning (National Research Council, 2014; Office of the Chief Scientist, 2014). Generally, integrated STEM education has the potential to train students to solve real-world problems, enhance students' understanding of how STEM disciplines benefit the world and their interest in STEM majors, and ultimately enable them to cope better with future challenges in their lives and careers.

Students' low aspiration level in STEM domains remains a concern in many regions worldwide (Marginson et al., 2013; OECD, 2019; Wang, 2017). Although many researchers have argued that STEM learning can foster students' interest (e.g., Kalogiannakis & Papadakis, 2020), studies have shown that engagement in STEM activities may not necessarily enhance STEM-related attitudes, including interest in STEM careers (Archer et al., 2014). How students interpret their STEM engagement and develop STEM career interests has been a focus of research in recent years (Lent et al., 2018). To date, researchers have found that students' career development in STEM domains is a complex process that begins in childhood, and involves many internal factors including adequate perceptions of STEM careers (Garriott et al., 2016; van Tuijl & van der Molen, 2016) and STEM identity (Archer et al., 2013).

Integrated STEM education emphasizes students' active application of STEM subjects in authentic contexts (Papadakis et al., 2022). From a career development perspective, the authenticity of real-life problem solving in STEM activities has offered them career-related experience, and may theoretically encourage students to think like a STEM professional, feel like a STEM professional, or consider whether or not they would pursue a STEM career. However, not much is known regarding how students interpret their STEM learning experiences with their understanding of STEM careers. The aim of this study was to explore whether and how students relate their practices in STEM learning with the work of scientists and engineers, and to examine patterns that emerged from students' reflections.

https://doi.org/10.33225/jbse/24.23.130

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Students' Perceptions of Scientists and Engineers and STEM Identity

Children begin to form a "map" of careers early in their lives (Gottfredson, 2002). However, many empirical studies have shown that students' perceptions of scientific and engineering careers were often biased, limited, or were based on gender stereotypes (Fralick et al., 2009; Liu & Chiang, 2020). For example, Fralick et al. (2009) analyzed and compared 1,600 U.S. middle school students' drawings of scientists/engineers and found that most drawings indicated males and scientists working indoors doing experiments, while there was limited understanding of engineers, with most existing perceptions involving performing outdoor manual labor. The findings of data from primary and middle school students in China were similar to the studies in Western contexts (Liu & Chiang, 2020). The gender stereotypes regarding students' judgment of who are scientists (Miller et al., 2018) and who could be scientists (Banchefsky et al., 2016) were confirmed in later studies using different methods. In addition, empirical evidence suggests that stereotyped perceptions of engineers and scientists are resistant to change (Montfort et al., 2013), which may hinder their future career development.

Students with more STEM career knowledge are more likely to pursue STEM careers (Blotnicky et al., 2018). Stereotyped perceptions of STEM careers may have a negative impact on adolescents' STEM identity (Steinke, 2017). A survey study involving over 3,500 students in Hong Kong SAR indicated that perceptions of engineers and career prestige mediated the positive effect of experiences in engineering learning on students' engineering aspirations (Chan et al., 2019). Researchers have argued that students' STEM career choices are influenced by the congruency and consistency among their perceptions of STEM careers, including gendered beliefs, career-related values, and identity (Wegemer & Eccles, 2019).

The gender-related imbalance of achievement in STEM careers noted by many researchers (Ampartzaki et al., 2022) may be related to students' perceptions of careers in this field. Students of different genders may have differences regarding perceptions of scientists' and engineers' work, which may further hinder their identity development. A quantitative survey study showed that compared to high school boys, girls' knowledge of engineers and their working environments was poorer (Salas-Morera, 2021). Some researchers have collected students' drawings of STEM professionals, and their results suggested that boys and girls may have different perceptions of what science and engineering are (Silver & Rushton, 2008). However, there are some contradictory results suggesting insignificant gender differences between boys' and girls' perceptions (Lampley et al., 2022; Liu & Chiang, 2020).

Relating the Work of Scientists/Engineers by Engaging Students in Practices in STEM Learning

There are both consistencies and inconsistencies between disciplinary science or mathematics learning in traditional classrooms and the processes of real problem solving that individuals are engaged in in their lives and at work. Some empirical studies have attempted to analyze the resemblance between science learning in school environments and the work of scientists. For example, Chinn and Malhotra (2002) found that commonly used inquiry tasks in school differ from scientists' work on cognitive tasks, including whether students initiate their research questions, are provided with variables, and have clear directions for procedures. Zhai et al. (2014) found that students generally viewed themselves as "acting like a scientist" when they were doing experiments, while some other students thought they were not similar to scientists because they believed that scientists work alone doing dangerous tasks, and do not need to be well-behaved as students are in science classes. To summarize, the resemblance between classroom science and "real" science mainly lies in "doing" science, namely engaging in scientific practices.

Another related concept is scientific and engineering practices, such as constructing explanations and designing solutions, which have been incorporated into national science curriculum standards in both the United States and China as prominent dimensions of learning (NRC, 2013; Ministry of Education, P. R. China, 2017), suggesting a shift from inquiry-based to practice-based learning and growing attention on engineering practices. According to the Next Generation Science Standards, these identified practices originated from "major practices that scientists employ" and "a key set of engineering practices that engineers use as they design and build systems" (NRC, 2014). It is expected that through engaging in these practices, students can relate disciplinary knowledge with its actual applications, understand how STEM disciplines are applied in real-world endeavors, and become aware of the careers in STEM domains (NRC, 2014).

A concept broader than scientific and engineering practices is STEM practices. Develaki (2020) argued that scientific and engineering practices such as modeling and argumentation that are applied across STEM domains

https://doi.org/10.33225/jbse/24.23.119

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

can be viewed as "STEM practices." These practices are embedded in integrated STEM learning in nature, according to Kelley and Knowles's (2016) definition of integrated STEM education as "the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context."

