Assessing Children's Understanding of the Work of Computer Scientists: The Draw-a-Computer-Scientist Test

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ABSTRACT

We developed the Draw-A-Computer-Scientist-Test (DACST) to better understand elementary school students' conceptions of computer scientists and the nature of their work. By understanding how young children perceive computer scientists, we can broaden their ideas about the activities and images of computer scientists. We administered the DACST to 87 fourth-grade students (ages 8-9) as a pre- and post-assessment to a computer science curriculum. All students attended the same school and were taught by the same female teacher. Before the curriculum, we found that students most often drew male computer scientists working alone, and featured actions that were connected to technology in general (e.g., typing, printing), but not specific to computer science. After the curriculum, more female students drew female computer scientists than before, and the featured actions were more specific to computer science (e.g., programming a game). We also share insights about the classroom-learning environment that may have contributed to changes in students' understanding of computer scientists and their work.

Keywords Computer science education; computer scientists; elementary school

1. INTRODUCTION

Computer programming provides avenues for young students to creatively express their ideas and interests using technology. With the recent increase of graphical, block-based programming environments, more students are starting to code at a younger age [1, 2]. This fervor around coding recently increased with President Obama's call for "Computer Science for All." This initiative aims to increase the available opportunities that young students have to code, empowering the next generation of American students with the computing skills necessary to thrive in a digital economy [3].

Much work has been done to ensure that computer programming environments are developmentally appropriate for younger age groups [4, 5, 6, 7], however, concerns still exist around ensuring novice programming experiences are equitable for all students, regardless of gender, ethnicity, language, socioeconomic status or

previous exposure to technology [8, 9, 10]. This is in part due to the fact that the field of computer science is still vastly unrepresentative of the larger population in terms of ethnicity and gender. To encourage underrepresented populations to pursue computer science requires that these students both have the confidence in their abilities to do so (hence, our focus on teaching programming in schools), and an understanding of computer science as a field that will be interesting and welcoming to them.

While many studies have reported positive results when teaching introductory programming to small groups of students in isolated settings [7, 11], more attention needs to focus on uncovering what young students think about computer scientists and the nature of computer science. Research indicates that early interest in the STEM disciplines greatly increases a student's likelihood to pursue a STEM career in the future [12]. By understanding what young students think about computer scientists, we can broaden their ideas about the activities and perceptions of computer scientists, potentially allowing students to more readily see themselves as a computer scientist (or, at the very least, capable of pursuing computer science in the future, should they choose).

In order to gauge how students perceived computer scientists, we adapted the Draw-A-Scientist-Test (DAST) [13] for computer science. The DAST and later the Draw-A-Scientist-Checklist (DAST-C) have been used to understand students' perceptions of professional scientists, albeit often stereotypical perceptions [14]. This activity has also been adapted for engineers [15, 16, 17]. With similar goals to the DAST, we sought to investigate how young students thought about computer scientists, particularly images of computer scientists and attributes of computer scientists' work. We piloted a computer science version in earlier work [18]. In this paper, we introduce a revised version of the instrument and report on findings from using the tool with 4th graders (ages 9-10) *before* and *after* these students participated in a computer science curriculum.

The paper is organized as follows. In section 2, we share relevant and related work. Section 3 discusses the research methods and data analysis. Finally, findings are presented in Section 4, with implications shared in the discussion.

2. RELATED WORKS

In the following section, we provide an overview of related literature that informed our research design in this study.

2.1 Drawing a scientist and engineer

Over the past fifty years, a growing body of research has been conducted on how people, especially students, perceive scientists and their work [14]. In early work by Mead and Metraux [19],

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35,000 high school students were asked to write an essay to describe their views of a scientist. The resulting analysis found that students often reported stereotypical images of scientists (e.g., White/European American, male, lab coat, working in a lab). Building off two decades of research in this area, Pion and Lipsey [20] concluded that often these images of science and scientists distorted the reality of who scientists actually are and what they do in the field, possibly discouraging students from pursuing a career in science if they differed from the stereotypical images.

