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Investigation of Elementary-School Students' Perception of Engineering using Drawing Analysis*

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Science, technology, engineering, and mathematics (STEM) education has become a popular academic model in recent years. Engineering education has been emphasized in the Next Generation of Science Standards (NGSS). A lack of career guidance has become a common problem in engineering education. Hence, it is pertinent to investigate how students understand the career in engineering so that their interests and abilities can be developed strategically. In this study, a drawing analysis method was adopted to investigate students' perceptions of engineering in an elementary school in Beijing. A *Draw an Engineer Test* (DAET) was conducted to 512 students from 15 classes in grades two to six. Our findings reveal that many students held a narrow view of a career in engineering. For example, younger students typically believed that engineers work in construction sites, whereas older students typically regarded engineers as designers or technicians. There were significant differences in the perception of engineering among students in different grades and different gender a. We also found that experiences in life and social networks, but not teaching in school, were most frequently used channels for students to understand engineering.

Keywords: Draw an Engineer Test (DAET); elementary school; engineering impressions; graphic analysis

1. Background

STEM education has become popular in recent years. The National Science Council (NSC) (2006) argued that engineering and technology strongly influence technological development and living standards. The NSC published two reports in engineering area – *Engineering in K-12 Education: Understanding the Current Situation and Upgrading the Future* in 2009 and *K–12 engineering education standards* in 2010. According to the new national science standards, we can find that engineering design and science inquiry have equal importance [1]. As engineering education has been gradually introduced into K–12 courses, many educators from different countries have designed engineering courses combining advanced teaching philosophies such as problem-based learning and design-based learning as well as some teaching tools such as Lego programming software [2, 3]. School engineering courses are expected to improve students' interest in engineering and to enhance their cross-disciplinary problem-solving abilities [4].

Due to the rapid development of society, the new generation of engineers need to be armed with high-quality education, including cross-disciplinary and superior knowledge and creative thinking, which can be developed through continuous practice, design, and creation [5, 6]. China has recently made substantial efforts to improve its engineering education. The 17th National Congress of the Communist Party of China put forward an "excellent engineers training program", which emphasized the importance of engineering to national economic development. Despite these efforts, engineering education in China is still in its infancy.

The lack of career guidance in tertiary engineering courses is a common problem, though it generally has little impact on students who have already enrolled in these courses [7]. Therefore, more research is needed to investigate the attitudes younger students have about a career in engineering.

As drawing is a more intuitive way for younger students to express their thinking with abundant information hard to be described in langrage, this study adopted a drawing analysis method to investigate students' perceptions of engineering. The objectives of this study were as follows:

1. To investigate student perceptions of engineering by analyzing their drawings.
2. To analyze and understand the influence of age and gender on their perceptions.

2. Literature Review

Teenagers are at a critical stage to plan their careers and learn about engineering, so it is necessary to understand their perceptions of engineering. Researchers and educators should master students' perception of engineering more comprehensively and help them to be more exposed to engineering. There were many studies exploring students' inter-

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est and impression in an engineering career. Here is a table displaying the related previous researchers.

We can see from Table 1 that almost all researchers adopted drawing as an effective and powerful method to figure out students' perceptions, especially for younger children. Compared to the United States, study in China is insufficient.

Garriott, Navarro, and Flores used questionnaires to investigate why college students opted to study engineering [9]. Capobianco et al. used a 20-item assessment called the Engineering Identity Development Scale and analyzed factors that influenced the perceptions students had about engineering [1]. Besides those approaches, analyzing children's drawings is an appropriate research method to collect information about their thinking on a topic. Using drawing as a research method requires subjects to draw a scene or a person [23]. In contrast to speaking and writing, drawing allows children to express themselves freely, clearly, and accurately [11]. MacPhail and Kinchin evaluated what students thought about sports education by analyzing their paintings on the subject [24]. Wang and Tsai investigated the perceptions that elementary students held about learning and discovered that the traditional classroom setting of sitting and listening appeared most in their illustrations [25]. Moreover, they found that as learning experiences increased, diversity of drawings decreased.

Some studies have used the drawing method to examine students' perceptions of an occupation. The Draw-A-Scientist Test (DAST) conducted by Chambers [8] is a notable example. The study analyzed the drawings based on several indexes such as books, glasses, formulas, clothes and typical objects showing the characteristics of the scientist depicted and revealed that drawings with more indexes came from smarter students with a relatively high socioeconomic background. Moreover, the gender of the depicted scientist significantly correlated with that of the student. Researchers have developed a checklist for assessing and quantitatively analyzing drawings produced in DAST-Chinese [26]. In recent years, studies have examined engineering education, where the Draw an Engineer Test (DAET) was used to test student perceptions of engineering [10, 27, 19]. Some DAET studies have also employed qualitative and quantitative research methods to increase the quality and reliability of the findings.

Numerous studies have highlighted the lack of talent in the fields of science, technology, engineering, and mathematics, which is likely due to insufficient investment in these subjects in elementary school education. Students generally lack an accurate understanding of engineering as a profession. In one DAET study, children drew a bearded senior engineer wearing a laboratory coat and glasses [11, 7]. In another study, a large proportion of students drew a mechanic or construction worker; few students drew a worker in a nonphysical domain such as designing or programming [7]. Karatas, Micklos and Bodner reported a similar result in their study of grade six students, where most students thought engineers manufactured products rather than designed or planned products [12]. However, children who participate in engineering training programs have been reported to usually draw more types of engineering tools and depict engineers performing less physical labor–intensive tasks [13, 14, 28]. Scherz and Oren considered the working environment – that is, indoors and outdoors – in their DAST study and whether the subjects held negative views about either working environment [11]. Their findings revealed that students were unfamiliar with the actual environment because they had never visited an engineer's working environment. Moreover, students' drawings have been found to reflect their gender, age, and affection for the profession; for instance, girls are more reluctant to become engineers than are boys while female individuals appeared more in girls' drawings [8, 11]. Moreover, students were found to change their stereotype of a male engineer if the instructor was a woman, indicating that information transfer affects students' perceptions [17]. In addition, Knight and Cunningham found that young children are limited in their perception [10]. Fralick and Kearn comparatively analyzed DAST and DAET and defined the indexes as "looking," "workplace," "conduct," and "objects." They found that students perceived scientists more favorably than they did engineers [15].

In China, Chou and Chen analyzed children's perceptions of engineering in Taiwan through a combination of coding content of student drawings with interviews and found that the drawings revealed an understanding of engineering but that the students held stereotypical views of gender [21]. Liu and Chiang implemented the investigation for middle school students and found students' expression for engineers became more accurate with the growth of grades, but there was serous gender stereotypes in children's impression [22]. Other areas have rarely paid attention to children's knowledge of engineering.