To summarize, the resemblance between STEM learning and the work of scientists or engineers is manifest in practices that students engage in. The importance of engaging students in scientific and engineering practices has been widely recognized by the educational community (Jaber & Hammer, 2016). By engaging in scientific and engineering practices, students could take up "epistemic values and aims" in science, comprehending what scientists and engineers seek to accomplish in their work (Chinn et al., 2011; Jaber & Hammer, 2016). Jaber and Hammer's (2016) analysis indicated that there is a consistency of emotions experienced within science practices between scientists doing science and students learning science. In addition, students with more engineering experience are less likely to hold stereotyped perceptions of engineers working as laborers (Chan et al., 2019), indicating that engagement in engineering practices may repel students' naïve perceptions of engineers.

The Resemblance between STEM PBL and the Work of Scientists/Engineers

Project-based learning (PBL) is one of the effective approaches that are widely applied (Barron, 2008; Krajcik, 2014; Larmer, 2015; Thomas, 2000) to engage students in scientific and engineering processes. Compared to traditional school science learning, PBL promotes goal-setting and ongoing constructive inquiries that are reflective and collaborative (Kokotsaki et al., 2016). Empirical evidence shows that STEM PBL can enhance students' learning motivation (Bhakti, 2020), and attitudes towards STEM (Tseng, 2013), and promote their scientific creativity (Siew, 2018). A great many informal STEM learning implementations take the form of PBL, which specifies no prescribed steps and is not implemented in a rigid linear way. For example, in science fairs or competitions, students may often experience PBL; they form groups, initiate, and conduct investigations, or design tasks that resemble scientists' or engineers' work.

STEM PBL provides opportunities for students to participate in a process that epistemologically resembles scientists' or engineers' work in knowledge construction and problem solving. Researchers have summarized a STEM framework consisting of the practices mentioned in STEM-related educational standards or significant documents, and have used it to analyze students' PBL reports presented at a science fair. The results showed that most of the analyzed STEM PBL groups performed practices in the STEM framework, such as defining the problem to be solved, creating and testing a solution, conducting an investigation, collecting data, and using technology (So et al., 2018). It can be reasonably hypothesized that, through engaging in STEM PBL, students may gain a deeper understanding of the work of STEM professionals' use of science, technology, engineering, and mathematics in real-world problem solving.

The resemblance between STEM PBL and the work of STEM professionals can be used in designing interventions with explicit instruction, making students realize that what they do in the classroom is similar to what STEM professionals do at work (Chen et al., 2022). For example, some interventions engage students in problem-solving activities that mimic those of STEM professionals, in which teachers explicitly inform students that they are doing tasks that certain STEM professionals, such as civil engineers or environmental scientists, deal with in their work (Beier et al., 2019; Chen et al., 2022; English et al., 2017; Kopcha et al., 2017). Empirical evidence suggests that these interventions explicitly relating STEM learning to STEM professionals' work could enhance students' understanding of STEM careers (Chen et al., 2022) and their STEM career aspirations (Beier et al., 2019).

To sum up, the following arguments are summarized based on the literature review. First, students have limited and biased perceptions of STEM professionals, which may inhibit their STEM identity development. Second, integrated STEM education has the potential to help students comprehend scientists' or engineers' work through practices. Last but not least, STEM PBL resembles scientists' and engineers' work in practice, which may help students acknowledge the resemblance and develop their STEM identity through participating in STEM PBL.

These arguments progressively reveal a significant research gap in how much resemblance between practices in STEM PBL and the work of scientists and engineers students can see after their STEM learning, especially when the learning involves little explicit career-related instruction. Addressing this research gap may enable STEM learning, including STEM PBL, to better provide opportunities for students to engage in processes similar to STEM professionals' work, which may increase their understanding of STEM careers, their STEM identity, and their aspirations.

It is worth noting that the word "practice" used in this study was not confined to scientific and engineering practices in curriculum standards (for example, in NRC, 2013 and Ministry of Education, P. R. China, 2017) or STEM practices. Rather, we defined practices to be broader, to include the minds-on or hands-on activities or processes

https://doi.org/10.33225/jbse/24.23.119

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

that happen in STEM learning. Students perceived scientist- or engineer-like practices as being "larger" than scientific or engineering practices, such as the scientific inquiry or engineering design process; or it may be "smaller," such as searching on the internet, or calculating means. Therefore, the broader definition is more helpful for analyzing students' perceived practice in their STEM PBL experiences, which is not necessarily consistent with the scholarly definition in curriculum standards.

Research Aim and Research Questions

Based on the research gap identified above, the study aimed to explore whether and how students related their practices in STEM PBL to their understanding of scientists' and engineers' work. Specifically, two research questions were proposed as follows:

RQ1: To what extent can upper-primary students relate the perceived practices in their STEM PBL to their understandings of scientists' and engineers' work? Are there gender differences?

RQ2: In students' reflections on their STEM PBL, what practices do students think they engage in that resemble scientists' or engineers' work? What are the patterns in these mentioned scientist- or engineer-like practices?

Through the lens of perception of scientists' and engineers' work, this study aimed to understand how students epistemically comprehend the connection between their STEM PBL practices and STEM careers. The analysis may help educators make sense of students' perceived practices in STEM PBL and how they build up their identity, self-efficacy, and career aspirations in STEM domains.

