Rodrigues-Silva, J., & Alsina, Á. (2023). Systematic Review About Students' Conceptions Of Engineering Accessed Through Drawings: Implications to STEAM Education, *International Journal of Cognitive Research in Science, Engineering and Education (IJCRSEE), 11*(2), 199-211.

Original scientific paper

UDC: 159.955.2-057.87

Received: February, 15.2023.
Revised: May, 20.2023.
Accepted: May, 29.2023.

10.23947/2334-8496-2023-11-2-199-211

Check for updates

# Systematic Review About Students' Conceptions of Engineering Accessed Through Drawings: Implications to STEAM Education

*Jefferson Rodrigues-Silva*[1*], *Ángel Alsina*[2]

[1]Department of mechanical engineering, Federal Institute of Minas Gerais (IFMG), Brazil, e-mail: jeffe.rodri@gmail.com
[2]Department of subject-specific didactics, University of Girona (UdG), Spain, e-mail: angel.alsina@udg.edu

**Abstract:** We aim to review students' conceptions of engineers and engineering accessed through their drawings. Accordingly, we enrolled in a systematic review following the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) protocols. For that, we established the Web of Science as the source of information. After applying eligibility criteria, the search resulted in ten records. We observed that many reviewed studies enrolled in research designs which contained comparisons of groups, cohorts (cross-age) or pre-post-tests. However, they generally overlooked appropriate statistical tests. Overall, the studies evidenced that most students conceive engineers as males who work individually in manual activities and outdoor environments. The major contribution of this study is providing an overview of the investigation of children's conceptions of engineering. Additionally, we call attention to the need for more research, teacher training, and carefully planned and executed activities that enhance students' conceptions of engineers and engineering instead of worsening stereotypes—especially considering current curriculum proposals, such as STEAM education embracing engineering at precollege levels.

*Keywords: Draw an Engineer Test, drawing, students, precollege engineering, STEM education, STEAM education.*

## Introduction

Educational approaches such as STEM (Science, Technology, Engineering and Mathematics) and STEAM (Science, Technology, Engineering, Arts/Humanities, and Mathematics) have gained ground worldwide (Marín-Marín et al., 2021). Countries such as The United States of America (NGSS, 2013), Korea (KOFAC, 2012), and Spain (MEFP, 2022) have incorporated them into their curriculum. Such educational approaches place interdisciplinarity as a crucial aspect of education, especially under the claim that siloed disciplines cannot address complex matters, e.g. sustainability which encompasses economic, environmental, and social spheres (Rodrigues-Silva and Alsina, 2023a; Guyotte, 2020).

Alongside interdisciplinarity, STEM or STEAM entails inserting into the precollege curriculum engineering—a discipline generally absent at this level. In this vein, discourses that promote STEM or STEAM mention the urge to increase students' interest in pursuing technical careers such as engineering, which would be highly required in a technological world (Perignat and Katz-Buonincontro, 2019). At the same time, researchers defend precollege engineering to increase girls' interest towards this career and, therefore, tackle the sustainable development goal of reducing the existent gender gap in engineering (Aurava and Meriläinen, 2022; Cabello et al., 2021; United Nations, 2015).

Conversely, practices involving precollege engineering might side effects engineering image if pedagogical planning and management overlook stereotypical conceptions (Fleer, 2021). For example, Fleer (2021) proposed a free play activity wherein preschool children were incentivised to imagine themselves as engineers while building bridges. The authors witnessed that boys mainly occupied the "engineering area"—a space with tools to design and construct the bridge—while girls avoided this area. Consequently, this activity may have reinforced their conception of engineering as a male profession. Contrary to simply incorporating engineering, Moore et al. (2014) presented a precollege engineering education framework and remarked that developing students' conceptions of engineers and engineering is essential. They argue that an accurate idea of engineering prevents reinforcing stereotypical views and

*Corresponding author: jeffe.rodri@gmail.com

gives meaning to learning the following knowledge and abilities related to engineering.

Willing to access children's conceptions of engineers, Knight and Cunningham (2004) proposed the Draw an Engineer Test (DAET) as an instrument that to explore their ideas through drawings. This instrument follows the theory of figurative thinking as the underpinning rationality of its analysis. According to this theory, children's symbolic expressions (signifiers) represent personal systems of mental images about objects (signifieds) (Piaget and Inhelder, 1971). In this sense, interpreting the results obtained through DAET is possible under the conception that children's drawings may offer insights into their mental images of engineering (Capobianco et al., 2011).

Researchers have applied this instrument in countries like the United States, China, and Turkey (Capobianco et al., 2011; Diefes-Dux and Capobianco, 2011; Knight and Cunningham, 2004). Results from those studies highlighted problems such as children's misconceptions of engineering that might prevent them from envisioning it as an intellectual activity. Additionally, from a very early age, children already express gender bias toward engineering as a male career. Such an image likely averts some girls from pursuing this profession.

In sum, countries gradually adopt educational approaches incorporating engineering at precollege levels; studies identify children expressing misconceptions about engineering and gender bias, and weakly structured activities are likely to worsen those misconceptions. This configuration conduces to two research questions. First, how have students' conceptions of engineers and engineering been investigated through drawings? Furthermore, what are students' conceptions of engineers and engineering?

Currently, no systematic review addressed studies exploring students' engineering conceptions through their drawings. In this sense, the literature lacks studies that provide an overview of this topic. Line up to those interrogations and the identified gap in the literature. We aim to review students' conceptions of engineers and engineering accessed through their drawings.

## Materials and Methods

Considering this research goal, we enrolled in a systematic literature review following the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) protocols. Accordingly, the investigation process is informed to guarantee its rigour and reproducibility (Moher et al., 2015). It was structured into the phases: 1) Search elements and Boolean logic, 2) Eligibility criteria, 3) Information sources, 4) Data collection, and 5) Data analysis.

### Search elements and Boolean logic

First, we identified engineer and engineering as central terms of the research goal. Then, the words draw and drawing were acknowledged as appropriate terms to filter studies that applied drawings to access people's conceptions. Two additional words, conception and stereotype, were considered to refine the search in order to prevent finding studies on engineering technical drawing. Given all that, the Boolean logic was created: ENGINEER* and DRAW* and (CONCEPTION or STEREOTYPE). Moreover, we established that the word engineer should be scanned in the title—given its centrality in this study—and the other terms of the Boolean logic in the title, abstract, author, keywords, or keywords plus.

### Eligibility criteria

In this second phase, we established the eligibility criteria applied in this review, as presented in Table 1. First, we fixed that the documents should be peer-reviewed because this evaluation indicates some research quality. Following this, we established that the records could have the format of an article or conference proceedings. We included documents published since 2004, which correspond to when the DAET instrument was created by Knight and Cunningham (2004). Since we are interested in students' conceptions, we secure that the document was classified in the educational research area and the population was centred on students. Finally, we included documents published in English because it is considered a universal language in the current scientific community. Moreover, we were open to considering Spanish and Portuguese documents to profit authors' knowledge in those languages to broaden the research scope. The exclusion criteria were essentially antonyms of the inclusion ones.