This study examined the perceptions of elementary students in China regarding engineering. We selected elementary school students in Beijing as the research subjects and administered the revised DAET to them; we then coded their drawings according to the scales devised in previous studies, engineers' gender, looks, clothes, working environ-

Table 1. Related literature overview

Study & Country	Researchers & year	Methods	Subjects	Findings
Stereotypic images of the scientist: The draw-a-scientist test. Science Education (USA)	Chambers (1983)	DAST (Draw an Engineer Test)	From grade school to high school	The stereotypic image of the scientist, which Mead and Metraux examined in high school students, was also found to appear among students at the grade school level. The evidence indicates that the various elements of the stereotype appear with greater frequency as students advance through the grades [8].
First-Generation College Students Persistence Intentions in Engineering Majors (USA)	Garriott, Navarro, and Flores (2016)	Questionnaires	College Students	Results showed that parental support predicted realistic/investigative-themed verbal persuasion and vicarious learning, while realistic/investigative-themed performance accomplishments and physiological arousal predicted engineering self-efficacy [9].
What is an Engineer? Implications of Elementary School Student Conceptions for Engineering Education (USA)	Capobianco et al. (2017)	A 20-item assessment called the Engineering Identity Development Scale	Grade 1 through 5 students	Students conceptualized an engineer as a mechanic, laborer, and technician [1].
Draw an engineer test (DAET): Development of a tool to investigate students' ideas about engineers and engineering (USA)	Knight & Cunningham (2004)	DAET (Draw an Engineer Test)	Grade 3–12	Students in this study have Preconceived ideas about engineers and engineering. Many students, especially younger students, think that engineers use tools to build buildings and fix car engines [10].
How to change students' images of science and technology (Israel)	Scherz & Oren (2006)	Questionnaires, drawing tasks, and interviews	Grade 9	Their impressions of the characteristics of scientists and technologists were superficial, misleading, and sometimes reflected ignorance. The findings demonstrate that the IST program stimulated a positive effect on students' images [11].
Gifted Students' Perceptions of Engineers -A Study of Students in a Summer Outreach Program (USA)	Oware (2007)	Drew an engineer doing engineering work, individual interview	3rd and 4th grade	Students held common misconceptions about engineers [7].
Sixth-Grade Students' Views of the Nature of Engineering and Images of Engineers (USA)	Karatas, Micklos, and Bodner (2011)	A series of 20 semi-structured interviews and drawings	Sixth-Grade Students	The 6th-grade students tended to believe that engineers were individuals who make or build product. Their concepts of engineers and engineering were fragile, or unstable, and likely to change within the time frame of the interview [12].
Investigating The Long-Term Impact of an Engineering-Based GK-12 Program on Students' Perceptions of Engineering (USA)	Lyons & Thompson (2006)	Draw a pre/post picture of an engineer working and write	3–8 grade	Involvement in the Engineering Fellows program significantly influenced students' understanding of engineering [13].
Engineers in the Classroom: Their Influence on African-American Students' Perceptions of Engineering (USA)	Thompson & Lyons (2008)	DAET	6th grade	Experimental group students were more likely to perceive engineering as involving mental tasks such as designing, presenting and experimenting [14].
How Middle Schoolers Draw Engineers and Scientists (USA)	Fralick and Kearn (2009)	Drawing	Middle school students	Students involved in this study frequently perceive scientists as working indoors. A large proportion of the students have no perception of engineering. Others frequently perceive engineers as working outdoors in manual labor [15].
Australian primary students' perceptions of engineering (Australia)	Duncan Symons (2015)	DAET	Primary school students	Students have an limited understanding of what engineers do.

Table 1 (*cont.*)

Study & Country	**Researchers & year**	**Methods**	**Subjects**	**Findings**
Measuring Engineering Perceptions of Fifth-grade Minority Students with the Draw-an-Engineer-Test (DAET) (Work In Progress) (USA)	Newley, A. D., Kaya, E., Yesilyurt, E., & Deniz, H. (2017)	Pre- and post- test	10 to 12 years of age	The results of this study may be used as a baseline to address the needs of minority students in elementary engineering curriculum [16].
Elementary Students' Perceptions of Engineers: Using a Draw-an-Engineer Test to Evaluate the Impact of Classroom Engineering Experiences and Explicit Engineering Messaging (USA)	Rivale, etc. (2011)	An engineering attitudes assessment and a Draw-an-Engineer Test (DAET)	5th grade students	The DAET study revealed that gender of the Graduate Teaching Fellow had significant impacts on the engineers drawn by the girls in the study; girls were more likely to draw a female engineer if they were taught by a female Graduate Teaching Fellow. The collective results of this pilot study imply that the CTC messages make a positive impact on 5th grade students' engineering attitudes [17]
A study examining change in underrepresented student views of engineering as a result of working with engineers in the elementary classroom (USA)	Thompson, S., & Lyons, J. (2005)	"Draw-an-Engineer" instrument	Grades 3, 4, and 5	Students were moving away from the notion that an engineer is a builder and towards a more accurate perception that an engineer is a designer [18].
An Informal Science Educator/Elementary School Teacher Collaboration: Changing Fifth Grade Girls' Perceptions of Scientists and Engineers (USA)	McCann, F. F., Marek, E. A., & Falsarella, C. (2016)	Pre- and post-test DAET	Gifted girls in the fifth grade	The girls maintained the traditional images of scientists that they brought to the Club, modified, however, to include more female images after participation in STEM Club. The girls' perceptions of engineers changed dramatically from non-existent or mechanics/ repairmen to realistic images of engineers [19].
From mechanic to designer: Evolving perceptions of elementary students over three years of engineering instruction (USA)	Rynearson, A. M. (2016)	A semi-structured interview, a Draw an Engineer Task, the Engineering Identity Development Scale, and a Student Knowledge Test.	From second through fourth grade	Students' conceptions of engineers and engineering evolved from naïve representations including mechanics and laborers to designers during the study [20].
Elementary school students' conceptions of engineers: A drawing analysis study in Taiwan. (China)	Chou, P., & Chen, W. F. (2017).	The Chinese-version of the Draw-an-Engineer Test (CDET)	Elementary school students	Most elementary school students tended to draw architectural-engineering-related engineer images, even though they conceived engineers to be laborers/ mechanics [21].
Middle school students' perceptions of engineers: a case study of Beijing students (China)	Liu, M., & Chiang, F. K. (2019).	Graphic analysis and questionnaire	Middle school students	The accuracy and comprehensiveness of students' perceptions in senior grades is better than that in lower grades. Serious gender stereotypes and the phenomenon of cognitive simplification are present in middle school students' perceptions of engineers [22].

ment and tools as well as signals appeared in the drawings are included.