Research Methodology

As the research questions were exploratory in nature, it was more appropriate to gather qualitative data that allow for students' flexibility in responding. However, since the research questions focused on general student epistemic understandings, adding quantitative analysis in addition to qualitative analysis was necessary to enhance generalization of the findings. Therefore, this study adopted a mixed-method approach, incorporating qualitative data as well as qualitative and statistical analysis, to address the research questions. In addition, interviewing techniques were used based on the consideration that the participants' written expression may have been limited due to their grade level, as some were as young as fourth grade. Structured interviews that can reduce interviewer variability (Bryman, 2016) were performed to obtain comparable and quantifiable data, which can be more easily administered, aggregated, and analyzed, especially on relatively large samples for more generalizable findings. This study used both qualitative and quantitative methods to analyze the interview data.

Sample

The study collected data from the participants of a typical annual large-scale informal STEM event held in Hong Kong. Over 100 groups of primary school students participated in the event after they completed months-long extracurricular STEM PBL. Each participating group was made up of four to six students from fourth to sixth grade in one primary school. Student groups were responsible for initiating, conducting, and presenting the student-led STEM project under their teachers' guidance (usually one to two teachers from the students' school). The themes in students' STEM PBL are widely diverse, ranging from developing and testing a solution or product to proposing and investigating a problem. The final project outcomes, including products and posters that describe their PBL processes, were presented by the student groups on the exhibition day, during which their projects were evaluated and awarded by the event organizers.

A randomly selected sample of 142 fourth- to sixth-grade participants, coming from 72 project groups in the event from 68 primary schools, participated in the structured interviews. All participants were from schools in the Greater Bay Area in China, with most of the participating students (134) from Hong Kong and the remaining students from schools located in Guangdong Province. The grade and gender distribution of the students are shown in Table 1.

https://doi.org/10.33225/jbse/24.23.119

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table1
Information Regarding the Interviewed Students

Grade	Number of students	Male	Female
4th grade	27	17	10
5th grade	51	35	16
6th grade	62	43	19
Invalid	2	1	1
Total	142	96	46

Interview Design and Procedures

Individual face-to-face structured interviews were conducted with each participant at the event by one of the four trained research assistants. The interview questions targeted the whole group ("your group members") rather than only the interviewed student because, firstly, students collaborated and followed labor division in the whole group, and every group member was responsible for completing a particular part of the project; therefore, targeting each individual's practices would be limited. Secondly, the students worked together to present their PBL on the event day for the awards. Hence, all participants were assumed to be very familiar with the whole group's PBL practices.

The major interview questions are listed as follows:

1. Have your group members done anything similar to scientists' work in the project activities?
2. If yes, can you describe the practices?
3. Have your group members done anything similar to engineers' work in the project activities?
4. If yes, can you describe the practices?

If the student gave an affirmative answer in response to the first interview question, the interviewer followed up by asking the second interview question. If the student gave a negative answer, he/she may give a reason for it as well. The same goes for interview questions three and four. All interviews were conducted by trained research assistants in the student's native language.

Data Analysis

To address RQ1, which is quantitative in nature, a quantitative approach was applied to analyze the data gathered from interview questions 1 and 3. In addition to descriptive statistics, a paired-sample t test was performed on the data to analyze whether there was a difference between the likelihood of students acknowledging having scientist-like practices and engineer-like practices. Fisher's test, which is a nonparametric test for analyzing the correlation between two categorical variables, was performed to analyze the gender differences regarding whether students related their practices in STEM PBL to their understandings of scientists' and engineers' work. The analysis was conducted using the GraphPad Prism 9.0 software.

To address RQ2, content analysis (Stemler, 2001), which can be used to analyze patterns and frequencies, was performed on responses to interview questions 2 and 4. Data were coded using a bottom-up approach, with most codes initially "emerging" from the data. Firstly, a draft coding scheme was developed by the first author after thoroughly reviewing the interview data, which was reviewed and revised by the corresponding author. The first author and a trained coder completed coding individually under the guidance of the coding scheme, during which the codes in the coding scheme were revised, re-organized, renamed, or combined for better parsimony and comprehensiveness, with reference to the STEM practices framework developed by So et al. (2018), which is a framework developed for and validated on upper-primary students participating in STEM PBL. The coding of the two coders was then compared, in which the differences were discussed until consensus was achieved on all the

https://doi.org/10.33225/jbse/24.23.119

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

coding among the coders and authors. To enhance the trustworthiness of the analysis, the draft coding scheme and codes were reviewed by the corresponding author to ensure that the codes were mutually exclusive and the coding was consistent with the data without over-interpretation. During the above-mentioned iterative process, the coding scheme was continuously revised, reorganized, and expanded until the coding was finalized.

Research Results

Percentages of Students Acknowledging their Practices as Being Like Scientists' or Engineers' Work and Gender Differences

Most of the students in this study could relate their practices in STEM PBL to the work of scientists, while only about 60% acknowledged that their practices resembled the work of engineers. Of the students, 84.40% (119 of 141, with one invalid response removed) responded that their group had done things similar to what scientists do, while only 15.60% believed that their group had done nothing like scientists (see Table 2). Moreover, 39.44% (56 of 142) claimed that there was nothing their group had done that resembled engineers' work. Paired-sample t tests showed that the mean difference in the sample fell between the range of 0.140 and 0.342. There was evidence that the mean difference between whether students thought their group had done work resembling scientists and engineers was significant with $t(140) = 4.707$, $p < .001$.

From a gender perspective (Table 3), male and female students' responses acknowledging scientist- or engineer-like practices exhibited no significant differences. Specifically, 84.21% of boys and 84.78% of girls thought that they had done practices similar to scientists. Fisher's test indicated that there was no significant gender difference ($p > .99$). Regarding students' understanding of engineers, 60.42% of boys and 60.87% of girls acknowledged that they had done things like engineers, while 39.58% of boys and 39.13% of girls believed not. Still, no significant gender difference ($p > .99$) was found using Fisher's test.