**Table 1**
*Eligibility criteria*

| Criteria | Inclusion | Exclusion |
|---|---|---|
| Type of document | Article or conference proceedings | Other formats |
| Publication period | From 2004 to 2022 | Before 2004 |
| Research area | Education | Other areas |
| Population | Students | Teachers and student teachers |
| Language | English, Spanish, and Portuguese | Other languages |

### Information sources

In this third phase, we selected the Web of Science (WoS) index from Clarivate as the information source because of its recognised rigour and importance in science, particularly in the educational field.

### Data collection

Once the Boolean logic, the eligibility criteria, and the source of information are established, we finally move to the review's fourth phase, which consists of collecting and treating data. A scan enrolled on 30 October 2022 resulted in 74 records. We used the WoS platform to filter the type of document, publication period, research area, and language. After that, we read the abstract and full texts to ensure the documents included were correct—DAET instrument and focused on students.

At this point, we observed that three articles were non-eligible—Thomas et al. (2020, 2016) had to be discarded because they were focused on students but developing a rubric and validating a modified version of the DAET, and Diefes-Dux and Capobianco (2011) study because they presented a specific analysis of data from another study which was already contemplated in the list of reviewed articles (Capobianco et al., 2011). Eventually, as shown in Figure 1, the data collection process was conducted to a final list of ten documents—articles and conference proceedings.

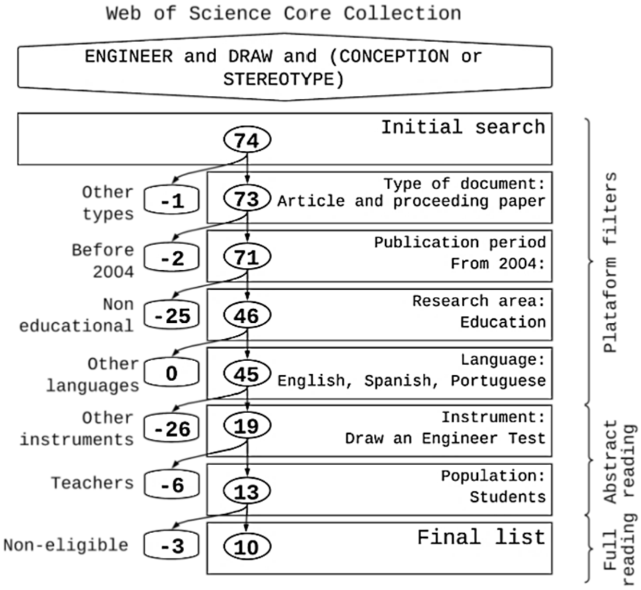


*Figure 1.* Data collection process.

### Data analysis

We used the Atlas-ti program to provide the word occurrence from those ten selected articles. For this, we excluded numbers and set the threshold of 80 accounts. Then, we plotted the information in word cloud format to visually analyse the accuracy of those documents concerning the Boolean logic and the research goal.

During analysing data, we did several reads and comparisons between the documents. We observed categories of information that could be organised into three blocks:

• **General research features:** methodology approach, sample size, design, intervention, educational level, publication year and region;

• **Data collection instrument and procedure details:** the instruction for making the drawing, the instructions and questions asking for a description of the drawing, application time, applicants, and complementary interviews;

• **Common results:** students' conception of gender (male or female), place of work (out-door or indoor), activity (manual or intellectual), and work setting (individual or collective). Moreover, we addressed the interventions, gender, and age comparisons.

For this last part regarding studies' typical results, whenever necessary, we recalculated the frequency percentages of the four variables— students' conception of gender, place of work, activity, and work setting— considering the total sample size of each study. Matusovich et al. (2021), for example, represented the results of students' opinions on engineering activities through a horizontal bar chart. In this case, we had to estimate the values using the scale presented in the figure.

Moreover, we run one-sample proportion tests on Statistical Package for the Social Sciences (SPSS) program to verify whether the frequency differs statistically between the levels of each variable— using a threshold of 5% of significance. Furthermore, researchers were not always able to interpret, for example, the gender portrayed in the drawings; children may not have pictured a human figure or represented both. Therefore, we created an extra class for each variable to account for indiscernible information from drawings.

Regarding the conception of engineers' activities, we accounted as manual undertaking: fix, build, construct, repair, drive, make a single product (craft), and operate machines. Furthermore, as an Intellectual undertaking, the activities: create, optimise, invent, design, supervise/observe, use math, use science, use technology, solve problems, research, experiment, test, and teach. We clarify that occasionally, engineers can be involved with all those activities, but engineering primarily deals with highly complex issues that demand more cognitive abilities (Moore et al., 2014).

We did not further the review aspects evaluated by a few researchers, such as skin colour (Ergun and Balcin, 2019; Fralick et al., 2009), smiling faces (Ata-Aktürk and Demircan, 2021a), and the presence of engineers in students' family (Capobianco et al., 2011).

## Results

Now on, we present the review results. Beforehand, we highlight the scarcity of studies exploring students' conceptions of engineering since only ten documents were eligible. In Figure 2, a word cloud demonstrates that the terms engineers, drawn, students, education, and conceptions are frequently written in the reviewed documents. This result confirms a substantial relationship between the selected manuscripts and our research goal. Additionally, we call attention to the words test, DAET, gender, design, and STEM occurrence. Those elements will be further addressed in this review.

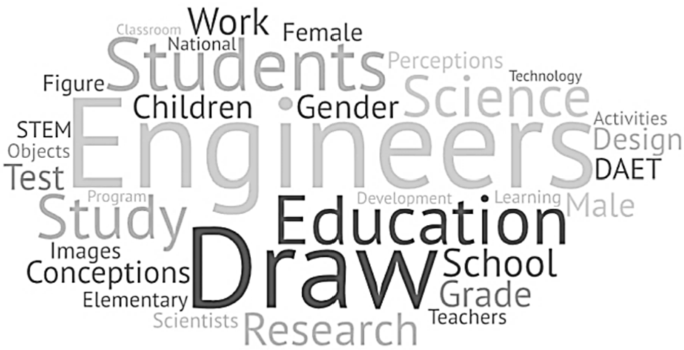


*Figure 2.* Word cloud of the reviewed documents.

### Review of general research features

Table 2 summarises the first block of information that explores general research features: author, year of publication, region, educational level, sampling, sample (N), intervention, grouping, design, and statistics. It is observable that authors contributed with only one record each, which indicates that no researcher could be considered an exponent of the topic. Regarding geographic distribution, the United States of America outstand as the country with more studies—six in total. Turkey has two studies, while China and Mexico have only one each.