To assess conceptions of younger students, Chambers [13] developed the Draw-a-Scientist-Test (DAST). Chambers asked 4,807 elementary students (grades K-5; ages 5-11) to draw a scientist. Researchers analyzed the drawings for the presence/absence of certain features: symbols of research, symbols of knowledge, visible attributes of the scientist (e.g., gender, ethnicity, clothing), and mythic stereotypes (e.g., Frankenstein, “mad scientists”). This analysis worked to refine common attributes that young students associate with being a scientist, primarily male (only 28 out of 4,807 students drew females), white lab coats, eyeglasses, facial hair, scientific instruments, technology, and signs of secrecy or danger [13].

The Draw-an-Engineer-Test (DAET) – modified after the DAST – prompts students to draw an engineer and include written responses to describe their engineer [17]. Fralick et al. [21] later used the DAET with over 1,800 elementary school students. Analysis revealed that when students included a person in their drawing, 50% were male while only 13% were female. The rest did not clearly indicate a gender. Additionally, common physical attributes included laborer’s clothing (e.g., overalls), glasses or goggles, and unkempt (“crazy”) hair. Students included objects such as vehicles, structures, and tools, and they drew engineers building with their hands or engaging in activities representative of blue-collar jobs such as auto mechanics and construction [21]. This suggests that young students often have inaccurate perceptions of what engineers do, potentially impacting their later career choices [22, 23, 24].

2.2 Student perceptions of computers

More recently, Grover et al. [25] investigated 20 middle school students’ perceptions of what a computer is by asking students enrolled in an introductory CS course to post responses in an online discussion board. Researchers were particularly interested in understanding commonly held notions of what a computer is, and what types of devices qualify as “computers.” The middle school students initially tended to report that a computer must be a certain size (i.e., a desktop computer is much larger than a phone, so a phone must not be a computer), although opinions changed throughout the online discussion. General consensus was reached, with middle school students concluding that a computer was based on its features (e.g., wifi connectivity, multiple uses), rather than size.

Grover compared the middle school responses to 117 high school students enrolled in the Exploring Computer Science (ECS) curriculum. On an end-of-unit assessment, students were asked if they thought a microwave qualified as a computer. Results indicated that 90% of students thought a microwave was a computer, but only 2% were able to list correct characteristics as justification (e.g., accepts input, stores information, etc.). Overall, researchers concluded that asking students about a computer caused a misplaced focus on the device, as opposed to the act of computing, and that the definition of a computer is confusing when considering varied types of devices.

2.3 Student perceptions of computer users

While we found no existing studies that asked young students to draw computer scientists, Mercier et al. [26] analyzed middle school students’ (aged 11-14) drawings of computer users. The most common item drawn was a man wearing glasses. Follow-up interviews conducted with a subset of students revealed that over 75% of students described a “computer-type” person. Such individuals were knowledgeable about computers, motivated to learn about computers, and spent a great deal of time working on computers. The majority of students did not view themselves as “computer-type” persons.

2.4 Student perceptions of computer scientists

Some studies have investigated student perceptions of computer scientists at the university level. Cheryan et al. [27] asked 118 undergraduates to “Describe a computer science major” on a questionnaire. They identified a number of stereotypes about computer scientists, such as that computer science majors were technology-oriented, singularly focused on computers, lacked interpersonal skills, intelligent, male, and with specific physical features (pale skin, abnormal body weight) and attire (glasses). Additionally, Cheryan et al. [27] found that undergraduate descriptions of computer science majors consisted of traits that may be incompatible with the female gender role, such as anti-social behavior and an unhealthy fixation on computers. This is similar to the arguments made by Lewis [28] regarding the development of the computing profession, which has a long history of deterring women from entering the profession.

Martin [29] asked incoming freshmen enrolled in an introductory computer science course: (1) what is computer science? and (2) to draw a computer scientist. Results indicated that these students most often drew “white males in various degrees of ‘geekiness.’” Drawings that were labeled as including levels of “geekiness” were described as including features such as glasses, pocket protectors, messy hair, acne, etc. Martin concluded that, “CS has a fundamental image problem.”

Hewner and Guzdial [30] analyzed autobiographical accounts of computer science majors compared to non-computer science majors. Computer science majors with a positive conception of computer science often viewed computing as fun and useful, as an interesting technology, and as intellectually stimulating. However, it was indicated that introductory computer science courses did not have a large effect on changing negative attitudes about computing, indicating that more work is needed earlier on in academic careers to expose individuals to computer science in a positive manner.

