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# Development of Engineering Habits of Mind for Students With Intellectual Disability

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**Abstract**

The *Next Generation Science Standards* framework outlines scientific and engineering practices as a key element of student development. Educators are just beginning to discover effective and meaningful ways to teach science content to students with intellectual disability; however, the literature on teaching science practices is still limited and engineering practices nonexistent. This study utilized a quasi-experimental group design to investigate the impact of universally designed engineering curriculum on 43 students with intellectual disability and autism display of engineering habits of mind (e.g., persist and learn from failure) during ongoing *Engineering is Elementary* design challenges. A statistically significant difference between the control and treatment groups was found. Findings suggest engineering instruction may support student development of problem-solving skills.

**Keywords**

engineering, intellectual disability, universal design, STEM, systematic instruction

In 1996, the National Research Council (NRC) established the National Science Education Standards (NSES) to provide educators with priorities and a framework for science education. In 2012, the NRC met the national call for updated science standards through the development of a conceptual framework to guide the next set of science standards. A specific focus of the *Framework for K-12 Science Education* was on the development of science education that cultivated student engagement in experiencing science, with the emphasis away from "scientific inquiry" (NRC, 1996) toward "engagement in scientific and engineering practices" (NRC, 2012). This framework identified the following eight scientific practices essential for all students to acquire (a) asking questions, (b) developing and using models, (c) planning and carrying out investigations, (d) analyzing and interpreting data, (e) using mathematics and computational thinking, (f) constructing explanations, (g) engaging in argument from evidence, and (h) obtaining, evaluating, and communicating information. From the NRC's new framework came the development of the *Next Generation Science Standards* (NGSS Lead States, 2013), providing learning progressions that break down the content and outline how science and engineering practices are embedded across the K–12 grade span.

## *Science Instruction and Disability*

While the research literature on teaching science to students with severe disabilities was growing (Spooner et al., 2011), this new set of standards introduced a different set of challenges and innovation in science education for all students. Educators are just beginning to discover effective and meaningful ways to teach science content to students with intellectual disability (ID) and/or autism spectrum disorder (ASD); however, the literature on teaching science practices is still limited and engineering practices nonexistent. In the most recent review of the literature by Knight et al. (2019) synthesizing the research for teaching science to students with ID and ASD, only 12 methodologically sound studies were located. Differing from previous literature reviews focused on science content (Courtade et al., 2007), this review of the literature sought to determine the evidence for teaching science practices (e.g., asking questions, communicating findings). While Knight and colleagues did find evidence to support the use of systematic instruction (e.g., time delay, task analysis) to support teaching across all eight of the NGSS science practices, only four studies explicitly focused on teaching science practices (Courtade et al., 2010; Jimenez et al., 2012; Knight et al., 2018; Smith

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et al., 2013). In addition, though not the main focus of the investigation, the other eight studies also used explicit strategies, such as multiple exemplars, task analysis, and time delay, to teach students how to ask questions, develop/use models, plan/carry out investigations, analyze/interpret data, construct explanations, argue from evidence, and obtain, evaluate, and communicate information.

Although all eight science practices were identified across the 12 studies found in Knight et al., the level in which students exhibited science practices—also referred to as habits of mind (HoM)—was somewhat limited. For example, some of the ways in which students engaged in HoM in the 2012 study conducted by Jimenez et al. was through the use of a KWHL chart to identify what they know, want to know, how they will find out, and then what they learned. Through completing the KWHL chart during ongoing lessons, students asked questions and used data to record what they learned (communication). Only a few of the studies identified in the Knight et al. review focused on content outside of science, specifically other science, technology, engineering, and mathematics (STEM)-related outcomes (i.e., technology, engineering, mathematics). Heinrich et al. (2016) investigated the effects of systematic instruction to teach STEM content to three secondary students with moderate ID. Students were taught geometric figures, science vocabulary, or use of technology to publish and chained tasks, such as Punnett square. Along with the need for further development and depth of application of science practices for students with ID, ASD, or both, Knight et al. also stated that additional research is needed on the teaching of engineering practices (i.e., HoM), a component of the NGSS, not taught or assessed in any of the studies reviewed in their synthesis.