**Table 2**
*General research features*

| Author | Region | Level | Sampling | N | Interven-tion | Grouping | Design | Statistics |
|---|---|---|---|---|---|---|---|---|
| Ata-Aktürk and Demircan (2021a) | Turkey | Preschool | Purposeful | 436 | No | One | Cross-sectional | Descriptive |
| Capobianco et al. (2011) | United States | Elementary school | Purposeful | 396 | No | One | Cohort (1-5th grade) | Chi-Square |
| Carr and Diefes-Dux (2012) | United States | Elementary school | Purposeful | 173 | Yes | One | Cohort (2-4th grade) and pre-post | Descriptive |
| Chou and Chen (2017) | China | Elementary school | Purposeful | 750 | No | Two (urban and suburban areas) | Cohort (4-6th grade) | Descriptive |
| Ergun and Balcin (2019) | Turkey | Middle School | Purposeful | 119 | No | One | Cross-sectional (5-7th grade) | Descriptive |
| Fralick et al. (2009) | United States | Middle School | Purposeful | 744 | No | One | Cross-sectional | Descriptive |
| Knight and Cunningham (2004) | United States | Elementary and Middle School | Purposeful | 384 | No | Two (male and female students) | Cohort (3-9th grade) | Descriptive |
| López et al. (2013) | Mexico | Higher education | Purposeful | 124 | No | Two (public and private universities) | Cross-sectional | Descriptive |
| Matusovich et al. (2021) | United States | Middle School | Purposeful | 757 | Yes | One | Pre-post | Descriptive |
| Rivale et al. (2020) | United States | Elementary school | Purposeful | 355 | Yes | Two (male and female tutors) | Pre-post and two cohorts | ANOVA |

Note: Cohort here is understood as a longitudinal-like design conceived through a cross-sectional collection of data, which means participants responded only once, but they have similarities that permit inferring a temporal relationship.

**Table 3**
*Data collection instrument and application procedure details*

| Author | Instruction for drawing | Description of the drawing | Time (min) | Applicant | Complementary Interview |
|---|---|---|---|---|---|
| Ata-Aktürk and Demircan (2021a) | Draw an engineer at work | Children were assumed as illiterate | 20 | Teachers | What is happening in your drawing? Is there an engineer in this drawing? What is this engineer doing? |
| Capobianco et al. (2011) | In the space below, draw an engineer doing engineering work | What is your engineer doing? | 30 | Teachers | Is your engineer a boy or a girl? What is the engineer doing? What can you tell me about this person? Complete: an engineer is a person who... |
| Carr and Diefes-Dux (2012) | Draw an engineer doing engineering work | Write about what this engineer is doing | - | - | No |
| Chou and Chen (2017) | How do engineers look? Please, draw an image of an engineer | Give a name to your engineer. Where does your engineer work? What is your engineer doing? | 30 | Teachers | 30 unstructured interviews |
| Ergun and Balcin (2019) | Draw a picture of an engineer at work | Give a name to your engineer. What are the personal characteristics of an engineer? How is the work environment of an engineer? What kinds of work does an engineer do? What is the engineer you drew doing? | 45 | Researchers | No |
| Fralick et al. (2009) | Draw an engineer at work | Engineer's name. Describe your engineer a) personal information, b) Work setting, c) Job description. What is the engineer in your drawing doing? | - | Teachers | No |
| Knight and Cunningham (2004) | Draw a picture of an engineer at work | What does an engineer do? | 15 | Teachers | No |
| López et al. (2013) | Participants were asked to close their eyes and imagine an engineer at work. Then they were required to draw it | Describe what the engineer is doing in your drawing. List at least three words/phrases that come to mind when you think of an engineer. What kinds of things do you think an engineer does? | 25 | Researchers | 28 unstructured interviews |
| Matusovich et al. (2021) | Draw a picture of an engineer at work | What does an engineer do? Do you know any engineers? Who are they? | 15 | Researchers | No |
| Rivale et al. (2020) | Draw a picture of what an engineer looks like | Name one thing invented by an engineer | - | - | No |

As presented in Figure 3, the reviewed documents are steadily distributed in time. Despite some gaps, since DAET's creation in 2004, there has been no production peak and a maximum of two papers published during the same year.

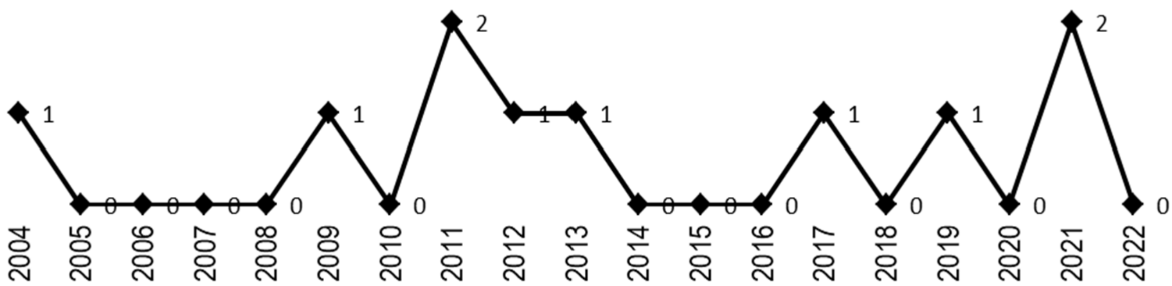


*Figure 3.* Time distribution of publications on the Web of Science of studies on students' conceptions of engineering through drawings.

Then addressing students' educational level, most documents investigated elementary or middle schools. Ata-Aktürk and Demircan (2021a) explored preschool students replacing the DAET written part with a short interview about the drawing (different modifications of this instrument will be seen later on). Studies on higher education were not frequent either. López et al. (2013) addressed higher education to observe how incoming engineering students conceive their course.

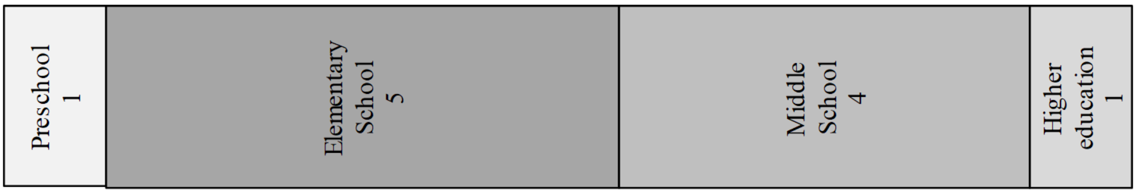


*Figure 4.* Educational levels addressed in the reviewed articles.

All studies followed purposive sampling and a non-randomised selection method—strategies commonly used in qualitative research. In this case, investigators select the participants from a particular context or reason (Lawson, Faul and Verbist, 2019). However, studies have relatively large samples of qualitative research standards. Figure 5 shows the sample size distribution: three studies have between 100 and 200 participants; four studies lay in a middle range of 350 to 450 participants, and the last three pieces of research had extensive samples with more than 700 participants each.

