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Engineering and Computational Thinking Talent in Middle School Students: a Framework for Defining and Recognizing Student Affinities

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***Abstract*— In this paper we describe our process for synthesizing frameworks for recognizing student talents in the areas of Computational Thinking (CT) and Engineering Design (ED) from prior research. Computer science education research has resulted in multiple, overlapping definitions of CT as an approach towards solving problems using methods and tools that are derived from computer science. Our development of operationalized definitions of CT talent for middle school educators is focused on uniting models for CT in a simplified structure. Our ED definition framework builds on multiple distinct models of the engineering design process along with concepts from systems engineering models and the design thinking process. We operationalize these frameworks to provide teachers with metrics and examples for recognizing and assessing the CT and ED skills of their students in non-technical classes. By training teachers to evaluate students' processes from the perspective of an engineer and computer scientist, teachers are more able to help their STEM-inclined students recognize the alignments between their own talents and possible careers. Through the analysis of teacher surveys and interviews from 19 classroom implementations, we evaluated the changes that the Arts & Bots program has had on teacher perceptions of student CT and ED skills and talents.**

Keywords*— *transdisciplinary; middle school; engineering pipeline; underrepresentation; educational robotics

I. Introduction

The preparation of students to be the innovators of the future is of critical importance for the US educational system. It is imperative that new technologies are created by engineers and computer scientists who are representative of the viewpoints, backgrounds, and needs of the entire population. Unfortunately, students from underrepresented minorities often do not participate in engineering extracurricular and elective classes that would increase experience and exposure to engineering and STEM career opportunities. For example, AP Computer Science classes in the United States are typically offered on an elective basis. Test takers of the 2013 AP Computer Science exam were 18.55% female, 8.15% hispanic, and 3.69% black [1] [2]. Similarly, participants in the popular STEM extracurricular FIRST LEGO League in 2013, consisting of students in grades 4-8, were 30% female, 11% hispanic and 4% black. In comparison, the distribution of students in US public schools is 49% female, 24% hispanic, and 16% black [3] [4]. Following on this lack of engagement equity with elective STEM opportunities, students from these underrepresented groups might also not receive encouragement to learn about STEM careers if STEM opportunities are limited in their schools.

II. Overview

We originally developed the Arts & Bots middle school robotics intervention to improve and diversify the engagement of students with STEM fields through the development of specific tools and teacher training. The Arts & Bots program combines robotics components, craft materials, a custom programming environment, and transdisciplinary curricula developed by teachers to bring creativity-oriented technology experiences to students. The creative and expressive focus of Arts & Bots differentiates it from other popular robotics programs such as FIRST LEGO League [5] and VEX Robotics [6] which are primarily task focused, are usually offered as elective programs, and can suffer from self-selection.

Another difference between Arts & Bots and other similar robotics programs is the transdisciplinary nature of Arts & Bots projects. While other in-school robotics programs are used in technology or engineering specific classes, we target teachers of required non-technical courses. These non-technical teachers -- those who teach any K-12 discipline except computer science, engineering, or technology education -- interact with more representative samples of students than teachers of technology electives and extracurriculars. The intention is that by exposing more students to STEM experiences in more classes, more students have the opportunity to explore a wide range of robotics activities, allowing us to "cast the net" of STEM activities wider. However, traditional teacher training in the US provides teachers with little computer science or engineering experience. Non-technical teachers lack the skills and opportunities needed to recognize student talents and affinities towards engineering and computer science. By training these teachers to be aware of computer science and engineering component skills, we hope to also help them recognize these skills within their students. This

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recognition is a first step in guiding students towards future experiences in STEM elective classes, advanced science and math programs, and STEM extracurriculars which we believe will improve the diversity of future STEM innovators.

Through the Arts & Bots in-school pilot and student data analysis, we identified areas where improvement and refinements can be made to the program software and hardware, the training that teachers receive and the guidance that we provide teachers for implementing Arts & Bots in lesson plans [7] [8]. We also collected many anecdotal comments and observations through interviews and informal discussions with teachers and through a limited number of classroom observations. One common theme we noticed among this evidence was that both students and teachers were discovering previously unnoticed or latent talents in areas that were not exercised in the traditional class activities [9]. Certain teachers were surprised to see students who did not usually engage with the content area of their class become very motivated by the Arts & Bots projects. One 7th and 8th grade language arts teacher stated: “It was nice for me as a teacher to see a different side of them. Sometimes we get caught up in our content because of course that's our passion [...] It was nice to see their passions for something else and [see] them in a different light.”.