Table 2
Number of Students' Acknowledging Doing Work Like Scientists and Engineers by Gender and Fisher's Test Result

Gender	Acknowledging practices like scientists	Not acknowledging practices like scientists	*p*	Acknowledging practices like engineers	Not acknowledging practices like engineers	*p*
Male	80	15	>0.99	58	38	>0.99
Female	39	7		28	18	
Valid total	119	22		86	56	

Students' Perceived Practices Resembling Scientists' or Engineers' Work and the Occurrences

The average number of practices reported by students resembling scientists or engineers were 1.61 and 1.43 respectively. The perceived practices mentioned by students with occurrences greater than 6% are shown in Figure 1.

The practices most mentioned by students as being those of scientists seemed convergent, revolving around experiments and making. Among all the 142 interviewed students, 35.21% mentioned experimenting, such as doing specific experiments, going to the laboratory for experiments, conducting scientific experiments, and so forth, while 11.27% mentioned measuring (e.g., measuring pH value, electrical flow, temperature, and so forth). Making (e.g., making solar energy materials, making a gate, making colorimetric cards, and so forth) was also mentioned by 11.27% of the students. In addition, 9.15% of the students mentioned researching (e.g., researching how beans grow or how to reduce pressure on landfills). Repeating (e.g., keep testing and keep failing; repeating experiments) was mentioned by 6.34% of the students.

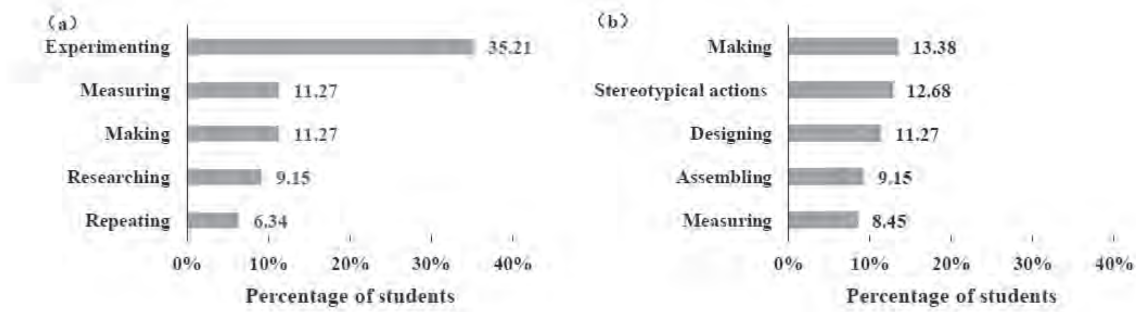
https://doi.org/10.33225/jbse/24.23.119

Journal of Baltic Science Education, Vol. 23, No. 1, 2024

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Figure 1

Percentage of different practices resembling scientists' work (Figure 1-a) and engineers' work (Figure 1-b) mentioned by students (valid n = 142)



The most mentioned engineer-like practices by the students seemed more divergent than the scientist-like practices, generally with lower occurrences (Figure 1-b). The most mentioned engineer-like practice was making (13.38%). Students mentioned making materials, roofs, homemade tinfoil cups, and so forth in their PBL. Moreover, 12.68% of the 86 students mentioned stereotypical actions. Here, stereotypical actions refer to skillful, manual, or operational practices that are not directly related to problem solving in STEM domains, such as drilling, cutting, stirring, or adding, while 11.27% of the students mentioned designing, such as designing the stand structure or designing how to make the whole system work. There were 9.15% of students who mentioned assembling (e.g., assembling a car, assembling a water pipe), and 8.45% who mentioned measuring (e.g., measuring the east-west and distance, measuring the size of the phone).

It is worth noting that, as for practices that are more abstract, more minds-on than hands-on, the occurrences are relatively low in the data. The occurrences of the students mentioning practices such as reasoning, testing hypotheses, making a conclusion, designing an experiment, revising experimentation, applying technology, testing a design, reasoning, or analyzing the data were all lower than five (3% of the sample). What's more, there were no students who mentioned hands-off cognitive processes such as raising a question, argumentation, making hypotheses, or answering the question, either as scientist-like or engineer-like practices.

Emergent Themes in Students' Reflections on Scientist- or Engineer-Like Practices

Some emergent themes were identified from the coding of students' reflections on their STEM PBL practices resembling scientists' and engineers' work. The identified themes reflected several aspects of students' perceptions of scientists or engineers.

In students' responses that compared what they did in STEM PBL and scientists' work, some students mentioned that like scientists, their PBL was also helpful, altruistic, and socially relevant. For example, the students said *"[what we have done is] similar to scientists doing the same research in environmental protection"* (B39-4, 6th-grade boy) and *"Scientists have to create things that are convenient for the citizens"* (B39-3, 6th-grade boy). These quotes suggest that some students saw the similarity between their goals in STEM PBL with those of scientists' work.

Many students seemed to reflect on their PBL with limited and superficial perceptions of scientists' work. Although many students admitted doing things like scientists, some of them also added that the experiments they did were different from those performed by scientists because the location or methods were different from those of scientists. For example, one sixth-grade girl responded *"But (our) experimental methods are different from those of scientists who work in laboratories, as we do not (work in laboratories)"* (B27, 6th-grade girl). For students who believed they did nothing like the work of scientists, their explanations usually exhibited a limited or superficial understanding of the work of scientists. For example, some students explained that they *"do not understand what scientists do"* (B30-4, 6th-grade boy) or *"scientists do work in chemistry, but we do not"* (B30-5, 5th-grade boy).