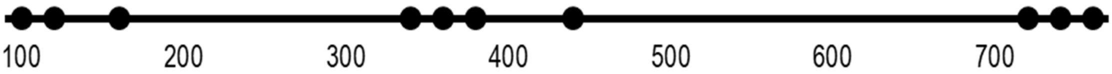


*Figure 5.* Sample size distribution of the reviewed articles.

Studies applied the DAET as their primary research data collection instrument. Consequently, they used similar strategies to analyse data—basically inducing categories by contrasting the drawings and the explanations about it provided by open-ended questions or complementary interviews. Nonetheless, researchers reached no consensus on whether this configuration of inquiry has a qualitative, quantitative or mixed approach. The confusion may be because the information source is qualitative, but subsequently, categories are created and treated as constructs with frequency quantification.

Ata-Aktürk and Demircan (2021a), for example, specified that their study had a phenomenography approach. They presented a cross-sectional study, no comparison groups, and not aiming to evaluate an intervention. Coherently to a qualitative approach, they focused on exploring the quality (phenomenon) of students' conceptions of engineers and engineering. In contrast, Capobianco et al. (2011) reported using qualitative data but, coherently to a (cross-age) cohort design, they had a quantitative part and, therefore, applied statistical testing. Similarly, Rivale et al. (2020) also used statistical tests (ANOVA). We clarify that here cohort is understood as a longitudinal-like design but through a cross-sectional data collection. It means participants respond only once, but as they keep common characteristics (being students), they are related to each other regarding the different grades, so we can infer a temporal change (Lawson, Faul and Verbist, 2019).

The remaining seven documents have at least one comparison condition: two groups, cohort design, intervention and a pre-post design (results of those articles will be explored later on). Notwithstanding, they present only descriptive statistics, and frequencies are directly compared without running hypothesis testing. Figure 6 shows the methodological panorama of the reviewed articles. We highlighted that "two groups", "cohort or pre-post design", and "intervention" are comparison conditions that should inherently be accompanied by hypothesis testing.

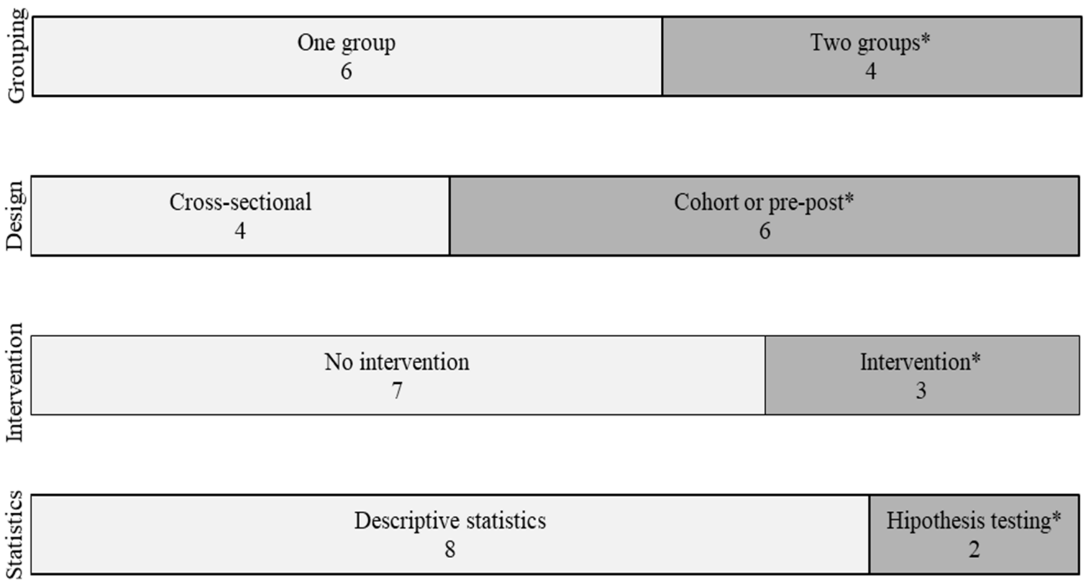


*Figure 6.* Methodological panorama of the reviewed articles.

**Review of data collection instrument and procedure details**

In the following paragraphs, we explore the second block of information concerning the data collection instruments of the reviewed documents. As stated earlier, authors used the DAET as their primary research instrument, but with some variations and adaptions (Table 3). Next, we address the DAET regarding the instruction for drawing, description of the drawing, time of application, applicant, and complementary Interview.

Knight and Cunningham (2004, p. 3) created the DAET with the primary instruction, "Draw a picture of an engineer at work." After that, the authors repeated this instruction in their research. Following the same idea, López et al. (2013) asked students to close their eyes, imagine an engineer at work, and then draw it. Differently, Chou and Chen (2017, p. 478) concentrated on engineers' appearance. They wrote, "How do engineers look? Please, draw an image of an engineer". Similarly, Rivale et al. (2020, 22.552.1 to 22.552.12) used, "Draw a picture of what you think an engineer looks like".

Additionally to DAET's primary instruction, Knight and Cunningham (2004) included the open-ended question, "What does an engineer do?" to help interpret students' drawings regarding the engineering activity. Equally, all authors had those auxiliary requests. However, while some of them kept the question about the general action of engineers (López et al., 2013; Matusovich et al., 2021), other authors modified it to address what the portrayed engineer was doing in the drawing (Capobianco et al., 2011; Carr and Diefes-Dux, 2012; Chou and Chen, 2017; Ergun and Balcin, 2019; Fralick et al., 2009). Additionally, three studies demanded the participants to name their engineers—helpful information for gender interpretation—and to describe the work environment (Chou and Chen, 2017; Ergun and Balcin, 2019; Knight and Cunningham (2004)). Any question directly requests the gender and the working setting—whether the engineer works individually or collectively.

Rivale et al. (2020) required students to cite one thing invented by engineers before drawing. This approach will likely have biased students to conceive engineers as inventors/designers.

In half of the reviewed studies, researchers counted on teachers to be the applicants of the DAET. Some authors commented on how teachers were prepared to do it properly. For example, Capobianco et al. (2011, p. 310) remark that "teachers were provided written directions describing the procedures for administering the drawing test". Also related to the application of the DAET, the average time designated to it was 25 minutes (SD 10 minutes).

Moreover, four studies mentioned an interview to clarify the drawings' reasons. Among those interviews, we highlight the work of Capobianco et al. (2011, p. 310), the sole document that reported directly addressing gender, "Is your engineer, boy or girl?". We also remark that Ata-Aktürk and Demircan (2021a) applied the Draw-and-tell technic—a quick (5 min) and informal narrative about the drawing. They claimed this strategy was an age-appropriate way of working with preschool students who were assumed illiterate and could feel uncomfortable with formal interviews.