Students also commented on discovering unexpected or latent abilities in themselves. Many students reflected that the Arts & Bots project was not as difficult as they had expected it to be [7]. Some students discussed how they really enjoyed particular aspects of the project, certain students being attracted by the hands-on nature of the project, by the creativity involved in creating an expressive robot, or by the challenges they found in debugging their programs [7]. One 8th grade language arts student commented that: "I realized that I am not as bad at technical stuff as I think.".

The refinement of Arts & Bots for the identification of unrecognized student affinities and talents was inspired by and developed from this anecdotal evidence collected during the Arts & Bots pioneer project between 2010 and 2013 [7] [8] [10]. We believe that through focused development of the Arts & Bots program, we will be able to refine the program to: (1) encourage a wide array of student talents and interests, (2) help students manifest these talents and affinities for identification, and (3) support non-technical educators in recognizing these student talents. These goals are centered around the core concept of training non-technical discipline teachers to identify the talents of their students and help those students to grow those abilities. In the end, it is crucial to develop tools and train teachers for identifying and supporting these student talents and interests in order to help each individual learner stretch and maximize their individual strengths [11]. This was highlighted by a junior-senior high school teacher who remarked: “[…] some of the students that excel at Arts & Bots aren’t traditionally gifted - who is looking out for and guiding those kids?” Our tools and preliminary evaluation of their impact are presented in this paper.

III. Related Works

The field of gifted and talented education is vast and evolving. There are many conflicting definitions of what it means for an individual to be gifted. One common, but outdated, definition is that the person scores in the 90th or 95th percentile in intelligence on an IQ test. There is no single federal definition of giftedness in the United States educational system, and most states also do not have standardized definitions or identification methods. However, schools in the majority of states use select teacher or parent referrals along with standardized assessments, such as IQ tests, and specific cut-off scores for student recognition [12].

In contrast to the concept of students being “gifted” or “not gifted” based solely on intelligence metrics, modern gifted education models instead present giftedness and student excellence as multifaceted concepts inclusive of creativity, persistence, and uncommon abilities in a least one domain [12] [13]. Other experts also treat giftedness as a mutable and developing quality, for instance, just because a young student is gifted does not mean they will be gifted through adulthood, and likewise a young student who is not identified as gifted in elementary school may qualify as having exceptional and gifted qualities later on [12]. Many have pointed out that standardized testing and intelligence-based metrics for giftedness may have biases that do not account for the diversity of student cultures and backgrounds, especially in regards to minorities underrepresented or underidentified for gifted intervention programs [12] [14]. Numerous research efforts have sought to correct for the imbalances in gifted identification and standardized assessment using new programs and non-traditional assessment methods [15] [16].

In 2011 the National Association for Gifted Children, defined gifted individuals as being those who “demonstrate outstanding levels of aptitude (defined as an exceptional ability to reason and learn) or competence (documented performance or achievement in top 10% or rarer) in one or more domains [17]. Domains include any structured area of activity with its own symbol system (e.g., mathematics, music, language) and/or set of sensorimotor skills (e.g., painting, dance, sports).” This concept of giftedness as a broad spectrum of potential domain talents is a powerful one. Further Pfeiffer [12], described giftedness as “transforming [...] potential talent in specific culturally valued domains into outstanding performance and innovation in adulthood.” Where identifying students who have talents in common academic areas such English Language Arts and math is standard practice for many educators, we sought to consider a new set of talents that individuals could possess which reflect the culturally valued domains and innovative potentials of computer science, design, and engineering [18]. For the Arts & Bots program, we use the word talent or affinity to describe an individual’s aptitude for a particular domain. This aptitude can result from a multitude of experiences including natural inclinations, prior experiences, and environmental influences. Through our Arts & Bots project, as described in this paper, we sought to develop definitions and models for computer science and engineering talents along with instruction programs, evaluation tools, and teacher training, and to study these models in use by practitioners. In no way is this program a comprehensive model of “giftedness”. Instead we focus on helping schools identify talents in Computational Thinking and Engineering Design, two domains not traditionally taught in schools but very relevant to modern society.

IV. Talent Definitions Framework

Arts & Bots supports and gives students the opportunity to display and build talent in two specific areas: computational thinking and engineering design. Our definitions of computational thinking and engineering are based on a diversity of related models, discussed below. We looked for common themes across these various models and developed a consolidated, hierarchical list of component skills. We simplified this list to be age-appropriate and suitable for both middle school students and the Arts & Bots project. For example data visualization is addressed in many computational thinking models, but due to limitations in the Arts & Bots program, is not a skill that frequently surfaces in these interdisciplinary projects. Finally we paired these skills with a concrete example of how each skill could be demonstrated by a middle school student during a project. In the interest of brevity, these examples are not presented in this paper. Our development, definitions, and related skills will be described and explored in the following sections.