Many students mentioned stereotypical actions as engineer-like practices, which may exhibit their superficial perceptions of engineers' work. These practices, such as "connecting wires," "moving things around," "cutting and fusing," "drilling," or "burning" describe very specific and skillful labor. Moreover, many students who believed their

https://doi.org/10.33225/jbse/24.23.119

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

work was similar to that of engineers often had no clear concept of what engineers do, or confused it with the work of scientists or with people working in construction. Here are four quotes from four students: *"I cannot imagine an example, but I am doing a similar job to engineering"* (B54, 4th-grade boy), *"I think it (engineers' work) is similar to the work of scientists"* (B55, 6th-grade girl), *"(We) built a frame, which is like an engineer who starts a building and (we) went to buy materials to make it after designing it"* (B33-1,6th grade boy), and *"Some engineering departments which are responsible for building and need light at night can use our research. We can use our research to generate electricity and light at night"* (B33-6, 5th-grade girl).

Likewise, some of the students who believed their work was different from engineering also showed these stereotyped, biased, or limited perceptions of engineers: *"Engineering is larger and belongs to buildings so has nothing to do with us"* (B55-2, 6th-grade boy), *"The work done by engineers is about science"* (A21,5th or 6th-grade boy), or *"I do not understand the definition"* (B80-2, 5th-grade boy).

On the other hand, some students mentioned design-related practices, claiming that their group had engaged in designing products or designing solutions like engineers. For example, a few students mentioned *"to design the generator and figure out how to build it"* (B30-2, 5th-grade boys) or *"to design how to make the whole system work"* (B70-1, 5th-grade boy). These reflections showed that a small number of students had a deeper understanding of engineering and engineers' work and were able to reflect on their engineering practices in STEM PBL. However, some other students who acknowledged designing as engineer-like practices limited the design practices to building, designing, or model designing.

Discussion

The results of this study suggested that, even after long-term PBL participation, many students reflected that they had done limited/no practice resembling that of scientists or engineers in their STEM PBL. Unlike some previous studies (e.g., Luo & So, 2023; Salas-Morera, 2021; Silver & Rushton, 2008), the results indicated no significant gender differences. Furthermore, identified themes in students' mentioned scientist- or engineer-like practices with previous findings regarding students' perceptions of scientists and engineers have been compared in the Discussion section.

Students' Limited Reflection of Scientist- or Engineer-Like Practices in STEM PBL

The percentage of students believing their group had done nothing like engineers or scientists and the low average number of practices mentioned by the students suggested that their reflections of scientist- or engineer-like practices in PBL were confined. The low occurrence of practices that are not directly related to hands-on practices, such as raising a question or solving problems, implied that very few students could recognize the epistemic resemblance of these minds-on practices between STEM PBL and scientists' or engineers' work.

This may be due to students' limited knowledge of the epistemic nature of science and engineering or, in other words, scientists' and engineers' work. A previous quantitative study on upper-elementary Hong Kong students who participated in STEM PBL showed that most students acknowledged that they had done these minds-on STEM practices such as making hypotheses, drawing conclusions, and designing models to solve a problem (So et al., 2018). Based on these previous findings and evidence from this study, it is plausible to hypothesize that students are aware of the practices they engage in in STEM PBL, but they often cannot relate what they do to scientists' or engineers' work because of their limited knowledge of such work. Therefore, career-related information could be introduced in ways such as inviting STEM professionals to class (Hopwood, 2012), presenting scientists' biographies (Lessard, 2011), or exposing students to authentic learning environments (Singer et al., 2020).

Naive Perceptions of Scientists and Engineers in Students' Reflections on STEM PBL

The results of the study echo previous research regarding students' naive, superficial perceptions of engineers and scientists (for example, Fralick et al., 2009, Lachapelle et al., 2012; Liu & Chiang, 2020). Specifically, some students' reflections regarding their practices in PBL viewing figurative manual activities as engineer-like practices echo previous findings that some students have similar misconceptions about engineers, and think of them as blue-collar skilled workers (Ergun & Balcin, 2019; Jordan & Snyder, 2013; Karatas et al., 2008), implying that students' beliefs regarding what they had done like engineers were confined to their limited or biased perceptions of engineers' work. A possible explanation for these patterned naive perceptions of engineers is that students do not have a deep

https://doi.org/10.33225/jbse/24.23.119

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

understanding of engineering, but rather have a superficial impression of engineers' practices (Lachapelle et al., 2012). Students tend to understand engineers' work through the "superficial" hands-on aspects but not the cognitive aspects of their work, which may lead to confusing engineers with skilled workers (Cunningham et al., 2005).

The data analysis suggests that students' acknowledged scientist-like practices in their STEM PBL are more realistic and convergent, while some engineer-like practices reflected their stereotypical perceptions of engineers' work. This finding supports some previous studies (for example, Fralick et al., 2009; Luo & So, 2023) in that students' perceptions of scientists are more accurate than their perceptions of engineers. However, some students believed they had done nothing like scientists because of their non-laboratory working location or specific methods. This superficial understanding of scientists' work echoes the finding of Zhai et al. (2014) that upper-primary students view their practices in science learning and scientists' work differently.

Conclusions, Limitations, and Implications

To sum up, the results of this study indicate that even when upper-primary students were deeply involved in STEM PBL for months, a small number of students believed that they had done nothing like scientists, while nearly half of them thought they had done nothing like engineers. These perceptions showed no significant gender differences. The upper-primary students' descriptions of their scientist-like practices in PBL mostly revolved around experiments and research. The engineer-like practices mentioned by the students were more divergent, with some reflecting students' stereotypical views of engineers as doing skillful labor. Moreover, the students seemed to neglect practices that are minds-on and hands-off when reflecting on their scientist- or engineer-like practices in PBL. The above conclusions are illustrated using a figure in the appendix.

The study does have several limitations that should be noted. First, the interviewed students were participants in a STEM event, which possibly indicates they have a higher interest in STEM domains than average students. What's more, although the study design involved structured interviews and a relatively large sample to improve generalizability, the findings should be interpreted with caution when extrapolating to students of different age ranges or cultural contexts. Future studies could investigate the applicability and generalizability of the findings with samples of larger populations and student diversity.