The idiom is likely to influence children's image of engineering. For example, Chou and Chen (2017) consider that students might conceive engineering as manual work because the word labourer in Chinese shares its initial character with the word engineer. Similarly, Knight and Cunningham (2004) observed that some students' answers indicated a vocabulary problem in English that may have misconducted their conception of engineering. They explain that students probably related engineering with the word engine and associated this profession with cars. For instance, one student wrote, "Engineer has the word engine in it, so I guess they must work with engines".

In this same vein, López et al. (2013) warn that the Spanish language places genders to nouns, so they included male and female engineers (ingenieros y ingenieras) in the DAET instrument. However, explicitly naming male and female engineers may have influenced the children to consider both genders. Silva-hormazábal, Rodrigues-Silva and Alsina (2022) proposed a STEAM activity of interdisciplinarity between engineering and mathematics using a Spanish version of the DAET. They suggested writing the expression "draw a person that does engineering—dibuje una persona que hace ingeniería" because "persona" is a gender-neutral term.

### Review of common results

Next, we review the results of the articles. As stated in the methodology, we identified aspects commonly studied between the documents, viz., students' conception of engineers' gender, place of work, activity, and work setting. Table 4 presents the frequency distribution of those aspects considering the total sample of each study—we bold the proportions statistically different. We gathered individuals from all groups and cohorts and considered only the pre-test results.

**Table 4**

*Typical results regarding students' conception of engineers' gender, place of work, activity, and work setting*

| Author | Gender | | | Place of work | | | Activity | | | Work setting | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Indiscernible/both | outdoor | Indoor | Indiscernible/both | Manual | Intellectual | Indiscernible/both | Individual | Collective | Indiscernible/both |
| Ata-Aktürk and Demircan (2021a) | **46%** | **19%** | 36% | **34%** | **6%** | 60% | **70%** | **4%** | 25% | **71%** | **4%** | 25% |
| Capobianco et al. (2011) | **58%** | **18%** | 24% | | - | | **72%** | **6%** | 22% | | - | |
| Carr and Diefes-Dux (2012) | | - | | | - | | **69%** | **8%** | 24% | | - | |
| Chou and Chen (2017) | **80%** | **16%** | 4% | 73% | - | | **55%** | **35%** | 10% | | - | |
| Ergun and Balcin (2019) | **87%** | **12%** | 2% | **56%** | **35%** | 10% | **36%** | **44%** | 20% | **87%** | **13%** | 0% |
| Fralick et al. (2009) | **49%** | **13%** | 38% | **32%** | **15%** | 51% | **42%** | **16%** | 42% | **79%** | **21%** | 0% |
| Knight and Cunningham (2004) | 15% | 10% | 75% | | - | | **67%** | **27%** | 6% | | - | |
| López et al. (2013) | **69%** | **23%** | 8% | | - | | - | | | | - | |
| Matusovich et al. (2021) | | - | | | - | | **24%** | **62%** | 14% | | - | |
| Rivale et al. (2020) | **55%** | **17%** | 28% | | - | | - | | | | - | |

Note: Multiple one-sample proportion tests show that frequencies of detectable levels of each category are statistically different, considering a significance threshold of 5%—highlighted in bold. Except for the gender distribution (male/female) in the work of Knight and Cunningham (2004).

Engineers' gender and engineering activity are the most studied domains, followed by the place of work and work setting. We comment that Knight and Cunningham (2004) had an oddly high level of indiscernible gender (75%). Those authors explained that about half of the drawings were "stick figures", which prevented discerning the representation of gender. Additionally, they explain that they observed an unusually higher occurrence of drawings depicting female engineers because two female undergraduate engineering students had worked with those students for a few months before the instrument application.

In this respect, we observed that researchers used stereotypical features associated with gender to analyse the drawings. López et al. (2013) explained that they considered dress, skirt, long hair, painted lips, and long eyelashes as female characteristics. Knight and Cunningham (2004) explained that they regarded short hair, square shoulders, and necktie as male characteristics, while long hair was considered a female trait. Researchers used questions to address gender so that such stereotypical analysis could be avoided. For example, Capobianco et al. (2011, p. 310) used the open-ended question, "Is your engineer a boy or a girl?" Differently, Fralick et al. (2009) demanded that the children give a name to their engineers so that this information could help infer the gender.

Matusovich et al. (2021) plotted a bar chart which shows that students' responses to an open-ended question on what engineers do have a high frequency of intellectual tasks such as design, solving problems, and using math and science. However, analysis associated with their drawings evidenced the verbs building and fixing and the nouns vehicle and tools, which are terms more closely related to manual tasks. Similarly to other studies, blueprints had a much lower occurrence.

In the sequence, we present Figure 7, which shows the aggregated results to account for a mean frequency distribution throughout the reviewed studies regarding students' conception of engineers' gender, place of work, activity, and work setting. Notably, students primarily conceive engineers as males who work individually in manual activities and outdoor environments.


*Figure 7.* Aggregation results regarding students' conception of engineers' gender, place of work, activity, and work setting.

Researchers observed that girls draw more female engineers than boys. However, both girls and boys draw more male engineers in total (Chou and Chen, 2017; Knight and Cunningham, 2004). Despite the difference in gender representation, girls and boys have similar conceptions of engineers and engineering—activity, place of work and work setting (Chou and Chen, 2017).

Moreover, a more significant proportion of students from lower grades represent engineers incorrectly as other professions, such as doctors and bombers, while higher grades demonstrate more accurate views of engineering activity. However, Ergun and Balcin (2019) observed that the frequency of female engineers' portrayed decreased among students from higher grades. Similarly, Chou and Chen (2017) concluded that younger students (4th grade) were more likely to picture female engineers compared to older ones (5th and 6th grades).

Now addressing the interventions enrolled in the reviewed articles, Carr and Diefes-Dux (2012) studied teachers who participated in a professional program designed to increase technological literacy and knowledge of the roles and types of engineers. For that, those teachers engaged in interdisciplinary engineering, math and science activities. Then, teachers were asked to practise at least one engineering design activity in their class. DAET showed that the number of students who conceived engineers as designers increased from 5 to 80 in a pre-post configuration. Qualitatively, the authors observed students portrayed engineers designing various objects such as bicycles, clocks, and a safer playground. They concluded that the teacher training on engineering had a positive outcome since it eventually impacted students' conceptions of engineering.

Additionally, gender representativeness seems influential in students' conception of engineering. Rivale et al. (2020, 22.552.1 to 22.552.12) comment that the gender of the tutor who conducted engineering activities impacted the frequency of female characters' drawings among the girls. According to them, "81% of the girls taught by a female fellow drew a female engineer, compared to 41% of the girls taught by a male fellow".