A. *Computational Thinking*

Computational Thinking (CT) is traditionally defined as a problem solving process which incorporates attitudes and skills that allow real world problems to be solved with methods from computing and computer science [19]. CT involves restructuring and modeling problems in order to solve them through logical, algorithmic thinking [20]. CT applies students' skills in deciphering complexity, ambiguity, and open-ended problems; persistence and determination in working with difficult problems; and communicating and working with others to achieve a common goal [20].

Our CT definition includes three categories of skills: problem-solving, abstraction, and algorithmic thinking (see Table 1).

Problem solving encompasses three skills which can be used to make solving a problem easier: problem breakdown, redefining problems, and strategic decision-making. Problem breakdown means taking a large problem and dividing it into smaller problems that are each more manageable and, when each is solved, the complex problem becomes easier. Redefining the problem is described as recognizing that a given problem cannot be solved with available resources, and as a result, taking the problem and expressing it in a different way so that available tools (such as the available motors and sensors) are more applicable. Strategic decision-making is the ability to compare and weigh possible strategies and solutions, and make a justifiable decision concerning how to proceed.

Abstraction is the process of taking away unnecessary details in order to expose the essential underlying components of a problem or solution. Our definition of abstraction includes: modelling, pattern recognition, and modularity. Modelling means creating a model or simulation to represent a complex system in order to better understand the system. A skillful model will represent key elements of the system while ignoring superfluous details. Pattern recognition is the ability to consider multiple tasks and recognize the common features that the tasks share. Modularity means recognizing which components may be useful for reuse and creating solutions that are generalizable for multiple tasks.

TABLE I. Computation Thinking Category Breakdown

CT Category	Category Components
Problem-Solving	Problem breakdown
	Redefining problems
	Strategy decision-making
Abstraction	Modelling
	Pattern recognition
	Modularity
Algorithmic Thinking	Algorithm design
	Incremental development and evaluation

Algorithmic Thinking is an approach toward solving problems that includes algorithm design and incremental development and evaluation. Algorithm design is defined as identifying the sequence of simpler steps that must be created and combined in order to create a more complex behavior. Incremental development and evaluation is the process of solving complex challenges by breaking the problem down and implementing simple, manageable parts. Each part of the solution must be tested and perfected one-by-one before eventually combining them into the full solution.

B. *Engineering Design*

Similarly, our *Engineering Design (ED)* definition is derived from the number of existing models. We combined and simplified from three separate models of engineering: Systems Engineering, Design Thinking [21], and Engineering Design Process. We selected these models as the foundations for defining the skills of engineering talent because all three are generalizable to all domains of engineering and together span a complete engineering process from idea conception to prototype evaluation and refinement. Engineering Design is the process of developing a concrete and specific solution for a loosely defined problem within technical feasibility constraints [21] [22]. Engineering Design practices students' skills in real world problem solving, simultaneously combining new thoughts and concepts, and communicating mental imagery through graphical and media representations [22].

Our ED definition includes six categories: defining the problem, intentional design, innovating, refining and testing, prototyping, and communicating design (see Table 2). Defining the problem refers to the way a person identifies the criteria for success, and the constraints and resource limits for a given problem.

Intentional Design relates to the planning stages of engineering through deliberate steps and following an outline. Deliberate planning is about developing a complete plan for constructing and programming the intended robot based on relevant criteria and constraints before beginning work on the robot. Much as it sounds, following a plan means persevering to follow a design for creating a robot despite challenges, rather than changing plans haphazardly while building.

Innovating involves demonstrating creativity in solution generation, including generating multiple solutions, solution analysis and evaluation, and "Outside the box" thinking.

TABLE II. ENGINEERING DESIGN CATEGORY BREAKDOWN

ED Category	Category Components
Defining the Problem	Defining the problem
Intentional Design	Deliberate planning
	Following a plan
Innovating	Generating multiple solutions
	Solution evaluation
	"Outside the box"
Refining and Testing	Systematic diagnosis
	Trade-offs consideration
	Thorough testing
Prototyping	Design for construction
	Making it real
Communicating Design	Clear communication of ideas

Generating multiple solutions requires the ability to brainstorm two or more possible solutions for each challenge or need rather than pursuing the first solution that comes to mind. Solution evaluation naturally follows solution generation. One must carefully consider the strengths and weaknesses of multiple potential solutions and describe the reason for making a choice based on success criteria and project and resource constraints. "Outside the box" thinking means coming up with possibly risky, very novel solutions to problems. These solutions might incorporate innovative uses of materials, creative mechanisms, or a solution unlike any examples shown in class.