3. Method

3.1 Samples

This study recruited the students of an elementary school in Beijing's Haidian District as the research subjects. Many grade one students are inexperienced drawers and tend to lack understanding, so we excluded them from the study. The DAET was administered to 512 students in 15 classrooms from grades two to six (three classrooms per grade; Table 2). We received 480 (93.8%) valid samples, of which 262 were from male students (51.2%) and 214 from female students (41.8%).

Table 2. Distribution of study subjects by grade

Grade	Total	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Total	512	99	102	114	99	98
Valid samples	480	90	100	103	99	88
Male – Valid samples	262	42	57	61	46	56
Female – Valid samples	214	48	41	42	53	30

Note: 4 students do not answer the gender.

3.2 Instruments

The students' impressions of engineering were investigated by coding and analyzing their drawings. Accordingly, the research instruments included drawing tools and coding tools.

3.3 Drawing Tools

>The drawing tools used in this study are a revised version of the tools we used in a previous study. These tools were previously used to investigate the impressions junior high school students had about engineering.

The DAET used in this study was presented on an A4 paper printed with the following instructions: In the space below, draw an engineer performing engineering work; the space consisted of an empty box. The students were then encouraged to use the right-hand side of the box to write their responses to the following questions: "What are the characteristics of the engineers you drew?" "Where is the engineer's workplace?" "Where did you learn about engineers?" "What is your engineer doing?"

3.4 Coding Tools

The coding tools used in this study follow the code table used to examine the students' impressions of engineering. In our previous study, we invited several persons to evaluate the code table used in this study, which are prominent engineering professors from Chinese universities, an engineering professor from a foreign university, two prominent senior teachers of digital painting from Shenzhen and three leading engineering designers [22]. The code table is divided into two code categories. The first category examines the following four dimensions – engineering products, areas of diversity, engineering processes, and engineering images – each scored on a scale of 0–3. This code category is designed to investigate whether the students think engineering is physical, low-grade work or intellectual, high-grade work. The second category examines the meaning of the drawings and examines themes such as gender, workplace, inferred behavior, objects in the drawing, and other characteristics. Detailed coding principles were used to interpret each area in the second category.

3.5 Data Analysis

We used SPSS17.0 and Microsoft Excel 2016 to analyze the descriptive statistics for the first and second code categories, the difference test (variance test), and statistical descriptions of the students' drawings. Our findings are presented herein.

4. Findings

Before the formal coding, the drawing from one class drawings were pre-analyzed by three science and technology education graduates with different undergraduate backgrounds. After two rounds of pre-analyzes, the Kendall coefficient of the precoding data of the three raters was 0.731, indicating high consistency.

4.1 Analysis of the First Code Category

4.1.1 Engineering Products

In the coding of engineering products, a score of zero meant that no knowledge, no engineering products, or no accurate descriptions were illustrated or written. A score of 1 was assigned when the drawing depicted a hammer, screwdriver, bulldozer, or other engineering tools or machines. A score of 2 was assigned when the drawing depicted a computer, model, design, or other related engineering products. The engineering products detailed in the drawings differed among the grades (Fig. 1). For example, 31.11% of Grade 2 students did not draw engineering products or related products, and this percentage gradually decreased as the grade and age of the students increased. The proportion of engineering products related to manual labor decreased from 67.78% to 37.5%. Conversely, the proportion of engineering products related to mental work increased from 1.11% to 38.64%. These findings suggest that the students' understanding of engineering improved with maturity. The more mature students in this study depicted engineers as either drawing or using computers or other advanced engineering tools and machinery.

4.1.2 Diversity in Engineering Fields

In the area of diversity, a score of 0 was given when no engineering domain was illustrated. A score of 1

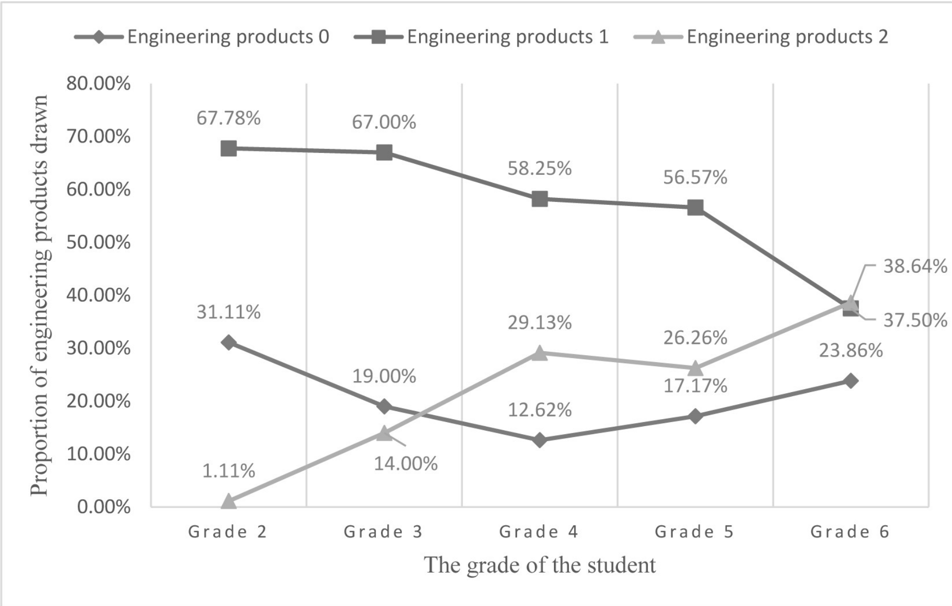

Fig. 1. Distribution of engineering products drawn by students of different grades.

was given when an engineering domain was illustrated, whereas a score of 2 was given when a variety of engineering domains were illustrated. Most students drew an engineering field (Fig. 2). For example, most students in grades two (84%) to five (92.93%) drew an engineering field. By contrast, 75% of grade six students drew an engineering field, with 5.68% of them drawing more than one engineering field.