Notably, depending on the subject and pedagogical approach, engineering activities may reinforce the stereotype of engineering as manual work. For example, Matusovich et al. (2021, p. 894) proposed some engineering activities, such as the maintenance of a flashlight. Throughout the activities, they also reported discussions centred on subjects such as cars and buildings. Afterwards, the authors observed students' images of engineering distanced from cognitive tasks. Such a non-intellectual perception hindered them from seeing engineering as a field connected to other knowledge areas, such as mathematics and science.

> Data revealed an increase in the frequency of responses coded as having the root terms of fix, build, and works on with a decrease in the frequency of the root terms create, help, and design when comparing pre and post-classroom engagement responses. Although low to start with, responses about using math and science and solving problems declined further on the post-test (Matusovich et al., 2021, p. 894).

Some researchers also analysed objects portrayed. Ata-Aktürk and Demircan (2021a), e.g. report that almost half of the drawings presented civil structures such as houses, schools, and roads. Comparatively, design-related objects were found in approximately 6% of them. Likewise, Chou and Chen (2017) highlighted that elementary children tended to draw civil structures and workers with tools such as cranes or drilling machines. The authors pinpoint that few images included design-based architectural engineers who created blueprints for residential buildings.

## Discussions

We aimed to review students' conceptions of engineers and engineering accessed through their drawings. Accordingly, we discuss the results of this literature review regarding the two research questions. Initially, we inquire how students' conceptions of engineers and engineering have been investigated through drawings.

First, we identified a dearth of research investigating students' conceptions of engineering through drawings, especially at the preschool level. One point that explains the literature gap is that engineering was traditionally absent at precollege levels (Moore et al., 2014). In this regard, we high-light the increasing interest in interdisciplinary approaches such as STEAM education—referring to integrating Science, Technology, Engineering, Arts/Humanities, and Mathematics (Marín-Marín et al., 2021; Rodrigues-Silva and Alsina, 2023b). Countries like The United States (NGSS, 2013), Korea (KOFAC, 2012), and Spain (MEFP, 2022) are recently adopting those interdisciplinary approaches in their curricula. This curricular change inherently incorporates engineering at school, which could foster investigations regarding students' conceptions of engineering. Especially addressing the lack of research in preschool, this stage has historically received less attention in research than other educational levels. Preschool is not mandatory in many countries, and it comprises a diversity of organisational formats (Davis, 2009). Such complexity is accompanied by specific ethical considerations to investigate very young children that may discourage some researchers (Abbott and Langston, 2005). Particularly referring to inquiry on students' conceptions of engineering, perhaps some researchers felt the DAET instrument was inappropriate for early children due to its written part. Notwithstanding, we suggest the strategy used by Ata-Aktürk and Demircan (2021a); they assumed preschoolers were illiterate and complemented the instrument with the

Draw-and-tell technique, consisting of informal and quick questions while children draw.

Additionally, we suggest investigations using DAET should be held in different parts of the world since the current ones are concentrated in the United States. Different cultural and socio-economic backgrounds can influence children's conception of engineering. Some researchers, for instance, observed that children's native language impacts children's understanding of engineering activities (Chou and Chen, 2017; Knight and Cunningham, 2004; López et al., 2013).

We highlight that many studies underwent quantitative research, including comparison groups, cohort (cross-age) or pre-post-test designs. However, they generally identified their methods as qualitative approaches and lacked statistical tests. In those cases, we suggest that authors embrace mixed research methodologies—while having qualitative data nature, they ought to use appropriate hypothesis testing if enrolling in such designs. Additionally, DAET could complement other research instruments to understand children's engineering conception comprehensively. Some studies have already applied complementary interviews (Capobianco et al., 2011; Chou and Chen, 2017). Likewise, researchers could combine it with concept mapping, focus groups, and surveys. Beyond the instruments mentioned, we highlight the potentiality of incorporating DAET in case studies that explore children's involvement in engineering-related activities. Accordingly, field observations, video recordings, and evaluations of their productions could provide valuable insights into their engineering conceptions.

Regarding the data collection instrument, the authors made minor modifications in the DAET, mainly regarding the complementary questions about the drawing. We suggest that, once children have finished their drawings, authors should consider using complementary questions about students' conception of gender, place of work, activity, and work setting portrayed. That way, researchers prevent applying bodily stereotypes such as long hair, eyelashes, and clothing to analyse portrayed genders. In addition, the indiscernible information rate will probably reduce.

In this same direction, Thomas et al. (2020, 2016) proposed a modified version of DAET, which explores students' opinions about how engineering is connected to mathematics and science. This contour may be attractive considering educational approaches such as STEAM education, which proposes integrating Science, Technology, Engineering, Arts/Humanities, and Mathematics knowledge areas (Perignat and Katz-Buonincontro, 2019). Additionally, using DAET consistently, such as adopting their version, would enhance the comparability of results among future studies.

For this literature review, we also query—what are students' conceptions of engineers and engineering? Overall, researchers concluded that students conceive engineers as males who work individually in manual activities and outdoor environments. Those conceptions are observed from a very early age, and they are likely to be a response to different sources of information. In this vein, the literature has shown that children's picture books carry misconceptions and gender stereotypes about engineers and engineering (Ata-Aktürk and Demircan, 2021b).

We verified that researchers qualified and quantified various actions related to engineering—such as fixing, constructing, observing and designing—but their conclusions were commonly centred on whether portrayed engineers were pursuing manual or intellectual tasks. Even though engineering may sometimes be involved in manual actions or processes, engineers are not likely to be those who physically execute them. Accordingly, we suggest differentiating one simple product construction from conceiving a product that will be reproduced. The former is more connected to crafting, while the latter relates to engineering design.

The reviewed studies showed that older students perceive engineers more accurately as designers. Cohort studies with appropriate statistical comparisons are needed to check whether older students tend to view engineering as a collective, intellectual, and indoor activity. However, studies already point out that gender stereotypes intensify with age. Those findings reinforce the urge to address Education for Sustainability (EfS) since Early Childhood Education (ECE) (Rodrigues-Silva and Alsina, 2023a; UNESCO, 2008), precisely the sustainable development goal of pursuing gender equity (United Nations, 2015). In this sense, while studies with DAET evidence gender stereotypes, to an extent, they indicate the necessity of developing strategies to inverse the critical gender inequality in technical areas. Ata-Aktürk and Demircan (2021a), for example, evidenced that picture books for children aged 3 to 6 years from Turkey mainly represent engineers as male characters. Accordingly, the authors suggest increasing children's contact with cultural content developed through a gender-inclusive prism. In a similar direction, Knight and Cunningham (2004) indicated that exposing children to female engineers' role models likely increased their perception of women in engineering. Furthermore, parents' and teachers' conceptions of engineering should be explored and developed so children's environment and social interaction do not transmit and reinforce gender stereotypes—studies utilising DAET with teachers observed they similarly represent more male engineers (Vo and Hammack, 2022).