Refining and Testing includes systematic diagnosis, trade-offs consideration, and thorough testing. Systematic diagnosis means utilizing a methodical process of elimination to determine the source of a problem. Trade-offs consideration is defined as recognizing when important goals of the robot are at risk of not being accomplished due to resource limitations, then prioritizing the success criteria and reducing or eliminating low priority features in order to reach high priority goals. Finally, thorough testing signifies carefully testing each subcomponent of the robot or program, in addition to the whole system, and comparing test results to the success criteria.

Prototyping requires design for construction, and making it real. When designing for construction, one carefully considers how each component will be constructed and considers the strengths and weaknesses of available materials to avoid problems during construction. Making it real involves taking an idea and creating a physical model that accurately reflects the original idea. The model is carefully crafted, constructed with attention to detail, and successfully and elegantly meets the initial design criteria.

Finally, **Communicating Design** means clear communication of design ideas to teammates, teachers, and others.

C. *Talent Skills Professional Development*

We share the Talent Framework with teachers through professional development. The first step in this training is a discussion of the motivations for focusing on ED and CT talent. We discuss the needs of society for diverse engineers and elaborate on the benefits to students and teachers in addition to the societal benefits. During our 2013 to 2015 professional development, we reviewed the definitions and background research of computational thinking and engineering design with the teachers, encouraging open teacher to teacher discussion. We conduct a pair and share activity with the teachers. We break down Computational Thinking and Engineering Design talents. Teachers receive talent component definitions and examples of how each component is evident in students. The teachers then work in pairs, reviewing the talent definitions for either ED or CT. Each pair then shares their understandings with the larger group. Through the "share" portion of the share and pair activity, we clarify talent questions and misconceptions.

After using this PD in 2013 to 2015, we analyzed feedback from teacher interviews and surveys [23]. Teachers asked for more training on talent identification. Since research on professional development has found that connection and coherence with teacher experiences and knowledge is critically important to the effectiveness of teacher training [24] [25], we address this need through the inclusion of more concrete examples of student built robots. From this teacher feedback, we developed a taxonomy of novice built Arts & Bots robot examples, described below.

V. EXEMPLAR NOVICE-BUILT ROBOT TAXONOMY

The talent definitions provide teachers with a framework for classifying talent and provide examples of the talents. To help teachers more concretely envision how these talents might be displayed by students during Arts & Bots projects, we created a taxonomy of exemplar robots. This taxonomy was generated through affinity diagramming of 179 images of completed novice built robots from 17 Arts & Bots classes and 21 teacher workshops. This taxonomy spans three domains: Mechanical Sophistication, Communication and Artistry, and Computational Sophistication. Because this taxonomy was developed specifically from images of expressive and creativity-focused robot projects, these domains focus on salient features of such robotic creations

A. *Mechanical Sophistication*

Mechanical Sophistication is the first domain of the taxonomy and exists along an analog scale which can be described in four tiers. From simplest to most complex they are: 1) direct motion, 2) secondary motion, 3) underactuated motion, and 4) transformation mechanism. Some examples of these different levels of sophistication are shown in Fig. 1 and Fig. 2.

1) Direct Motion

Moving components of the robot are directly connected to the fundamental hardware/mechanical units. The final motions are directly derived from the basic actuators of motion (eg Motors, Servos, and Vibration motors); for example, moving an arm attached to a servo, spinning a pinwheel with a motor, or shaking a leaf with a vibration motor. This is the most common type of robot constructed by novices.

2) Secondary Motion

The main movement of the robot is still clearly derived from the basic actuators however there is some indirectness in the resulting or side effect motions. These secondary motions are "one step removed" from the basic hardware unit. The side effect, while not direct, has a one-to-one relationship with the motion of a basic actuator, e.g., changing the length of a stretchy material attached to a lever. Whereas the motion of a motor turning a wheel is a direct motion on the robot, if that wheel causes the robot to move across the ground this is a secondary motion. However unlike an underactuated motion, the robot is always fully in control of these secondary motions.

3) Underactuated Motions

A robot is underactuated when a single basic actuator causes motions in more than one degree of freedom. The resulting degrees of freedom cannot be controlled independently. For example, a motorized robot lever with a freely moving bell on the end. While the robot has direct control of the lever, the ringing of the bell is an uncontrolled (e.g, underactuated) resulting motion. Another robot could have a model spider dangling on a string, which is lowered with a pulley driven motor but has uncontrolled side-to-side motion. Sometimes these motions may include the purposeful use of randomizing physics, such as dropping marbles to simulate rain.