4.1.3 Engineering Processes

In the coding of the engineering processes, a score of 0 was given when none engineering process was illustrated. A score of 1 was given when the student illustrated a physical process, and a score of 2 was given when the student illustrated an engineering-related psychological process. A score of 3 was awarded when more than one process was illustrated, with at least one of them being a mental process. The number of drawings of an engineering-related psychological process increased with age (Fig. 3). For example, 2.22% of Grade 2 students illustrated a psychological process, compared with 45.45% of Grade 6 students. Conversely, the number of drawings that illustrated a physical process decreased 78.89% (Grade 2) to 27.27% (Grade 6). This shows that as the students mature, their understanding of engineering processes

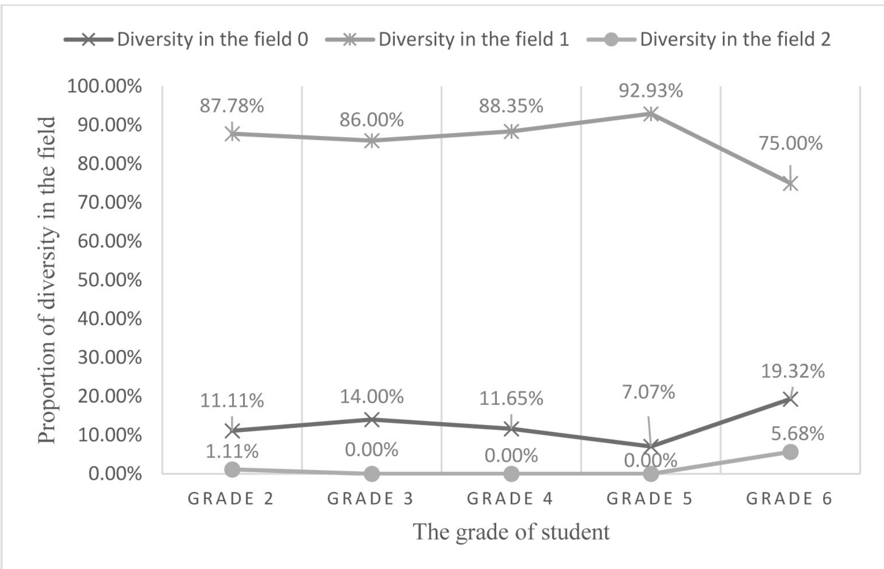

Fig. 2. Distribution of engineering fields drawn by students of different grades.

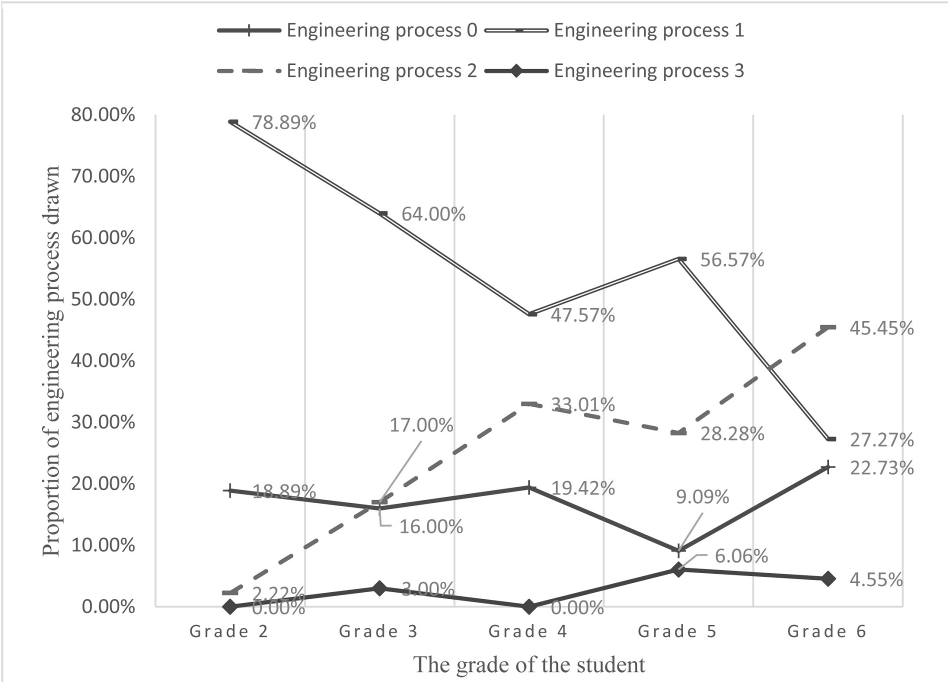

Fig. 3. Distribution of engineering processes drawn by students of different grades.

changes from low-level physical processes to advanced psychological processes.

4.1.4 Engineering Portraits

In the coding of the engineering portraits, a score of 0 was given when students could not illustrate an engineer because they were unfamiliar with the word. A score of 1 was given when a mechanical operator or driver was illustrated, whereas a score of 2 was given when a builder, mechanic, or someone similar was depicted. A score of 3 was given for drawings of an inventor, creator, designer, or similar. The number of students who drew a designer or senior engineer increased with age (Fig. 4). For example, 2.22% of Grade 2 students received a score of 3 in this section, compared with of Grade

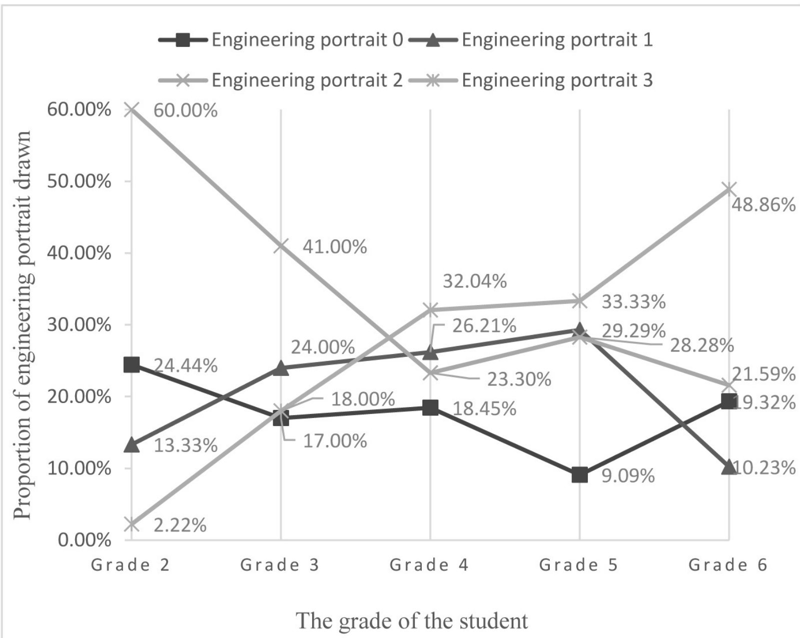

Fig. 4. Distribution of engineering portraits drawn by students of different grades.