Teacher education is vital for effectively addressing and challenging these stereotypes in engineering. Literature warns that poorly planned activities in engineering worsen stereotypical gender (Fleer, 2021; Matusovich et al., 2021). Gender equality concerns could be incorporated into teacher training programs focused on developing teachers' STEAM planning ability (Rodrigues-Silva and Alsina, 2022).

STEAM education fundamentally requires beyond diagnosticating students' conceptions of engineers and engineering and providing pedagogical strategies to develop such conceptions. In this sense, Moore et al. (2014) recommend a framework wherein they claim the conception of engineers and engineering must be a topic for precollege engineering teaching.

Therefore, there is a need for activities that enhance the conceptions of engineering. Knight and Cunningham (2004) incentivised the teacher applying the DAET to seize the opportunity and have a discussion class about engineering after the students responded to the instrument. In this vein, Silva-Hormazábal, Rodrigues-Silva and Alsina (2022) proposed a STEAM activity wherein students from primary education responded to the DAET and then enrolled in a statistical investigative cycle. Children formulated hypotheses and analysed their drawings in class. For that, students count the frequency of similar categories presented in this review, such as gender, and eventually, they discuss the results.

Studies show that teachers lack knowledge about STEAM as an educational approach (López et al., 2021). Overall, the literature in STEAM education carries misconceptions of engineering and frequently reduces it to crafting. Specifically, teachers report unfamiliarity and difficulty integrating engineering and technology into their lesson plans (Rodrigues-Silva and Alsina, 2022). In this sense, studies using DAET showed teachers present similar misconceptions of engineers and engineering of those to the students (Hammack and Vo, 2019; Vo and Hammack, 2022). Notwithstanding, we should highlight that an inappropriate pedagogical approach to engineering may induce misconceptions about it. This unintended effect occurred, for example, with the interventions reported by Matusovich et al. (2021), wherein students did activities such as fixing flashlights and discussing cars and civil constructions. Pre and post-test indicated that more students perceived engineering as manual work. In this case, the pedagogical planning of those activities failed to remark that engineers are involved with electrical devices, machinery, and civil structures, but their activity is not about manually fixing or constructing them. On the contrary, engineers deal with intellectual tasks such as designing electrical devices, machinery, and civil structures; and planning and supervising production and maintenance processes.

## Conclusions

The major contribution of this study is providing an overview of the investigation of children's conceptions of engineering through their drawings. There were no similar previous systematic reviews, and related work concerns empirical studies which address specific regional contexts.

The results of this review allow drawing some conclusions on exploring children's conceptions of engineers and engineering:

- There is a dearth of studies investigating students' conceptions of engineering through drawings;
- Researchers should converge DAET instructions to help comparability of results and prevent misguided analysis such as applying stereotypes to identify genders;
- Researchers undergo complex research designs such as comparison groups, cohort (cross-age) or pre-post-test using DAET. However, those studies frequently lack appropriate statistical tests;
- At a very early age, children already exhibit misconceptions or stereotypes of engineering as a profession of men working individually in manual activities and outdoor environments;
- Teachers must have the proper training to embrace precollege engineering activities. Otherwise, they will likely enrol in poorly designed activities that worsen misconceptions about engineering.

The study provides exciting insights for research and educational practices, especially considering the current interest in engineering in interdisciplinary STEAM education and the aspiration of a sustainable society which pursues gender equity. Among the future directions, we highlight using the draw-and-tell technique for more studies in preschool age. Consistently writing DAET instructions and questions for drawings descriptions, such as proposed by Thomas et al. (2020, 2016) version, to enhance comparability among the studies. Asking children directly about the gender portrayed prevents applying stereotypes to infer gender representations. Finally, conceiving activities explicitly addressing engineering and placing it more accurately as an intellectual practice instead of one product construction such as crafting.

## Acknowledgements

We acknowledge the Federal Institute of Education, Science and Technology of Minas Gerais (IFMG) for the qualification license that enabled this research.

**Conflict of interests**
The authors declare no conflict of interest.

## Author Contributions

Conceptualization, J.R.-S. and Á.A.; methodology, J.R.-S. and Á.A.; formal analysis, J.R.-S.; writing—original draft preparation, J.R.-S.; writing—review and editing, Á.A.; supervision, Á.A. All authors have read and agreed to the published version of the manuscript.

## References

Abbott, L., & Langston, A. (2005). Ethical research with very young children. inA. Farrell, (Ed.), *Ethical Research with Children*. (pp.37-48). Maidenhead, England; New York, USA: Open University Press.

Ata-Aktürk, A., & Demircan, H. Ö. (2021a). Engineers and engineering through the eyes of preschoolers: a phenomenographic study of children's drawings. *European Early Childhood Education Research Journal*, 1–20. https://doi.org/10.1080/1350293X.2021.1974067

Ata-Aktürk, A., & Demircan, H. Ö. (2021b). An Analysis of Picture Books for Children Aged 3 to 6 Years: Portrayals of Engineers and the Engineering Design Process. *International Journal of Early Childhood, 53*(3), 261–278. https://doi.org/10.1007/s13158-021-00294-8

Aurava, R., & Meriläinen, M. (2022). Expectations and realities: Examining adolescent students' game jam experiences. *Education and Information Technologies, 27*(3), 4399–4426. https://doi.org/10.1007/s10639-021-10782-y

Cabello, V. M., Martinez, M. L., Armijo, S., & Maldonado, L. (2021). Promoting STEAM learning in the early years: "Pequeños Científicos" Program. *International Journal on Math, Science and Technology Education, 9*(2), 33–62. https://doi.org/10.31129/LUMAT.9.2.1401

Capobianco, B. M., Diefes-dux, H. A., Mena, I., & Weller, J. (2011). What is an Engineer? Implications of Elementary School Student Conceptions for Engineering Education. *Journal of Engineering Education, 100*(2), 304–328. https://doi.org/10.1002/j.2168-9830.2011.tb00015.x

Carr, R., & Diefes-Dux, H. (2012). Change in Elementary Student Conceptions of Engineering Following an Intervention as Seen from the Draw-an-Engineer Test. *2012 ASEE Annual Conference & Exposition Proceedings*, San Antonio, Texas. 25.299.1-25.299.12. https://doi.org/10.18260/1-2--21057

Chambers, D. W. (1983). Stereotypic images of the scientist: The draw-a-scientist test. *Science Education, 67*(2), 255–265. https://doi.org/10.1002/SCE.3730670213

Chou, P. N., & Chen, W. F. (2017). Elementary school students' conceptions of engineers: A drawing analysis study in Taiwan. *International Journal of Engineering Education, 33*(1), 476–488.