4) Transformation Mechanism

The main motions of the robot are distanced from the basic actuator motions and are enhanced and transformed by mechanisms. Some transformations allow the robot to exhibit motion or forces otherwise not possible with the primitive motion components, such as a smooth oscillating motion or a high speed linear motion. The robots when examined make use of principles of mechanical advantage and mechanisms, including levers, cams, sliders, etc. The motions can also be the result of a chain of mechanisms or mechanical transformations. An example of this type of robot is shown and described in Fig. 1. These motions have more than one step of removal as seen in the secondary motion but still have the one-to-one relationships between actuators and resulting motions, differentiating them from underactuated motions.

B. Communication and Artistry

Communication and Artistry has two levels. The most basic is "Practical Construction", and the more advanced is "Consideration of the Audience". The visual form and communicative elements of the robot both contribute to classification of a robot into these two categories. Some examples of these different levels are shown in Fig. 2.

1) Practical Construction

a) Non-Distracting Details

When the raw materials from which the robot is constructed are obvious and unhidden, it can distract from the expressed idea or purpose of the robot. The wires and hardware components themselves are obvious, visible, and not contributing to the message of the robot. When the materials chosen are solely practical or mechanical in nature and no materials are used to cover or decorate the raw structure or mechanism, the outcome is indicative of a lower tier Communication and Artistry. Additionally, excessive details that are not relevant to, or worse that are distracting from the idea being expressed are also not considered to be contributing to the artistry.

b) Direct Communication

The robot is a direct and literal representation of the idea being expressed. For example, a robot dog is constructed to represent a dog. Building a direct model without much novelty added to the interpretation does not signify a high artistry level.

2) Consideration of the Audience

a) Surprising Form and Relevant Detail

When robots are constructed with audience consideration in mind, it signifies a higher level of Communication and Artistry, revealing a surprising form with relevant details. The robot can be constructed from materials, but the form and appearance of the robot are surprising or non-obvious. The media and materials used enhance the idea expressed by the robot rather than detracting or distracting from it. The perspective of the viewer is actually taken into account to better express ideas, meaning components are hidden from view to minimize distractions.

b) Metaphorical

Indicating an even higher tier of Communication and Artistry, some robots incorporate novel ideas and artistic

Fig. 1: A student works a robot which illustrates the Mechanical Sophistication tier of "Transformation Mechanism". This robot uses counterweights, shown in the student's hand, and a pulley system to rapidly open the red paper curtains when the robots' servo opens a trapdoor supporting the counterweights.

Fig. 2: Four robots illustrating different degrees of Mechanical Sophistication, and Communication and Artistry: (clockwise from top left) audience consideration with direct motion; audience consideration with transformation mechanism; practical construction with transformation mechanism; practical construction with direct motion.

visions, taking the robots beyond a direct model of the idea being expressed. Using metaphors and relevant details to represent deeper or more abstract ideas than the surface representation, the robot expresses a new interpretation of the idea.

C. Computational Sophistication

Computational Sophistication describes the level of sophistication of the robot program. The categories and their descriptions are tailored to the programming language used in Arts & Bots, and the resulting program structures and behaviors exhibited in typical Arts & Bots robots [10].

1) Structure

The overall structure of the robot's programming and states of the robot form computational behaviors of differing levels of sophistication. Consequently, the state-based programming environment was developed to be analogous to single stream storyboards in narrative development [10].

a) Repetitive Action

A robot exhibiting repetitive action is simple and consists of one or more states which are output by the robot cyclically and in a repeated fashion. This includes for example a simple dog robot with two expression states "tail left" and "tail right" which are cycled between in a loop. Repetitive actions can also encompass a larger number of expression states, such as a robot with arms and lights that cycles through a number of different poses and light combinations in a dance.

b) Storyboard

Storyboard robot behavior differs from the repetitive action behavior by the existence of a fixed, intentional behavioral start and end state. The robot moves through a series of actions in the process of communicating a coherent concept or narrative. For example, a robot traffic light with an animated car can be programmed to sequentially light red, yellow, and green LEDs before the car moves forward a set distance. Similarly, an art-producing robot with an attached marker would draw a specific image, such as a star polygon, through its intentional motions and then stops when it is complete.

c) Synchrony

Synchrony robot behavior is similar to a storyboard computational structure in appearance, as the sequence of behavior is also intentionally laid out with a specific series of actions with a fixed program start and end points; however, it is set apart from the storyboard by the relative importance of the timing of the robot actions. In synchronous programs, the timing of the robot actions are carefully and purposefully delineated by external factors. For example, a theater robot with moving actors in which the motions and actions needs to be carefully timed in order to happen at appropriate times and in synchrony with the audio of the robot. Additionally, if two or more robots were programmed to interact following a specific storyboard or script, the timing of both robots would need to be carefully synchronized following timing agreed upon in the script.