Table 3. Chi-square test results in gender differences

Asymp. Sig. (2-sided)								
	Grade*				**Gender***			
	Engineering products	**Diversity in the field**	**Engineering process**	**Engineering portrait**	**Engineering products**	**Diversity in the field**	**Engineering process**	**Engineering portrait**
Pearson Chi-Square	**0.000**	0.001	0.000	0.000	0.044	0.132	0.666	0.719
Likelihood Ratio	**0.000**	0.004	0.000	0.000	0.045	0.133	0.658	0.720
Linear-by-Linear Association	**0.000**	0.967	**0.000**	0.000	0.038	0.045	0.385	0.399

Table 4. Chi-square test results in gender, other characteristics, workplace, inferred behavior, and objects depicted

Asymp. Sig. (2-sided)				
	Engineer gender *Student gender	**Engineer characteristics *Grade**	**Engineer behavior *Grade**	**Engineer object *Grade**
Pearson Chi-Square	**0.000**	0.000	0.000	0.000
Likelihood Ratio	**0.000**	0.000	0.000	0.000

6 students (48.86%). To summarize, we believe that students' understanding of engineering improves as they mature.

4.1.5 Grade and Gender Differences in the First Category

We used chi-square tests to analyze grade and gender differences. The students' understanding and depictions of engineering products, engineering diversity, engineering processes, and engineering portraits differed greatly among the grades (Table 3). Overall, boys and girls significantly differed in their illustrations of engineering products.

4.2 Analysis of the Second Code Category

The second code category examined differences in gender, other characteristics, workplace, inferred behavior, and objects depicted. Table 4 presents the test probability values, all of which were < 0.005 by Pearson Chi-Square test and Likelihood Ratio test, indicating that there were significant grade differences in the characteristics, behavior and object of the drawn engineer.

4.2.1 Gender

Fig. 5 illustrates the differences in thinking between male and female students. The percentage of students who did not clearly indicate the gender of their engineer reduced from 54.44% to 18.18%. Gender awareness of engineers improved with age. Half the students in grades three, four, and six believed engineering is a man's job, compared with 70% of grade five students. Thus, as age increases, the students gradually develop gender stereotypes.

We examined whether the gender of the drawn engineer is related to the gender of the corresponding student. As the foregoing findings demonstrate, 60% of male students and 60% of female students

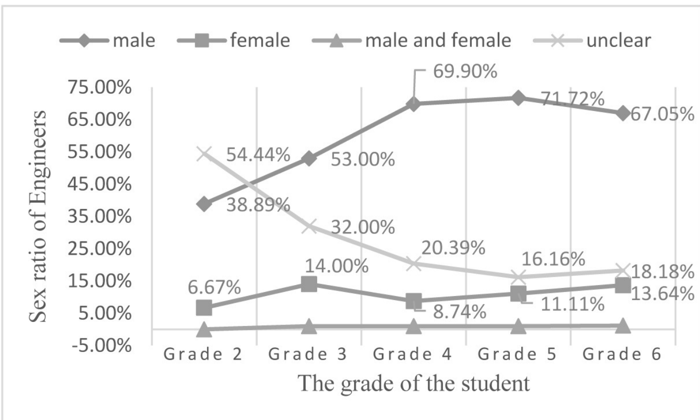

Fig. 5. Gender distribution of engineers drawn by grade students.

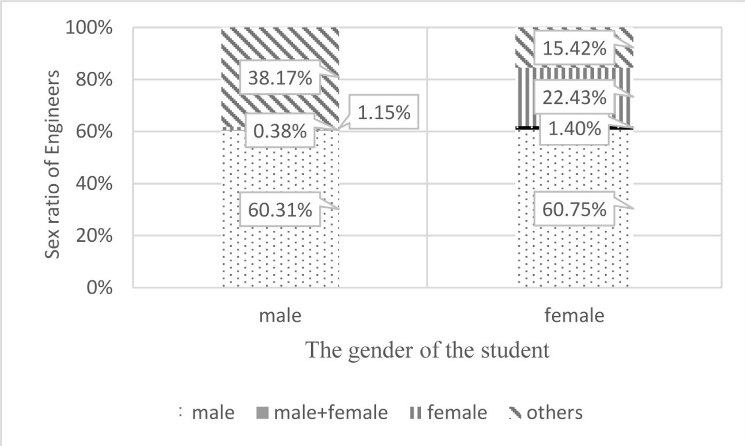

Fig. 6. Gender ratio of the engineers drawn by male and female students.

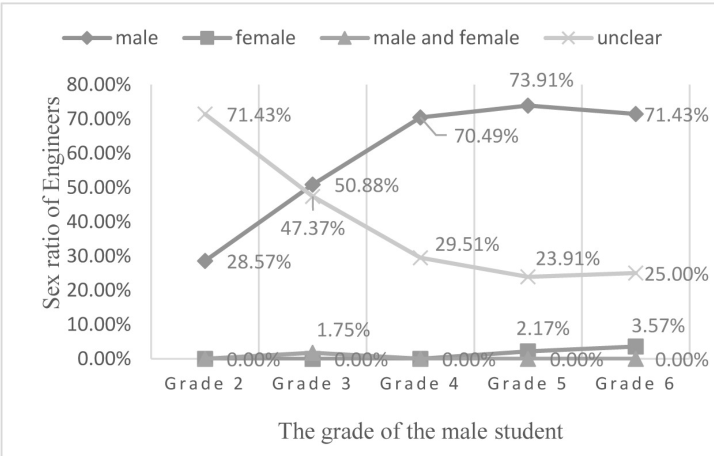

Fig. 7. Gender ratio of engineers drawn by male students of different grades.

drew male engineers. By contrast, only 1.15% of male students drew a female engineer, whereas 22.43% of female students drew a female engineer. Three students did not know the gender of their engineer, two students drew a robot engineer, and one depicted the engineer as an animal. The chi-square test (Table 4) revealed a significant mismatch between the gender of the illustrated engineer and the student.

Fig. 7 shows the gender ratio of the engineers drawn by the male. As illustrated, 71.43% of male Grade 2 students did not have an explicit awareness of the gender of the engineer they drew; however, this number decreased with age. Only a small number of students in Grade 5–6 drew a female engineer. This suggests that senior students have a clearer understanding of an engineer's gender and by this stage have developed a gender stereotype of engineers.

Fig. 8 shows the gender ratio of the engineers drawn by female students. As illustrated, 40% of female Grade 2 students did not know the gender of their engineer; however, this decreased to 10% in Grade 3. Overall, understanding the gender of an engineer increased with age. The female students drew more male engineers than female engineers, but they did not have as strong a gender stereotype for engineers as the male students did.

4.2.2 Other Characteristics of Engineers

This study also examined the physical characteristics of engineers, namely, messy hair, glasses, safety helmets, work clothes, casual wear, and other features. Table 5 illustrates the proportion of students who drew each of the listed features. The findings are as follows:

1. More than 50% of students drew safety helmets.
2. Approximately 30% of students drew work clothes.
3. Few students (6%) painted engineers with a beard and messy hair.