The findings of this study have both theoretical and practical implications. The study addressed the research gap by examining students' reflections on scientist- or engineer-like practices in STEM PBL, which are rarely explored, thus filling a theoretical void. The present findings extended prior research by suggesting that students' naive perceptions of scientists and engineers' work may inhibit students' identity formation by limiting their reflections on their PBL experiences.

As regards practical implications, the findings emphasized the value of explicit instruction regarding career-related reflections in STEM learning, indicating that, without instruction, students may not "naturally" realize the resemblance between their practices and STEM endeavors in the real world, even after long-term STEM PBL engagement. Future interventions that integrate career information with STEM activities are suggested, as they may repel stereotypical perceptions of STEM professionals and help students relate their STEM engagement with real-world STEM endeavors and careers, through which students may better develop STEM-related identity and career interest derived from their own experiences.

Acknowledgments

This work was supported by the R&D Program of Beijing Municipal Education Commission (SM202310028007).

Declaration of Interest

The authors declare no competing interest.

References

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2013). 'Not girly, not sexy, not glamorous': Primary school girls' and parents' constructions of science aspirations. *Pedagogy, Culture & Society*, *21*(1), 171-194. https://doi.org/10.1080/14681366.2012.748676

https://doi.org/10.33225/jbse/24.23.119

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Archer, L., Dewitt, J., & Dillon, J. (2014). 'It didn't really change my opinion': exploring what works, what doesn't and why in a school science, technology, engineering and mathematics careers intervention. *Research in Science & Technological Education*, *32*(1), 35-55. https://doi.org/10.1080/02635143.2013.865601

Banchefsky, S., Westfall, J., Park, B., & Judd, C. M. (2016). But you don't look like a scientist!: Women scientists with feminine appearance are deemed less likely to be scientists. *Sex Roles*, *75*, 95-109. https://doi.org/10.1007/s11199-016-0586-1

Barron, B., & Darling-Hammond, L. (2008). *Teaching for meaningful learning: A review of research on inquiry-based and cooperative learning*. Book Excerpt. George Lucas Educational Foundation. https://doi.org/10.1002/tea.21465

Bhakti, Y. B., Astuti, I. A. D., Okyranida, I. Y., Asih, D. A. S., Marhento, G., Leonard, L., & Yusro, A. C. (2020, February). *Integrated STEM project-based learning implementation to improve student science process skills*. In Journal of Physics: Conference Series (Vol. 1464, No. 1, p. 012016). IOP Publishing. https://doi.org/10.1088/1742-6596/1464/1/012016

Blotnicky, K. A., Franz-Odendaal, T., French, F., & Joy, P. (2018). A study of the correlation between STEM career knowledge, mathematics self-efficacy, career interests, and career activities on the likelihood of pursuing a STEM career among middle school students. *International Journal of STEM Education*, *5*(1), 1-15. https://doi.org/10.1186/s40594-018-0118-3

Bryman, A. (2016). *Social research methods*. Oxford University Press. https://doi.org/10.1038/s41586-022-04554-y

Chan, C. K. Y., Yeung, N. C. J., Kutnick, P., & Chan, R. Y. Y. (2019). Students' perceptions of engineers: dimensionality and influences on career aspiration in engineering. *International Journal of Technology and Design Education*, *29*, 421-439. https://doi.org/10.1007/s10798-018-09492-3

Chen, Y., Chow, S. C. F., & So, W. W. M. (2022). School-STEM professional collaboration to diversify stereotypes and increase interest in STEM careers among primary school students. *Asia Pacific Journal of Education*, *42*(3), 556-573. https://doi.org/10.1080/02188791.2020.1841604

Chinn, C. A., Buckland, L. A., & Samarapungavan, A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational Psychologist*, *46*(3), 141-167. https://doi.org/10.1080/00461520.2011.587722

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175-218. https://doi.org/10.1002/sce.10001

Colston, N., Thomas, J., Ley, M. T., Ivey, T., & Utley, J. (2017). Collaborating for early-age career awareness: A comparison of three instructional formats. *Journal of Engineering Education*, *106*(2), 326-344. https://doi.org/10.1002/jee.20166

Cunningham, C., Lachapelle, C., & Lindgren-Streicher, A. (2005). *Assessing elementary school students' conceptions of engineering and technology* (2005 Annual Conference Proceedings). Portland, Oregon. https://doi.org/10.18260/1-2--14836

Develaki, M. (2020). Comparing crosscutting practices in STEM disciplines: Modeling and reasoning in mathematics, science, and engineering. *Science & Education*, *29*(4), 949-979. https://eric.ed.gov/?id=EJ1264548

Donmez, I. (2021). Impact of out-of-school STEM activities on STEM career choices of female students. *Eurasian Journal of Educational Research*, *91*, 173-203. https://doi.org/10.14689/ejer.2021.91.9

Drymiotou, I., Constantinou, C. P., & Avraamidou, L. (2021). Enhancing students' interest in science and understandings of STEM careers: the role of career-based scenarios. *International Journal of Science Education*, *43*(5), 717-736. https://doi.org/10.1080/09500693.2021.1880664

Education Bureau. (2015). *Promotion of STEM education—unleashing potential in innovation* (pp. 1-24). Curriculum Development Council: Hong Kong.