2) Interactivity

Beyond the structuring of robot programming and behaviors, the computational complexity of novice-built robots is also dependent on how sensors and inputs are utilized in adding interactivity and feedback to the robot behaviors. Some robots created by novices have no interactivity or sensors; however by the definition of a robot as a device that can complete tasks and respond to its environment autonomously, these novice built devices lacking sensors are more electromechanical devices or computational sculpture than true robots.

a) Triggers and Forks

At the simplest level, robots use sensors in straight-forward "if-else" structures which determine behaviors based on whether or not certain threshold conditions are reached by the sensor values. Abstractly, these behavioral forks determine whether or not the robot will perform behavior 'A' or behavior 'B' based on the sensor or input values. For example, a simple robot that is programmed to wave a flag left if an infrared distance detects an object less than one foot away, or wave the flag right if there is not. A very simple version of this fork interaction, uses the sensor reading as more of a trigger condition, meaning the robot only does an action if the threshold is met. Otherwise, it performs no action. For example, a simple robot is programmed to wait before acting and then move forward when triggered by a threshold crossing change detected by a light sensor.

b) Hierarchical Logic

Another tier of sophistication is achieved when multiple "if-then" statements are used in the robot program to form more elaborate logic trees or hierarchies. This could be through the use of nested if-else statements relying on a single sensor input to select between greater than the two conditions permitted by a single if-else statement as used in forking behaviors. For example, a robot programmed to work as a range detector which uses an IR distance sensor and lights up red when an object is closer than 6 inches, yellow when the distance is measured to be 6 to 12 inches and red if the object is greater than 12 inches away. These robots can also combine if else statements in hierarchies to create robots that modify behaviors based on two or more sensor values. For example, a robot that opens or closes a greenhouse roof based on a number of cases of specific light and temperature sensor quantities.

c) Feedback Based

The highest tier of computational sophistication that can be achieved with the Arts & Bots programming environment are behaviors that are built around concepts of engineering feedback. Whereas the other tiers of interactivity combine the use of outputs and sensor inputs that are not directly related, like a distance sensor prompting the actions of lights and audio; feedback interactions have direct cause-and-effect relationships between inputs and outputs. The most common form of feedback in our novice-built robots use a bang-bang style control scheme, for example, a robot that is programmed to maintain a certain distance from a object in front of it. If the distance is too large, it is programmed to move closer. If the distance is just right or too close, the robot moves away. In this way, the robot is constantly in motion, adjusting its position with feedback from the sensor. Another example would be a robot with a temperature sensor which controls operation of a fan.

D. Training Teachers on Novice-Built Robot Taxonomy

In response to teacher requests for more training on talent identification and concrete examples, we enhanced PD with photos of example student robots. In order to allow robot comparison, examples were from the same class. We presented student projects to teachers, discussing positive and negative qualities of each. Robots were discussed in terms of the three components of the taxonomy. We related ED to Mechanical Sophistication and Communication and Artistry. We related CT to Computational Sophistication. Many of the ED and CT talent components are expressed through the process of creating a robot, and are not necessarily evident by solely viewing the final product; however discussion of students' robots provided a framework for delving into concrete talent examples.

VI. RESEARCH FOCUS AND PRELIMINARY EVALUATION

Teachers receive professional development around the research-informed talent framework and taxonomy. They then integrate creative robotics projects into class curricula. The projects provide students with experience creating new technological artifacts and provide teachers opportunities to observe and recognize students' CT and ED skills and talents. We worked with two school districts to do a preliminary evaluation of these talent identification tools. We collected data on the tools' and trainings' effectiveness via quantitative Talent Inventories and qualitative teacher interviews. All of our quantitative analysis was performed using SPSS.

Our evaluation examines whether or not providing a teacher with the above talent identification professional development and the opportunity to implement a creative technology program, such as Arts & Bots, changes their recognition of computational thinking and engineering design student talents. It is important to note, that in this intervention, we are not treating ED or CT Talent as outcomes that we seek to improve. The goal of the project is to find exceptional students whose talent was not previously recognized by the teachers. We are not looking for the talent score of all students to increase.

A. Talent Inventory

The Talent Inventory is completed by each teacher participating in an implementation at three separate occasions. The first Talent Inventory is completed at least two weeks (preferably more) before the start of their implementation, the second is completed at the start of their implementation, and the third is completed after the completion of the implementation. Talent Inventories were collected from eleven teachers across eleven classes between December 2014 and May 2015 (1.5 years). Each student is rated by the teacher from 1 to 7 in both Engineering Design and Computational Thinking. Numerical scores are supplemented with descriptions "1 - Does not show special promise in this area", "3-Shows occasional evidence of talent", "5-Shows frequent evidence of moderate talent" and "7-Shows frequent evidence of outstanding talent". Training the teachers on our talent framework makes it a multi item scale. If we were to include the full scale, teachers would need to score every sub talent for every student. Training the teachers on the framework enables them to avoid that.