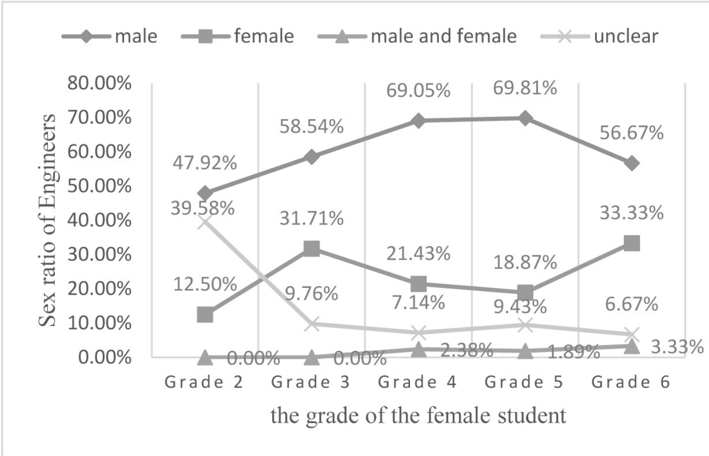

Fig. 8. Gender ratio of engineers drawn by female students of different grades.

Table 5. Proportion of features of the engineers drawn by students

	Total	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
1. Messy hair/bearded	3.54%	2.22%	6.00%	2.91%	2.02%	6.82%
2. Glasses / goggles	8.33%	2.22%	3.00%	8.74%	7.07%	21.59%
3. Helmet	59.38%	62.22%	56.00%	58.25%	67.68%	52.27%
4. Coverall	33.54%	32.22%	32.00%	20.39%	24.24%	39.77%
5. Casual clothes	2.50%	1.11%	3.00%	2.91%	3.03%	1.14%
6. Other	40.42%	65.56%	53.00%	33.01%	24.24%	28.41%

4. Only 1%–2% of students painted engineers wearing casual clothes.
5. A miniscule proportion of students from Grade 2–5 painted glasses or goggles on their engineer, but this increased to more than 20% in Grade 6.

Table 5 details the other physical characteristics of the illustrated engineers. Overall, 52 students drew an engineer with a smile, indicating that some of the students held a positive attitude about engineers. Moreover, some students (38) drew sweaty engineers, which indicates that some students perceived engineering as laborious. The STEM logo featured in one student's drawing, a possible connection between the STEM course and the engineer.

4.2.3 Engineer's Workplace

Table 6 shows the students' perceptions of an engineer's workplace. Almost half the students (47.92%) thought that their engineer worked on a construction site, whereas 9.17% of students thought their engineer worked in an office. Moreover, 7.71% of students thought their engineer worked in a factory, and 4.79% a house. Only 1.88% students thought their engineer worked in a research laboratory. In summary, most students thought that engineers work on a construction site.

4.2.4 Inference Behavior

Descriptive statistics were used to infer engineer behavior from student drawings (Table 7). Across

Table 6. Descriptive statistics of features drawn by students

6 Other specific descriptions	None	Smile	Sweat	Dark skin	Dirty	Frowning or serious	Head-lights	Acne	Gauze mask	STEM logo
Amount	89	52	38	4	3	3	2	1	1	1

Table 7. Distribution of Engineer's workplace as drawn by students

	1 Inside the house	2 Factory	3 Office	4 Laboratory	5 Construction site	6 Other
Percentage	4.79%	7.71%	9.17%	1.88%	47.92%	30.42%

all grades, 53.13% of students drew engineers as being engaged in labor, repairing, or operating activities, approximately 13% drew engineers as performing design and mapping behaviors, and 10% depicted no behavior. In addition, less than 5% students drew engineers as someone who drive the vehicle, examine the design draft, test and interpretation products, observe others' behavior. When stratified by grade, the number of students who drew labor and repairing behaviors largely reduced with age, and only 23.86% of the students in Grade 6 drew an engineer showing simple hands-on labor. Moreover, the number of students who depicted four (design, invention, product creation), five (experiment, test), six (interpretation teaching), seven (observation) behaviors increased substantially with age. Among them, the most obvious trend from the Grade 2–6 was the gradual increase from, 0% to 26.14%, in the proportion of students who drew engineers performing design, invention, and creation behaviors. Furthermore, with increase in age, students' cognition of engineer behaviors changed from simple operation, such as hand operation and production, to advanced mental activities, such as design, invention, teaching, observation, and learning. Moreover, the test probability values were all < 0.005 in various ways, indicating that the behavior of the drawn engineer differed significantly among the grades.

4.2.5 Drawing Objects

Table 8 shows the descriptive statistics for all objects drawn by the students. Overall, 48.33% of students drew, whereas approximately 21% of students drew design-related objects. The number of students who drew objects pertaining to repair-related objects decreased with age, with older students generally drawing design-related objects. Nearly 7% of Grade 6 students used symbol such as mathematical symbols. The remaining objects drawn were mostly environmental objects such as farmlands, trees, and the sun. Table 3 illustrates that the test probability values were <0.005 by Pearson Chi-Square test and Likelihood Ratio test, indicating that the objects drawn differed significantly among the grades.

4.2.6 Source of Student Drawing Creation

This study analyzed the contents of the students' drawings and identified eight creative sources: family, school, life experiences, comics/books, network/film/news, imagination, people other than family members, and unknown (Table 9). 44.79%

Table 8. Descriptive statistics for inferring engineer's behavior

	Total	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
1. Make / repair / operate by hand	53.13%	74.44%	66.00%	44.66%	55.56%	23.86%
2. Operate / drive machinery or vehicle	4.38%	1.11%	3.00%	1.94%	9.09%	4.55%
3. Look at the design drawings	4.17%	0.00%	3.00%	9.71%	2.02%	5.68%
4. Design / invent / create a product (e.g., design, drawing)	13.75%	0.00%	11.00%	10.68%	19.19%	26.14%
5. Experiment / test / calculation / creation knowledge (including programming)	3.33%	1.11%	3.00%	4.85%	1.01%	6.82%
6. Interpretation / instruction	5.21%	2.22%	4.00%	2.91%	3.03%	7.95%
7. Observation	1.88%	0.00%	1.00%	1.94%	4.04%	2.27%
8. Learning	0.42%	1.11%	0.00%	0.97%	0.00%	0.00%
9. No behavior	10.00%	3.33%	6.00%	18.45%	5.05%	17.05%
10. Other	11.25%	18.89%	12.00%	7.77%	4.04%	14.77%