*Potential of Engineering Education.* Science and engineering are related disciplines, therefore aspects of each overlap in educational programming. However, they also diverge, "what makes science and engineering distinct disciplines are the differences in their *epistemic practices* (Kelly, 2011): how they (socially) achieve the solution of technical or theoretical problems" (Cunningham & Carlsen, 2014, p. 5). Scientific problems may be "solved" through the development of evidence and data to support a general knowledge claim, and then evaluated by peers with similar expertise. However, an engineering problem might be "solved" through the development of a very specific solution, based upon its evaluation using very different areas of expertise, such as economics, safety, and aesthetics.

While the nature of science is to understand the world around us, engineering education enables students to use science and math to solve practical problems, even without deep disciplinary understanding (Cunningham & Carlsen, 2014). Hence, engineering problems and design challenges can be developed that are challenging and productive, while accessible to young learners (Levy, 2013). Research even suggests that students who engaged in engineering tasks (e.g., improving the speed of boats in a canal system) outperform their peers who engage in science tasks on increased science content and reasoning skills (e.g., investigating factors that affect spring length in mechanical systems; Schauble et al., 1991). In science, we begin with conceptual models, whereas engineering typically ends with something real, concrete, and usable. Addressing engineering's relevance to helping people may engage students with ID, ASD, or both. While socially directed, engineering capitalizes on the need for personally relevant curriculum for students with ID (Trela & Jimenez, 2013), through engineering design challenges situated within real-life contexts.

In the seminal work, *Science for All Americans*, Rutherford & Ahlgren (1991) defined HoM as "the values, attitudes, and skills that shape our outlook on knowledge and learning." Based upon the National Academy of Engineering's (2009) six ways of thinking—(a) systems thinking, (b) creativity, (c) optimism, (d) collaboration, (e) communication, and (f) ethical considerations—various versions of Engineering Habits of Mind (EHoM) have been developed by different science educators and curriculum designers. However, all iterations of EHoM are similar in nature, aligned to the National Academy's six ways of thinking, and grounded in *why* engineering education is important. With increased interest in STEM education for students with ID/ASD, EHoM highlight the importance of problem-solving skills (e.g., systems thinking, creativity) and those imperative to developing ethical solutions (e.g., collaboration, communication). With continued value on the balance between general curriculum access and personally relevance skill instruction for students with ID (Courtade et al., 2012; Trela & Jimenez, 2013), directed attention to HoM within STEM education is a necessity. Engineering education affords educators with the context necessary to address science, technology, and mathematics education in meaningful ways. In addition, for students with disabilities, engineering units may provide a viable format for systematically planned math, science, and technology instruction, that naturally embeds opportunities to teach students skills promoting increased self-determination.

*Engineering is Elementary.* One specific research-based curriculum focused on engineering education for young children is the Engineering is Elementary (EiE)® program (2019). EiE is a curriculum that introduces primary school-aged children to principles of engineering and technology, with math and science embedded throughout. The impact of EiE has been evaluated, and data suggest that EiE materials are engaging for girls, children of color, children from low socioeconomic groups, and children with disabilities (i.e., learning disabilities and attention-deficit hyperactivity disorder [ADHD]) and have resulted in learning gains related to both engineering and science (Gruber-Hine, 2018; Lottero-Perdue & Parry, 2017; Lottero-Perdue et al., 2011). In a study by Lachapelle et al. (2011), the authors used statistical analysis to compare EiE student performance on pre- versus postassessments of five engineering units using $t$ tests and confidence intervals. Lachapelle and colleagues found that EiE students participating in all five units improved significantly on engineering questions ($p < .001$) and science questions ($p < .001$). The developers of EiE have identified 16 EHoM (e.g., develop and use processes to solve problems, construct models and prototypes, make evidence-based decisions, investigate properties and uses of materials) and embedded them within and throughout all EiE units. To date, several studies indicate positive outcomes for the use of the EiE curriculum in elementary classrooms; however, no research exists to support its use in students with ID. Even more specifically, no research exists to support engineering instruction and/or EHoM with this population of students.