Davis, J. (2009). Revealing the research 'hole' of early childhood education for sustainability: a preliminary survey of the literature. *Environmental Education Research, 15*(2), 227–241. https://doi.org/10.1080/13504620802710607

Diefes-Dux, H. A., & Capobianco, B. M. (2011). Interpreting elementary students' advanced conceptions of engineering from the Draw-an-Engineer Test. *2011 Frontiers in Education Conference*, USA, F3J-1-F3J-2. https://doi.org/10.1109/FIE.2011.6142936

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

Fleer, M. (2021). When preschool girls engineer: Future imaginings of being and becoming an engineer. *Learning, Culture and Social Interaction, 30*(PB), 100372. https://doi.org/10.1016/j.lcsi.2019.100372

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

Guyotte, K. W. (2020). Toward a Philosophy of STEAM in the Anthropocene. *Educational Philosophy and Theory, 52*(7), 769–779. https://doi.org/10.1080/00131857.2019.1690989

Hammack, R. J., & Vo, T. (2019). Development of the draw-an-engineering-teacher test (DAETT) (work in progress). *2019 ASEE Annual Conference & Exposition*, Tampa, Florida.

Knight, M., & Cunningham, C. (2004). Draw an Engineer Test (DAET): Development of a tool to investigate students' ideas about engineers and engineering. *2004 ASEE Annual Conference Proceedings*, Salt Lake City, Utah. https://doi.org/10.18260/1-2--12831.

Korea Foundation for the Advancement of Science and Creativity (KOFAC). (2012). *Hand-knuckle STEAM education*. Seoul, Republic of Korea: KOFAC.

Lawson, T. R., Faul, A. C., & Verbist, A. N. (2019). Research and statistics for social workers. In *Routledge Taylor & Francis Group*. https://doi.org/10.4324/9781315640495

López, C. C., Hernández Hernández, A., Lopez-Malo, A., & Palou, E. (2013). Eliciting Incoming Engineering Students' Images of Engineering and Engineers at Two Mexican Institutions. *2013 ASEE Annual Conference & Exposition Proceedings*, Atlanta, Georgia, 23.475.1-23.475.9. https://doi.org/10.18260/1-2--19489

López, P., Rodrigues-Silva, J., & Alsina, Á. (2021). Brazilian and Spanish mathematics teachers' predispositions towards gamification in STEAM education. *Education Sciences, 11*(10), 618. https://doi.org/10.3390/educsci11100618

Marín-Marín, J.-A., Moreno-Guerrero, A.-J., Dúo-Terrón, P., & López-Belmonte, J. (2021). STEAM in education: a bibliometric analysis of performance and co-words in Web of Science. *International Journal of STEM Education, 8*(1), 41. https://doi.org/10.1186/s40594-021-00296-x

Matusovich, H. M., Gillen, A. L., Montfrans, V. van, Grohs, J., Paradise, T., Carrico, C., Lesko, H. L., & Gilbert, K. J. (2021). Student Outcomes from the Collective Design and Delivery of Culturally Relevant Engineering Outreach Curricula in Rural and Appalachian Middle Schools HOLLY. : *International Journal of Engineering Education, 37*(4), 884–899.

Ministerio de Educación y Formación Profesional (MEFP) (2022). Real Decreto 157/2022, de 1 de marzo, por el que se establecen la ordenación y las enseñanzas mínimas de la Educación Primaria. Madrid, Spain: MEFP. https://bit.ly/3MWojuA

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews, 4*(1), 1. https://doi.org/10.1186/2046-4053-4-1

Moore, T. J., Glancy, A. W., Tank, K. M., Kersten, J. A., Smith, K. A., & Stohlmann, M. S. (2014). A Framework for Quality K-12 Engineering Education: Research and Development. *Journal of Precollege Engineering Education Research, 4*(1). https://doi.org/10.7771/2157-9288.1069

NGSS Lead States (2013). Next Generation Science Standards: For States, by States. Washington DC, USA: The National Academies Press. Retreived from https://nap.nationalacademies.org/catalog/18290/next-generation-science-standards-for-states-by-states

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity, 31*(October 2018), 31–43. https://doi.org/10.1016/j.tsc.2018.10.002

Piaget, J., & Inhelder, B. (1971). Mental Imagery in the Child: A Study of the Development of Imaginal Representation. *British Journal of Educational Studies, 19*(3), 343. https://doi.org/10.2307/3120455

Rivale, S., Yowell, J., Aiken, J., Adhikary, S., Knight, D., & Sullivan, J. (2020). Elementary Students' Perceptions of Engineers. *2011 ASEE Annual Conference & Exposition Proceedings*, 22.552.1-22.552.12. https://doi.org/10.18260/1-2--17833

Rodrigues-Silva, J., & Alsina, Á. (2022). Effects of a practical teacher-training program on STEAM activity planning. *Revista Tempos e Espaços Em Educação, 15*(34), e17993. https://doi.org/10.20952/revtee.v15i34.17993

Rodrigues-Silva, J., & Alsina, Á. (2023a). STEM/STEAM in Early Childhood Education for Sustainability (ECEfS): a systematic review. *Sustainability, 15*(4), 3721. https://doi.org/10.3390/su15043721

Rodrigues-Silva, J., & Alsina, Á. (2023b). Conceptualising and framing STEAM education: What is (and what is not) this educational approach? Texto Livre. In press.

Silva-hormazábal, M., Rodrigues-Silva, J., & Alsina. (2022). Conectando matemáticas e ingeniería a través de la estadística : una actividad STEAM en educación primaria. *Revista Electrónica de Conocimientos, Saberes y Prácticas, 5*(1), 9–31. https://doi.org/10.5377/recsp.v5i1.15118

Thomas, J., Colston, N., Ley, T., DeVore-Wedding, B., Hawley, L., Utley, J., & Ivey, T. (2016). Fundamental Research: Developing a Rubric to Assess Children's Drawings of an Engineer at Work. *2016 ASEE Annual Conference & Exposition Proceedings*, New Orleans, Louisiana. https://doi.org/10.18260/p.26985

Thomas, J., Hawley, L. R., & DeVore-Wedding, B. (2020). Expanded understanding of student conceptions of engineers: Validation of the modified draw-an-engineer test (mDAET) scoring rubric. *School Science and Mathematics, 120*(7), 391-401. https://doi.org/10.1111/ssm.12434

UNESCO. (2008). The contribution of early childhood education to a sustainable society. In I. Pramling Samuelsson & Y. Kaga (Eds.) *The Role of Early Childhood Education for a Sustainable Society*. Paris, France. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000159355

United Nations. (2015). Transforming Our World: the 2030 Agenda for Sustainable Development United Nations. In *United Nations*, New York, USA. Retrieved from https://wedocs.unep.org/20.500.11822/9814

Vo, T., & Hammack, R. (2022). Developing and Empirically Grounding the Draw-An-Engineering-Teacher Test (DAETT). *Journal of Science Teacher Education, 33*(3), 262–281. https://doi.org/10.1080/1046560X.2021.1912272