English, L. D., King, D., & Smeed, J. (2017). Advancing integrated STEM learning through engineering design: Sixth-grade students' design and construction of earthquake resistant buildings. *The Journal of Educational Research*, *110*(3), 255-271. https://doi.org/10.1080/00220671.2016.1264053

Ergun, A., & Balcin, M. D. (2019). The perception of engineers by middle school students through drawings. *Eurasian Journal of Educational Research*, *19*(83), 1–28. https://doi.org/10.14689/ejer.2019.83.1

Fralick, B., Kearn, J., Thompson, S., & Lyons, J. (2009). How middle schoolers draw engineers and scientists. *Journal of Science Education and Technology*, *18*(1), 60–73. https://doi.org/10.1007/s10956-008-9133-3

Garriott, P. O., Hultgren, K. M., & Frazier, J. (2016). STEM stereotypes and high school students' math/science career goals. *Journal of Career Assessment*, *25*(4), 585-600. https://doi.org/10.1177/1069072716665825

Gottfredson, L. S. (2002). Gottfredson's theory of circumscription, compromise, and self-creation. *Career Choice and Development*, *4*, 85-148.

Hopwood, A. (2012). *Hosting professional scientists in the classroom: The effect on rural sixth graders' attitudes toward science*. Montana State University. https://scholarworks.montana.edu/xmlui/bitstream/handle/1/1504/HopwoodA0812.pdf

Jaber, L. Z., & Hammer, D. (2016). Learning to feel like a scientist. *Science Education*, *100*(2), 189-220. https://doi.org/10.1002/sce.21202

Jordan, M. E., & Snyder, J. (2013). *Middle school students' conceptions of engineering*. 2013 IEEE Frontiers in Education Conference (FIE), 1945–1950. https://doi.org/10.1109/FIE.2013.6685174

Kalogiannakis, M., & Papadakis, S. (2020). The use of developmentally mobile applications for preparing pre-service teachers to promote STEM activities in preschool classrooms (pp. 82-100). IGI Global.

Karatas, F., Micklos, A., & Bodner, G. (2008, June). *Sixth grade students' images of engineering: What do engineers do?* In 2008 Annual Conference & Exposition (pp. 13-1083). https://doi.org/10.18260/1-2--4012

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), Article 11. https://eric.ed.gov/?id=EJ1181772

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools*, *19*(3), 267-277. https://doi.org/10.1177/1365480216659733

https://doi.org/10.33225/jbse/24.23.119

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Kopcha, T. J., McGregor, J., Shin, S., Qian, Y., Choi, J., Hill, R., Mativo, J., Choi, I. (2017). Developing an integrative STEM curriculum for robotics education through educational design research. *Journal of Formative Design in Learning*, *1*, 31-44. https://doi.org/10.1007/s41686-017-0005-1

Korkmaz, H. (2011). The contribution of science stories accompanied by story mapping to students' images of biological science and scientists. *The Electronic Journal for Research in Science & Mathematics Education*, *15*(1), 1-41. https://files.eric.ed.gov/fulltext/ED583992.pdf

Krajcik, J. S., & Shin, N. (2014). Project-based learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences*. Cambridge University Press. https://doi.org/10.1007/s41686-017-0005-1

Lachapelle, C. P., Phadnis, P., Hertel, J., & Cunningham, C. M. (2012). What is engineering? A survey of elementary students. In *Proceedings of the 2nd P–12 Engineering and Design Education Research Summit*. Washington. https://www.researchgate.net/publication/268203801_What_is_Engineering_A_Survey_of_Elementary_Students

Lampley, S. A., Dyess, S. R., Benfield, M. P. J., Davis, A. M., Gholston, S. E., Dillihunt, M. L., & Turner, M. W. (2022). Understanding the conceptions of engineering in early elementary students. *Education Sciences*, *12*(1), 43. https://doi.orėg/10.3390/educsci12010043

Larmer, J., & Mergendoller, J. (2015). *Why we changed our model of the "8 Essential Elements of PBL"* (pp. 1-3). Buck Institute for Education.

Lent, R. W., Sheu, H. B., Miller, M. J., Cusick, M. E., Penn, L. T., & Truong, N. N. (2018). Predictors of science, technology, engineering, and mathematics choice options: A meta-analytic path analysis of the social–cognitive choice model by gender and race/ethnicity. *Journal of Counseling Psychology*, *65*(1), 17. https://doi.org/10.1037/cou0000243

Liu, M., & Chiang, F. K. (2020). Middle school students' perceptions of engineers: A case study of Beijing students. *International Journal of Technology and Design Education*, *30*(3), 479-506. https://doi.org/10.1007/s10798-019-09513-9

Luo, T., & So, W. W. M. (2023). Elementary students' perceptions of STEM professionals. *International Journal of Technology and Design Education*, *33*(4), 1369-1388. https://doi.org/10.1007/s10798-022-09791-w

Macdonald, A. (2016). STEM: Not for people like me? *School Science Review*, *97*(360), 90.

Salas-Morera, L., Ruiz-Bustos, R., Cejas-Molina, M., Olivares-Olmedilla, J., García-Hernández, L., & PalomoRomero, J. (2021). Understanding why women don't choose engineering degrees. *International Journal of Technology and Design Education*, *31*(2), 325–338. https://doi.org/10.1007/s10798-019-09550-4

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: Country comparisons: International Comparisons of Science, Technology, Engineering and Mathematics (STEM) Education*. Final report.

McCann, F. F., Marek, E. A., & Falsarella, C. (2016). An informal science educator/elementary school teacher collaboration: Changing fifth grade girls' perceptions of scientists and engineers. *Creative Education*, *7*(16), 2459. https://doi.org/10.4236/ce.2016.716234

Miller, D. I., Nolla, K. M., Eagly, A. H., & Uttal, D. H. (2018). The development of children's gender-science stereotypes: a meta-analysis of 5 decades of US draw-a-scientist studies. *Child Development*, *89*(6), 1943-1955. https://doi.org/10.1111/cdev.13039

Ministry of Education (of the People's Republic of China) (Ed.). (2018). *Quality monitoring report on compulsory education in China*. China Basic Education Quality Monitoring Collaborative Innovation Center.