Grover et al. [31] investigated perceptions of computer scientists among 26 middle school students (ages 12-14) before and after these students had completed a 6-week computer science curriculum. Pre-assessments revealed that many students associated computer science with notions of fixing, building, and studying; whereas post-assessment results revealed that more students were apt to depict computer science as problem solving. This indicates that computer science curriculum can help younger students more accurately understand the nature of computer science.

Across all these studies is the consistent thread that computer scientists, computer science majors, and computer users are white, male and associated with “geekiness.” Yet, with one exception of the study of middle school students, these studies were all conducted with young adults or older. Understanding younger children’s views will help identify when this stereotype begins.

3. Methods

During the 2014-2015 academic year, we created and piloted the Draw-A-Computer-Scientist-Test (DACST) with 185 students in fourth-sixth grade (ages 8-11) [9]. These students completed the DACST after participating in approximately 12 hours of an introductory computer science curriculum [6] that featured block-based programming, similar to Scratch [7].

In the subsequent academic year (2015-2016), we repeated a similar activity and analysis with students, but with two main changes. First, the prompt was modified. Instead of asking students to draw a computer scientist *programming*, we asked students to draw a computer scientist *working*. We hoped this change would better elicit the students' ideas about what computer scientists did. Second, the activity was given to students as a pre-assessment, before they began any official computer science curriculum in their classrooms. We hoped this change would decrease the impact that our curriculum had on the responses students provided. Additionally, this allowed us to also give the same activity as a post-assessment, after students had completed the curriculum. Our research questions for the follow-up study presented here were as follows:

- How do elementary school students conceptualize computer scientists?
- How do elementary school students conceptualize the work of computer scientists?
- How does our computer science curriculum impact student conceptions of a computer scientist?

The revised prompt was given to 87 fourth grade students (aged 8-9) who attended the same school and were taught computer science by the same female teacher. These students had no prior experience with our computer science curriculum. The DACST was administered by the classroom teacher, without researchers present. The participating school had approximately equal numbers of male and female students. The majority of enrolled students identified as either Hispanic (46%) or White (47%). Approximately 40% of students at this school qualify for free or reduced lunch (a proxy for socioeconomic status).

3.1 Data Analysis

A preliminary coding scheme was developed for analysis after reviewing a subset of the drawings, which was further refined through group discussion. Multiple rounds of coding were conducted on subsets of the drawings by researchers, with each round refining the coding scheme. In the final coding scheme, drawings were coded for the following: observable demographic information (e.g., gender), worn accessories (e.g., glasses), emotionality (as depicted in speech or thought bubbles), technologies included, the setting (e.g., classroom, garage), the title (e.g., computer scientist, scientist), actions (e.g., coding, fixing), and the object of the actions (e.g., computer, website). The final scheme was used by multiple researchers individually before coming together to check for inter-rater reliability. When codes differed, researchers discussed until consensus was reached. Finally, all drawings were coded for the presence or absence of the characteristics described above.

It is important to note that researchers refrained from coding their personal assumptions or inferences. For example, gender was only coded if a student included an explicit gender-specific pronoun in the written description (e.g., "he", "she"). Additionally, student drawings were sometimes coded more than once per category. For example, a student who wrote their computer scientist was

programming a game for a website was coded for "programming" as the action, but as both "game" and "website" for the object.

4. FINDINGS

In this section, we share the results of our analysis. Results are organized by research question, and separated into two main sections: pre-CS curriculum and post-CS curriculum.

4.1 Pre-CS Curriculum

Before students completed any formal instruction in computer science, they were asked to draw an image of a computer scientist working and describe what was going on in the picture. Pre-assessment results are shared below.

4.1.1 Who is a computer scientist?

Depictions of computer scientists matched common stereotypes. Seven percent of student drawings featured a bald computer scientist, and 4% of drawings featured a computer scientist wearing glasses. Other findings are shared below. Please note that while the following subheadings may seem definitive, there was, of course, variation observed across student responses. The subheadings reflect common student responses.

Computer scientists are male

On the pre-assessment, 71% of students drew a male computer scientist, while only 27% drew a female computer scientist. The remaining 3% of student drawings were not coded for gender because the images were unclear (e.g., stick figure drawings and no gender-specific pronoun in the written description.) These results are consistent with the results from the pilot study conducted the previous academic year.