*Universal Design for Learning (UDL).* The UDL framework, when used for planning, teaching, and assessing, offers all students equal opportunities to learn and demonstrate knowledge and skills (Hall et al., 2012). Educators who use the UDL framework accept learner variability as a strength to be leveraged, not a challenge to overcome. Rather than focusing on the individual barriers that many learners may have in each lesson or activity, the UDL provides guidance to expect variability and plan for it in advance (Rose & Meyer, 2002). Essentially, UDL is "a set of principles for curriculum development that give all individuals equal opportunities to learn" (CAST, 2018). To build the research base in engineering education for students with ID, the potential of universally designed engineering units using EiE lessons and activities may provide access to EHoM by taking into consideration potential barriers to learning students may have. Specific barriers may include access to the content (e.g., reading skills, prior knowledge, level of vocabulary), ability to "show what they know" to demonstrate their depth of knowledge and skills (e.g., limited English writing or speaking, social skills working in peer groups, writing proficiency), and limited engagement in the learning task (e.g., attention, previous successes in content area, organization skills).

### Purpose of This Study

The purpose of this study was to investigate the impact of engineering instruction on the EHoM of primary students with ID. We also had a strong interest in exploring the use of research- and evidence-based practice to support universally designed engineering instruction. Two research questions were addressed as follows:

**Research Question 1 (RQ1):** What is the effect of universally designed engineering instruction on the EHoM of elementary students with ID?
**Research Question 2 (RQ2):** What is the effect of the use of the EiE program on special education teacher perceived ability to teach high quality engineering curriculum to students with ID?

## Method

This study utilized a quasi-experimental group design. Students with ID were assigned into either the treatment or control group. All participants were pretested at the beginning of the academic year before the intervention was implemented and posttested after the first engineering unit of work and again after the second engineering unit of work. The following sections describe the participants and setting, method of assignment of participants, instrumentation, dependent and independent variables, and analytic techniques.

### Inclusion Criteria

Four special education teachers across two grade bands (two teaching Grades 3 or 4 and two teaching Grades 5 or 6) participated in the study. All student participants met the eligibility criteria that included the following: (a) mild to moderate ID, with or without comorbid autism; (b) enrolled in Grades 3 to 6; (c) adequate hearing and vision to respond to curricular materials and instruction, responsive to ongoing instruction in English; and (d) parental informed consent to participate in the research. From the initial pool of 45 students across the four classes, 43 met the criteria for inclusion in the study. Two students did not have parental permission to participate in the study; however, they did still participate in the engineering instruction with their classmates.

### Description of Participants

The 43 student participants were enrolled in Grades 3 through 6 at a K–12 school for students with ID in New South Wales, Australia. Based upon school records and psychological reports, all of the participants had an ID in the mild to moderate range. None of the students qualified as limited English. A description of student participants by group assignment is reported in Table 1. Chi-square analysis indicates no statistically significant differences ($p > .05$) between the control and treatment groups for gender or English as a Second Language (ESL). The $t$ test analyses indicated a minor difference ($p < .05$) between the control and treatment groups for age. Although the results were not significant, the students in the treatment group were actually younger ($M_{age}$ = 9.8 years) than their peers in the

**Table 1.** Description of Treatment and Control Groups.

| Characteristics | Control (N = 22) N | Control (N = 22) % | Treatment (N = 21) N | Treatment (N = 21) % |
|---|---|---|---|---|
| Gender | | | | |
| Male | 18 | 82 | 14 | 67 |
| Female | 4 | 18 | 7 | 33 |
| Language | | | | |
| LBOTE | 5 | 23 | 6 | 29 |
| No LBOTE | 17 | 77 | 15 | 71 |
| Intellectual disability | | | | |
| Mild | 10 | 45 | 6 | 29 |
| Moderate | 12 | 55 | 15 | 71 |
| ASD comorbid | 13 | 59 | 6 | 29 |
| Age (years) | M | Range | M | Range |
| | 9.86 | 9–13 | 10.86 | 8–12 |

*Note.* N = number of participants; LBOTE = Language Background other than English; ASD = autism spectrum disorder.

control group ($M_{age}$ = 10.9 years). Comparison of group differences at pretest found no significant differences between the groups on any of the three EHoM (i.e., first dependent variable).