Montfort, D. B., Brown, S., & Whritenour, V. (2013). Secondary students' conceptual understanding of engineering as a field. *Journal of Pre-College Engineering Education Research (J-PEER)*, *3*(2), 2. https://doi.org/10.7771/2157-9288.1057

National Institute of Education Sciences. (2017). *White Paper on STEM Education in China*. http://doi.org/10.1787/9789264273856-en

National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.

Office of the Chief Scientist, Australia. (2014). *Science, technology, engineering and mathematics: Australia's future*. Australian Government.

Organisation for Economic Co-operation and Development. (2019). *Education at a Glance 2019: OECD Indicators*. OECD Publishing. https://doi.org/10.1787/f8d7880d-en

Papadakis, S., Kalogiannakis, M., & Gözüm, A. I. C. (2022). STEM, STEAM, computational thinking, and coding: Evidence-based research and practice in children's development. *Frontiers in Psychology*, *13*, Article 1110476. https://doi.org/10.3389/fpsyg.2022.1110476

Salas-Morera, L., Ruiz-Bustos, R., Cejas-Molina, M., Olivares-Olmedilla, J., García-Hernández, L., & PalomoRomero, J. (2021). Understanding why women don't choose engineering degrees. *International Journal of Technology and Design Education*, *31*(2), 325–338. https://doi.org/10.1007/s10798-019-09550-4

Siew, N. M., & Ambo, N. (2018). Development and evaluation of an integrated project-based STEM teaching and learning module on enhancing scientific creativity among fifth graders. *Journal of Baltic Science Education*, *17*(6), 1017-1033. https://10.33225/jbse/18.17.1017

Silver, A., & Rushton, B. S. (2008). Primary-school children's attitudes towards science, engineering and technology and their images of scientists and engineers. *Education 3-13*, *36*(1), 51-67.

Singer, A., Montgomery, G., & Schmoll, S. (2020). How to foster the formation of STEM identity: Studying diversity in an authentic learning environment. *International Journal of STEM Education*, *7*(1), 57. https://doi.org/10.1186/s40594-020-00254-z

So, W. W. M., Zhan, Y., Chow, S. C. F., & Leung, C. F. (2018). Analysis of STEM activities in primary students' science projects in an informal learning environment. *International Journal of Science and Mathematics Education*, *16*, 1003-1023. https://doi.org/10.1007/s10763-017-9828-0

Steinke, J. (2017). Adolescent girls' STEM identity formation and media images of STEM professionals: Considering the influence of contextual cues. *Frontiers in Psychology*, *8*, Article 716. https://doi.org/10.3389/fpsyg.2017.00716

Stemler, S. (2001). An overview of content analysis. *Practical Assessment, Research and Evaluation*, *7*(17), 137-146. https://doi.org/10.12691/education-2-1-8

https://doi.org/10.33225/jbse/24.23.119

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Thomas, J. W. (2000). *A review of research on project-based learning*. The Auto desk Foundation.
Tseng, K. H., Chang, C. C., Lou, S. J., & Chen, W. P. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education*, *23*, 87-102. https://doi.org/10.1007/s10798-011-9160-x
van Tuijl, C., & van der Molen, J. H. W. (2016). Study choice and career development in STEM fields: An overview and integration of the research. *International Journal of Technology and Design Education*, *26*(2), 159-183. https://doi.org/10.1007/s10798-015-9308-1
Wang, J. Y. (2017). Follow the STEM career expectation in teenagers' scientific literacy education: Based on the reflection of PISA 2015 and NARST 2017 [关注STEM职业期望的青少年科学素质教育：基于PISA2015和NARST2017的反思]. *Science and Society*, *7*(3), 33-42. https://doi.org/10.19524/j.cnki.10-1009/g3.2017.03.033
Wegemer, C. M., & Eccles, J. S. (2019). Gendered STEM career choices: Altruistic values, beliefs, and identity. *Journal of Vocational Behavior*, *110*, 28-42. https://doi.org/10.1016/j.jvb.2018.10.020
Zhai, J., Jocz, J. A., & Tan, A. L. (2014). 'Am I like a scientist?' Primary children's images of doing science in school. *International Journal of Science Education*, *36*(4), 553-576. https://doi.org/10.1080/09500693.2013.791958

Received: *October 20, 2023* Revised: *December 03, 2023* Accepted: *January 16, 2024*

Cite as: Luo, T., Zhao, J., So, W. W. M., & Zhan, W. (2024). Students' reflections on their scientist- or engineer-like practices in STEM project-based learning. *Journal of Baltic Science Education*, *23*(1), 119-130. https://doi.org/10.33225/jbse/24.23.119

Tian Luo PhD, Assistant Professor, College of Teacher Education, Capital Normal University, 105 West Third Ring Road North, Haidian District, Beijing, 100048 P. R. China.
E-mail: luotian@cnu.edu.cn
Website: https://jsjy.cnu.edu.cn/szdw111/slkxjyx/boda_1601555900_2001.htm
ORCID: https://orcid.org/0000-0001-5019-9343

Jiayue Zhao MEd, College of Teacher Education, Capital Normal University, 105 West Third Ring Road North, Haidian District, Beijing, 100048 P. R. China.
E-mail: 2223702230@cnu.edu.cn
ORCID: https://orcid.org/0009-0001-8854-6352

Winnie Wing Mui So *(Corresponding author)* PhD, Professor, The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, New Territories, Hong Kong, P. R. China.
E-mail: wiso@eduhk.hk
Website: https://repository.eduhk.hk/en/persons/wing-mui-winnie%E8%98%87%E8%A9%A0%E6%A2%85-so
ORCID: https://orcid.org/0000-0002-9649-074X

Wencong Zhan MEd, Beijing Zhaodengyu school, 17, Siliga Garden 1, Western of Majiapu Road, Feng Tai, Beijing, P. R. China.
E-mail: 13127282616@163.com