Table 9. Descriptive statistics of objects drawn by students

	Total	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
1. Building and repair	48.33%	66.67%	75.00%	35.92%	37.37%	32.95%
2. Design	20.83%	1.11%	11.00%	26.21%	26.26%	38.64%
3. Engineering products – Machinery	4.79%	4.44%	8.00%	1.94%	5.05%	4.55%
4. Civil engineering products	50.83%	65.56%	51.00%	40.78%	48.48%	22.73%
5. Engineering experiment tool	1.25%	1.11%	2.00%	1.94%	0.00%	0.00%
6. Symbol	2.08%	2.22%	2.00%	0.00%	1.01%	6.82%
7. Dangerous symbol	0.63%	1.11%	0.00%	0.00%	0.00%	0.00%
8. Other	15.63%	14.44%	15.00%	2.91%	12.12%	25.00%

Table 10. Sources of influence on student drawings

The source of creation	Student number	Percent
1. Family	31	6.46%
2. School	3	0.63%
3. Real life	99	20.63%
4. Comics/books	29	6.04%
5. Network / film / news	88	18.33%
6. Imagination	12	2.50%
7. Listen to others' (except family members)	3	0.63%
8. Don't know/none	215	44.79%

of the students could not describe where they got the information about engineers which was showed in their pictures. Life experiences influenced 20.63% of the students' drawings, with most of them claiming they had visited a construction site. Almost one-fifth (18.33%) of students said their understanding of engineering came from television or videos. The proportion of students who said family, books, or their imagination influenced their drawing was 6.46%, 6.04%, 2.5%, respectively. Less than 1% (0.63%) of students said that their school taught them about engineering, which demonstrates a lack of engineering education in schools in China. In summary, most students learnt about engineering outside of school.

5. Discussion

This study examined the impressions elementary students in China had about engineering. In particular, the students' knowledge of engineering tools, processes, workplaces, and fields was explored. Perceptions among students changed with age. For example, younger students were either unfamiliar with engineering or believed engineering was primarily outdoor, laborious work. By contrast, older students drew engineers involved in indoor, problem solving – type work. In addition, the proportion of students who stereotypically believed that engineering is a man's job increased with age, and this belief was more prominent in male students than in female students.

A drawing analysis study completed in the United States (US) divided engineers into following four categories: engineers who fix engines or drive cars and trucks (mechanic), engineers who fix or build roads and other structures (laborer), engineers who fix electronics and computers (technician), and engineers who design (designer) [29]. We compared the classification of engineers in these two studies. Firstly, the mechanic in the American study was equivalent to the mechanical operator or driver of this study. Secondly, the laborer in the American study was equivalent to the builders of this study. Finally, the designer and the technician were equivalent to the inventor or designer of this study.

The following show how the present study and the US study compare:

1. In this study, from Grade 2–5, the proportion of students who drew a mechanic increased with age but decreased in Grade 6. But in American study, the proportion of students who situate the engineer as mechanic accounted for 46%, which was the highest.
2. The proportion of students who painted construction workers decreased with age in this study, but there were different results in American study [29]. A slightly smaller percentage of Grade 3 and 4 students (10%, 14% respectively) conceptualized an engineer as a laborer compared to the percentage of Grade 1, 2, and 5 students (30%, 32%, 27% respectively).
3. From the second grade, designers were depicted, and the proportion increased with grade, reaching 48.86% in Grade 6. However, the US study found that designers only appeared in drawings by Grade 4–5. The total ratio of technicians and designers was less than 30% in Grade 5. In another study, a large proportion of students drew scientific and technical personnel repairing cars, building houses, and completing other types of manual labor [7]. Thus, in lower grade, most students conceptualized an engineer as a manual worker.

Table 11. Difference between the American study [29] and this study in term of the classification of engineers a mechanical operator or driver was illustrated, whereas a score of 2 was given when a builder, mechanic, or a someone similar was depicted. A score of 3 was given for drawings of an inventor, creator, designer, or similar. The number of students who drew a designer or senior engineer increased with age (Fig. 4). For example, 2.22% of Grade 2 students received a score of 3 in this section, compared with of Grade 6 students (48.86%). To summarize, we believe that students' understanding of engineering improves as they mature.

	American study	This study
The classification of engineers	Mechanic	Mechanical operator, driver and so on
	Laborer	Builder, mechanic and so on
	Technician	Inventor, creator, designer and so on
	Designer	

Previous studies have found that most students draw male engineers, as was the case in this study. The American study found that only male students (less than 10%) in Grade 3 drew female engineers, whereas female engineers were drawn by both male and female students. In addition, the number of female students who drew male engineers increased with age, in particular, 70% of the Grade 5 students drew male engineers, whereas less than 20% drew female engineers. Students in this study tended to think the engineer as a man, it can be inferred that students in the US have a narrow understanding of the gender of engineers. This study also found that Chinese students hold a similar belief about the gender of engineers. Other studies also show that drawings of female engineers are typically drawn by female students [7, 11, 21]. In addition, in contrast to previous studies, this study found that the difference between the proportion of male engineers and female engineers drawn by students increased with age (students in higher grades tend to draw male engineers more than students in lower grades). Knight and Cunningham [10] concluded that lower-grade students' cognitive limitations were significantly higher than those of senior students, which means that senior students should have a more comprehensive understanding of engineering. On the contrary, this study found that senior students (Grade 4, 5 and 6) had a clearer understanding of engineer's gender than junior students (Grade 1, 2, and 3), but more informative and stereotyped.

This study found that nearly half of students (48.33%) drew repair-related objects or civil engineering products. In addition, this study also found that most students believed engineers work on a construction site, indicating that most students correlated engineers with repair, construction and so on. Student are familiar with something access to information every day, which may have inspired their perceptions of engineers. Moreover, many students in Grade 6 drew glasses or goggles. It means that when "engineer" is mentioned, it is easy for them to think of "safety".

Based on our findings, we conclude that with increase in age, the students' understanding of engineering shows the trend of transformation from simple manipulation such as hand operation and production to advanced mental activities such as design, invention, teaching, observation, and learning. Moreover, we speculate that most of the students in this study learnt about engineering from real-life experiences. Numerous studies found that the career choices Chinese teenagers make are heavily influenced by family members, teachers, media, and museums [21, 30]. Network platforms are the main channels for students to know the engineers, so we can publish some learning resources related to engineering education and engineer's speech video through the network to strengthen the guidance of the students' engineer cognition.

We suggest that efforts be made to strengthen student understanding of engineering. The National Science Education Standards and the National Educational Technology Standards have emphasized the importance of students learning problem-solving skills. STEM education seeks to teach students about engineering. Some studies have reported that teaching students about engineering will improve their career decisions [12].

6. Limitations

The data from this study are derived from typical downtown of Beijing and the results could be referred by other urban area. The mapping analysis method was used in this study, but some students could not fully express their understanding by drawing. Furthermore, the researchers used their subjective judgment when using the codes, which may produce inconsistent results among researchers. We suggest that additional interviews be held to gain a better understanding of the students' drawings. Future studies should also look at the influence socioeconomic background on students' beliefs about engineering.