Computer scientists have a mean age of 25

Despite not prompting students to include an age of their computer scientist, 17% of students did so. When a specific age was mentioned, the mean age was 25 years old, and the mode was 30. Several students referred to their computer scientist as a "college student." In one example, a student wrote, "A computer scientist can be anyone. A boy, a girl, or a kid."

4.1.2 What do computer scientists do?

Figure 1. Drawings of a computer scientist working alone (left) and collaboratively (right).

Computer scientists work alone

Similar to results from the pilot study, 90% of students drew computer scientists working alone, in isolation. In one extreme example, a student drew a computer scientist working in an empty computer lab, and wrote, "She is the only one working." In contrast, only 10% of students drew more than one computer scientist working together. See Figure 1 for examples of both. This finding may be a result of the prompt that asked students to draw "a computer scientist," implying one individual.

Computer scientists predominantly use computers

When considering the technologies that students included in their drawings, not surprisingly 82% of students drew a computer (either a desktop or a laptop), and 27% of students drew multiple computers. Fewer students drew phones (3%), printers (2%) and tablets (1%).

Computers scientists perform a vague set of tasks

Based on the verbs used in the written descriptions of pictures, commonly reported actions of computer scientists included *working* (23%), *coding* (18%), *making* (16%), *typing* (9%), *doing* (7%), *looking* (7%), *fixing* (7%), and *testing* (6%). When considering the object that the computer scientists were working on/coding/making, common responses included *computers* (26%), *ideas* (18%), *games* (7%), and *science experiments* (7%).

Computer scientists are often scientists who use computers

A compelling finding that was not present in the pilot study was that roughly 25% of students referred to their computer scientist as a *scientist*, without the qualifier of “computer”. Many of these students also drew objects (e.g., lab coats, beakers filled with chemicals, explosions, etc.) that indicated they confused the term computer scientist with other types of scientists (see Figure 2).

Figure 2. A drawing demonstrating the confusion between “scientist” and “computer scientist.”

4.2 Post-CS Curriculum

After students completed roughly 12 hours of programming instruction within a block-based environment, they were asked to repeat the same activity: draw a computer science working, and describe what is going on in the picture. Note that the curriculum did not address explicitly who could be a computer scientist or stereotypes. Post-assessment results are shared below, with considerations for how the results differed from the pre-assessment and how computer science curriculum within the school may have impacted the differences observed.

4.2.1 Who is a computer scientist?

Computer scientists can be male or female

After the computer science instruction, the percentage of drawings featuring a male computer scientist dropped from 71% to 51%, whereas the number featuring females increased from 27% to 31%. One possible explanation for this could be related to the gender of the teacher; a female teacher taught all participating students computer science. There was also an increase in the number of drawings that were unclear for gender (3% to 20%).

For some of these drawings, only a computer screen was visible; in others, non gender-specific pronouns were used in the written description, and, thus, were not coded for gender.

Seven percent of students changed from an initial drawing with a *male* to a drawing with a *female*; all of these students were female. Considering that computer science is a male-dominated profession, this is a promising finding because it indicates that computer science experiences in school can change student perceptions about the field, allowing students to more readily see themselves as computer scientists. Figure 3 depicts a pre- and post-assessment for one student who displayed this change. In the pre-assessment, this female student drew a picture of a male computer scientist working and wrote, “This man is working on this computer writing some notes.” In her post-assessment drawing, this student drew a female computer scientist, and wrote, “In my picture, she is working on Sandbox” (part of the programming environment used by students in the classroom).

Figure 3. Pre- (left) and post-assessment (right) results for one student who changed the gender depicted.

Computer scientists are increasingly bald and bespectacled

The number of bald computer scientists increased from 7% in the pre-assessment to 17% in the post-assessment. The number of computer scientists that featured glasses also increased from 4% to 7% in the post-assessment. This increase was surprising, but could possibly be explained based on videos that the teacher showed students during class, some of which featured computer scientists who were bald or wearing glasses.

Computer scientists have positive emotions

Interestingly, while we were unable to code for emotional expression in most pre-assessment drawings, 7% of students indicated positive emotions in their post-assessment drawings. For example, these students often included speech or thought bubbles in their drawings with exclamations such as, “I love coding!” or “This is fun.” This is promising because it indicates the learning experiences that occur in a classroom can impact and shape students’ perceptions of computer science. Unlike the pilot study, no students included any indication of a negative emotion (such as frustration or anger) related to computer science.