However, due to the self-administered nature of our teacher evaluation, all three Talent Inventories were not reliably completed for each class. In order to have a suitable sample size, we compared pre-scores from either the first or second inventory with post-scores from the third. The second inventory score was

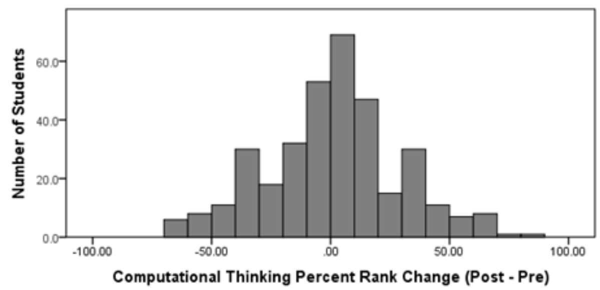

Fig. 3: Computational Thinking percent rank change, M = 1.1, SD = 28.4.

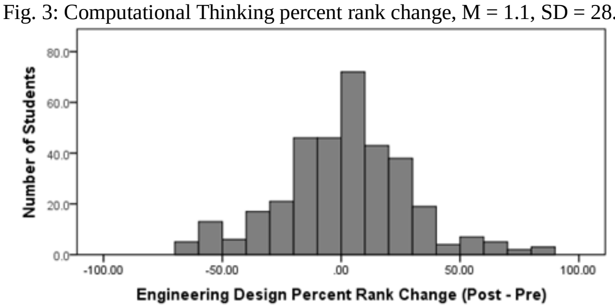

Fig. 4: Engineering Design percent rank change, M = 1.4, SD = 26.8

preferred if both the first and second were completed. Matched sets of pre and post scores were available for 347 students.

During two co-taught classes, two teachers performed pre and post scoring of the same set of 41 seventh grade students. Comparing the pre-CT, pre-ED, post-CT, and post-ED scores from each teacher pairwise by individual student, we found that all four of the score sets demonstrated significant levels of correlation (pre-CT $r=.467$, $p=.002$; post-CT $r=.657$, $p<.000$; pre-ED $r=.493$, $p=.001$; post-ED $r=.663$, $p<.000$). However, while correlated, a paired samples t-test, indicated that the scores were also significantly different. For the pre-CT scores, between teacher 1 scores ($M1=3.15$, $SD=1.152$) and teacher 2 scores ($M2=4.41$, SD= 140) was a significant difference ($t(40)=-6.861$, $p<.000$). Similarly pre-ED, post-CT, and post-ED scores were also significantly different (pre-ED: $M1=3.31$, $M2=4.10$, $t(40)=-4.261$, $p<.000$; post-CT: $M1=3.46$, $M2=4.29$, $t(40)=-4.204$, $p<.000$; post-ED: $M1=3.46$, $M2=4.49$, $t(40)=-4.924$, $p<.000$). This indicates that while the teachers had generally correlated scores, with high scoring students receiving corresponding high scores from both teachers, teachers did not score on a consistent scoring curve. Teacher 1's mean scores were consistently lower than those of teacher 2. Spacing between numerical scores is subjective and variable by teacher and dependent on teacher experiences, i.e. the range of talents observed by a teacher will set her expectations for the endpoints of the scale. This means that direct comparisons between numerical scores are not currently possible, without further refinement of teacher training and tools. However, the teacher-perceived ranking of student talents and identification of high- and low-talent students compared to class averages is useful once the numerical scores are normalized.

In order to permit the meaningful combination of Talent Inventory data from different classes and teachers, we convert these numerical talent scores to class ranking scores. We calculated each students' rank in the class as a percentage of class size. For example, a student who has a score above 5 of her peers in a class of 20 would be in the 25th percentile. This percentile rank scale is consistent with modern giftedness research, where a student scoring in the top 90th percentile among her peers in a domain is identified as being exceptional [17]. Each student has four percentile ranks, two for ED and two for CT on the pre-inventory and the post-inventory respectively.

Standard parametric tests are not appropriate for our research focus and data. Parametric tests evaluate hypotheses about differences in the mean scores of a sample. Conversely, our research focus is on a small number of exceptional students and not the sample mean as a whole. ANOVA and t-tests also rely on the assumptions of normally-distributed, interval data which are not met by Talent Inventory scores.