7. Conclusion

Considering the present survey as a representative of Chinese elementary school students, we conclude that students' understanding of engineering progresses is improved with age and is largely influenced by experiences out of the classroom. Younger students tended to believe that engineers work on construction sites, whereas older students generally believed engineers work as designers and do more advanced intellectual tasks (indoors). Moreover, gender stereotypes about engineers were more pronounced in older students, with most believing that engineering is a man's job; however, while most female students drew male engineers, female students drew more female engineers than male students did.

Most students learn about engineering out of the classroom, so we suggest that digital media be used to promote engineering to elementary students. Furthermore, many studies have proved that instructional intervention and practical activities can enhance children's understanding of engineering [16, 17, 19]. We propose that engineering courses be developed and integrated into existing school curricula. In particular, the courses should enhance the students' understanding of engineering processes and specialties and should promote engineering as a career for both men and women.

Compliance with Ethical Standards
We have no conflicts of interest. The educational aspect of our research posed no potential threats to the human subject (students) and was exempt.

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References

1. B. M. Capobianco, E. D. Deemer and C. Lin, Analyzing predictors of children's formative engineering identity development, *International Journal of Engineering Education*, **33**(1), pp. 44–54, 2017.
2. E. A. Plant, A. L. Baylor, C. E. Doerr, and R. B. Rosenberg-Kima, Changing middle-school students' attitudes and performance regarding engineering with computer-based social models, *Computers & Education*, **53**(2), pp. 209–215, 2009.
3. K. B. Wendell and C. Rogers, Engineering design-based science, science content performance, and science attitudes in elementary school, *Journal of Engineering Education*, **102**(4), pp. 513–540, 2013.
4. N. Mentzer, K. Becker and M. Sutton, Engineering design thinking: High school students' performance and knowledge, *Journal of Engineering Education*, **104**(4), pp. 417–432, 2015.
5. C-T. Wei and M. He, Quality Structure of Applied Outstanding Engineers and its Training, *Higher Education of Sciences*, **1**, 2012.
6. S.Y. Luo, Research on the Key Qualities of Chinese Engineers in the Field of Engineering Innovation, *Doctoral dissertation*, Beijing Institute of Technology, 2015.
7. E. Oware, B. Capobianco and H. Diefes-Dux. Gifted students' perceptions of engineers? A study of students in a summer outreach program, *Proceedings of the 2007 American society for engineering education annual conference & exposition, Honolulu*, 2007.
8. D. W. Chambers, Stereotypic images of the scientist: The Draw-a-Scientist Test, *Science Education*, **67**(2), pp. 255–265, 1983.
9. P. O. Garriott, R. L. Navarro and L. Y. Flores, First-generation college students' persistence intentions in engineering majors, *Journal of Career Assessment*, **25**(1), pp. 93–106, 2017.
10. M. Knight and C. Cunningham, Draw an engineer test (DAET): Development of a tool to investigate students' ideas about engineers and engineering, *ASEE Annual Conference and Exposition*, Vol. 2004, 2004.
11. Z. Scherz and M. Oren, How to change students' images of science and technology, *Science Education*, **90**(6), pp. 965–985, 2006.
12. F. O. Karatas, A. Micklos and G. M. Bodner, Sixth-grade students' views of the nature of engineering and images of engineers, *Journal of Science Education and Technology*, **20**(2), pp. 123–135, 2011.
13. J. Lyons and S. Thompson, Investigating the long-term impact of an engineering-based GK-12 program on students' perceptions of engineering, *ASEE Annual Conference and Exposition*, 2006.
14. S. Thompson and J. Lyons, Engineers in the classroom: Their influence on African-American students' perceptions of engineering, *School Science and Mathematics,* **108**(5), pp. 197–211, 2008.
15. B. Fralick J. Kearn, S. Thompson and J. Lyons, How middle schoolers draw engineers and scientists, *Journal of Science Education and Technology,* **18**(1), pp. 60–73, 2009.
16. A. Newley et al. Measuring engineering perceptions of fifth-grade minority students with the draw-an-engineer-test (DAET). *Proceedings of the American Society for Engineering Education Annual Conference & Exposition, Columbus, OH, USA, June 25*, **29**, 2017.
17. S. Rivale, et al., Elementary students' perceptions of engineers: Using a Draw-an-Engineer Test to evaluate the impact of classroom engineering experiences and explicit engineering messaging. *American Society for Engineering Education*, 2011.
18. S. Thompson and J. Lyons, A study examining change in underrepresented student views of engineering as a result of working with engineers in the elementary classroom, *Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education*, Portland, OR, USA, 2005.
19. F. F. McCann, E. A. Marek and C. Falsarella, An Informal Science Educator/Elementary School Teacher Collaboration: Changing Fifth Grade Girls' Perceptions of Scientists and Engineers, *Creative Education*, **7**(16), p. 2459, 2016.
20. A. M. Rynearson, From mechanic to designer: Evolving perceptions of elementary students over three years of engineering instruction, *Purdue University*, 2016.
21. P. Chou and W-F. Chen. Elementary school students' conceptions of engineers: A drawing analysis study in Taiwan, *International Journal of Engineering Education*, **33**(1), pp. 476–488, 2017.
22. M. Liu and F-K. Chiang, Middle school students' perceptions of engineers: a case study of Beijing students, *International Journal of Technology and Design Education*, pp. 1–28, 2019.
23. L. J. Rennie and T. Jarvis, English and Australian children's perceptions about technology, *Research in Science & Technological Education*, **13**(1), pp. 37–52, 1995.
24. A. MacPhail and G. Kinchin, The use of drawings as an evaluative tool: students' experiences of sport education, *Physical education & sport pedagogy*, **9**(1), pp. 87–108, 2004.
25. H-Y. Wang and C-C. Tsai, An Exploration of Elementary School Students' Conceptions of Learning: A Drawing Analysis, *Asia-Pacific Education Researcher (De La Salle University Manila)*, **21**(3), 2012.
26. K. D. Finson, J. B. Beaver and B. L. Cramond, Development and field test of a checklist for the Draw-A-Scientist Test, *School Science and Mathematics*, **95**(4), pp. 195–205, 1995.
27. C. Yap, C. Ebert and J. Lyons. Assessing students' perception of the engineering profession, *South Carolina educators for the practical use of research annual conference, Columbia SC*, 2003.
28. National Academies of Engineering, Ninth Annual Symposium on Frontiers of Engineering, *National Academy of Science*, Washington, D.C., 2004.
29. B. M. Capobianco, et al., What is an engineer? Implications of elementary school student conceptions for engineering education, *Journal of Engineering Education*, **100**(2), pp. 304–328, 2011.

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