4.2.2 What do computer scientists do?

Similar to the pre-assessment results, the vast majority of students still drew computer scientists working in isolation. While the number of drawings featuring collaboration increased from 10% to 14%, the increase was not significant. While this may be an artifact of the instrument prompt, it is potentially indicative of how the classroom was structured and operated. Typically, students worked through each programming activity individually. While they were not prevented from sharing ideas or discussing with a nearby peer, it was not a requirement to do so. This might imply that young students should be encouraged to work collaboratively through programming activities to create more

accurate conceptions (and prevent possible stereotypes that might deter some students from pursuing computer science).

Computer scientists use computers, some with peripherals

When considering the technologies that students included in their drawings, more students (93%) included a computer in the post-assessment than the pre-assessment (82%). While fewer students (15%) included multiple computers on the post-assessment, there was an increase in other types of technologies drawn. For example, 10% of students included a technology that was outside of the original coding scheme (such as speakers and headphones), which was an increase from the pre-assessment. This could be due to the fact that students were provided headphones during programming activities in class so they could use the read-aloud function for task instructions.

Computer scientists mostly program

Student conceptions of the work of computer scientists increased in sophistication between the pre- and post-assessment, as indicated by their vocabulary in the written descriptions. In the pre-assessment, students often used general words to describe the actions of computer scientists; such as working, playing, typing, researching or fixing. In the post-assessment, while the frequency of *working* and *making* remained similar, the use of *coding* and *programming* increased to 40% (vs. 18%). These more specific vocabulary words were connected to reasonable items (such as coding on a computer, or programming a website). We noticed this change in 27% of students' drawings when comparing their pre- and post-assessment results.

When considering the product of the actions depicted, results differed from the pre-assessment. The percentage of students who explicitly wrote their computer scientist was working on a computer increased from 26% to 47%. Additionally, more students (16%) mentioned games compared to pre-assessment results (7%), as well as websites (24% vs. 4%). Recall that students' drawings were sometimes coded as including more than one product, so reported percentages may not equal 100.

Figure 4. A post-assessment student drawing depicting a teacher leading a computer science lesson.

Computer scientists program in block-based languages

Many students drew the website and/or programming language that was taught to them during computer class. Perhaps an unsurprising finding, in the pre-assessment results there was no mention of the specific curriculum or programming language used with the students, yet 29% of students included this in their post-assessment, which is similar results to the initial pilot study. Additionally, in contrast to the pre-assessment results, 11% of students indicated that their computer scientist was either teaching or learning computer science (see Figure 4). This speaks to the importance of what and how computer science is taught in school. Early experiences in computer science can motivate a student's desire to pursue this discipline later in life, which is why it is

crucial to understand student conceptions at an early age and how classroom-learning experiences may shape this.

Computer scientists are not scientists

When considering pre-assessment results, 38% of student drawings were coded as potentially including scientific symbols or written descriptions (e.g., beakers, chemicals, researching animals or space, etc.). Additionally, roughly 25% of these students used the word *scientist* instead of computer scientist in their written descriptions. However, these numbers decreased in the post-assessment. Only 18% of students used the term *scientist* instead of computer scientist in their written descriptions. Furthermore, only 6% of these students' drawings were coded as including scientific content (e.g., lab coats, beakers). This discrepancy suggests that students demonstrated a more accurate understanding of the work of computer scientists, despite some students still using the term *scientist*. Figure 5 is an example of a student drawing that used the word *scientist*, but was coded as depicting actions of a computer scientist.

Figure 5. Post-assessment drawing that used the term *scientist* to describe work associated with computer scientists. Student wrote, "This scientist is programming a drone."

5. DISCUSSION

As coding becomes more prevalent, and integrated into the school day, it is crucial that we understand young students' conceptions of computer scientists. By understanding student perceptions of stereotypical computer scientists, we can broaden their ideas about the activities and images of computer scientists. This work serves as another step in uncovering what, specifically, young children think about computer science. It is particularly noteworthy because this instrument was administered before and after a computer science curriculum, indicating how the specific curriculum, programming environment, and classroom may have impacted student conceptions.

We also consider the instrument itself, the DACST, as an important contribution to the field of computer science education. One possible revision that may elicit additional information from students is to have students write a story about their computer scientists to accompany the picture, instead of just a short description. Writing a narrative may elicit increased information that was missed in a short description.

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