In order to assess teachers' change in perception of students, we compared change in student percentile ranks from pre to post (Fig. 3, Fig. 4). These distributions are roughly centered around a percentile rank change of zero as is appropriate and expected as the mean percentile for each class is always approximately the 50th percentile (CT percentile rank change M=1.1, ED percentile rank change M=1.4).

The distributions of CT and ED percentile rank changes had relatively large standard deviations (SD=28.4 and SD=26.8 respectively). The large standard deviations indicates that the percentile rank changes of some students vary greatly from the means of the distributions. However, the positive excess kurtosis of the distributions (CT kurtosis = .192, ED kurtosis = .777) indicate that the distributions are leptokurtic, indicating that a greater number student rank changes are concentrated around the mean than would be in a normal curve. Most students' ranks changed very little while some changed a lot. For CT, 17 students (4.9%) increased 50 percentiles or more, and 14 students' ranks (4.0%) decreased by 50 percentiles or more. For ED, 17 students' ranks (4.9%) increased by 50 percentiles or more, and 18 students' ranks (5.2%) decreased by 50 percentiles or more. These outliers on the distributions show that teacher perceptions of some students' talent are changing greatly. For 4.9% of students, their CT or ED talents are newly recognized as being much higher than expected. Teacher positive assumptions about students' talents are being challenged and found to be lower than expected for 4.0% and 5.3% of students for CT and ED respectively. Conversations with teachers during subsequent professional development sessions suggest that some teachers originally expect academically talented students to automatically be skilled in CT and ED, but may change their minds after observing students during class.

B. *Teacher Interviews*

Qualitative analysis of teacher interview data is ongoing and we are developing a coding scheme that will allow us to quantitatively analyze their open-ended responses. However, preliminary interview data also suggest that teachers are identifying talent through their Arts & Bots implementations. We present here some of anecdotal quotes from the interviews and some qualitative discussion of potential outcomes, to aid in contextualizing the Talent Inventory data above.

Teachers were interviewed following their classroom implementations. Interviews included questions about recognizing talent. Sometimes teachers expressed uncertainty in their ability to recognize talent saying, "I don't know if I'm missing it, if I'm too hard on myself, because I keep reading over what they all mean, you know? And I'm like, am I seeing it? Am I not seeing it? I don't know." (computing teacher). However, teachers often stated that they were able to recognize previously hidden talents in their students: "...when this new lesson comes into play…, sometimes you see different sides to people. You see a different ability that was hidden." (science teacher).

In interviews teachers commented on specific components of our talent framework. Innovating was mentioned by several teachers, for example: "[They] take different materials, manipulate them … I would never have thought to manipulate a material in that way. I started to see some talent from people that started doing that. They look at a bottle … Like 'oh, I can use this in a whole bunch of different ways' … I started to really see some design talent come out of kids like that, or engineering talent" (health teacher). One teacher not only recognized designing for construction, but also communicating design and abstraction, all within her class: "... there are some who really have a high aptitude for figuring out, well, I need to make sure it holds up, so I need to add this to it, and they kind of take the others with them, which has been interesting to watch, and it's been a lot of fun. … Now I do have some who are good at thinking more abstractly … they're really good about bringing everyone else with them. Like they help each other, and a lot of times they don't even ask for me. They just start talking to each other and they figure it out, which is really cool." (art teacher).

VII. Conclusions and Future Work

In this paper, we presented a talent definitions framework with three primary categories of skills in CT talent and six categories of skills for ED talent. This framework was created to help non-technical teachers better understand and recognize student skills that contribute to talents in CT and ED. To further aid teachers, we presented a taxonomy for classifying novice-built robots which distinguishes three primary domains of differentiation: Mechanical Sophistication, Artistry and Communication, and Computational Sophistication. This taxonomy was generated from robot examples generated during our middle school creative robotics program, Arts & Bots. Finally, we presented early findings from data collected with teacher surveys and interviews. Using teacher completed Talent Inventories, we examined how perceived rankings of student talent changed over the course of an Arts & Bots project. For 4.9% of students, their CT or ED talents were newly recognized by teachers as being much higher than expected.

Future work includes additional analysis of Talent Inventory and interview data. We plan to analyze individual teachers across time to see if they are more able to identify talent in later implementations. As the Talent Inventory data set grows, we plan to utilize the first Talent Inventory as a within-group control to see if perception changes are due to the passage of time or result from the Arts & Bots implementation. Further analysis of teacher interview data through coding may reveal a more in-depth understanding of teacher perceptions on student talent. Additionally, we aim to analyze student self-perceptions of talent, comparing student survey results that assess self-perceived ED and CT talent with teacher talent inventories to see if teachers and students recognize talents in the same ways.

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