There was a significant difference between the treatment and control groups for number of students with a mild versus moderate ID, the control group had double the number of students with mild ID than the treatment group. In addition, the control group had more students with ASD ($n$ = 13) than the treatment group ($n$ = 6). Implications of these differences between the control and treatment groups are discussed further in the section "Discussion."

The four teachers who administered the control and treatment intervention were all primary special education teachers. All four teachers were White, female licensed educators; however, only one treatment and one control group teacher had special education credentials (Australian educators are only able to be credentialed in special education as an add-on, via certification after an undergraduate degree or via a special education master's degree). Teacher experience ranged from 1 to 26 years. The two treatment group teachers had 17 and 3 years of experience. The control group teachers had 1 and 26 years of experience. All four teachers had experience teaching science; however, none had previously taught engineering.

*Assignment of Classes.* Two teachers were initially identified to investigate the effect of engineering instruction on their students' EHoM. The control group participants were then chosen based on same age/grade level. For example, the two treatment teachers taught students in Grades 3 to 6. Therefore, the two control group teachers taught the other two Grades 3 to 6. This simple sampling method was chosen due to feasibility to the logistics of the applied context. Further matching by type of disability, gender, or age was not feasible. Due to the small sample size, statistical tests to examine the mean differences between the treatment and control groups on the pretest measures were conducted. Initial statistical analyses indicated that both groups were equivalent for all pretest measures. Additional details of these analyses are presented in the results section.

### Dependent Variables

Prior to beginning this study, three of the EHoM identified by EiE were chosen based upon consultation with an expert in elementary engineering and science education. Via her suggestions, our research team chose three EHoM identified as essential to active and engaged participation in the specific EiE units to be taught. The three EHoM were as follows: (a) see themselves as engineers, problem solvers; (b) investigate properties and uses of materials; and (c) persist and learn from failure. The first dependent variable was measured using the *Engineering Habits of Mind Rubric of Behavior* (see Table 2 for three levels of depth of application across each EHoM), developed by the research team. The rubric was developed by the research team and validated by our content expert, based upon the work of Cunningham and Lachapelle (2016) and the NGSS (2013).

Finally, the second dependent variable evaluated special education teachers' perceptions of and ability to generalize engineering instructional programming using an open-ended interview structure and follow-up classroom observations.

### Intervention

The independent variable in this study was the use of a modified version of the EiE curriculum. Using the UDL framework and more specifically the UDL guidelines, the research team used two existing EiE curriculum units (i.e., A Work in Process: Improving a Play Dough Process; Now You're Cooking: Designing Solar Ovens) to develop universally designed units of work (see Figure 1). The two units of work were chosen from the 20 available EiE design challenges, based upon the greatest alignment of content (i.e., science and technology curriculum outcomes) to the outlined scope and sequence of the grades of the participating students. The two treatment group classroom teachers were also part of the research team, therefore, receiving ongoing consultation with the other two research team members, to ensure procedural fidelity. All lessons were videotaped and implementation fidelity recorded for 100% of lessons. The

**Table 2.** Engineering Habits of Mind: Example of Behaviors From Playdough Process Unit.

| | Student depth of application of engineering practice → | | |
|---|---|---|---|
| HoM | Level 1 | Level 2 | Level 3 |
| Sees self as problem solver | Identify questions presented as part of lesson.<br>• S asked "what happens with hot/cold water"—while stirring mixture<br>• S indicates "too sticky—need to make high quality" in reference to playdough | Pose questions on own.<br>• "when you use pink sand (mixing chocolate)—the liquid might be pink" (referring to mixture color)<br>• "I wonder what (the mixture) it would taste like"<br>• "What if we mixed water first, then flour, then salt."<br>• "If we put more flour it will be less sticky—if we put warm water, it will stop the grainy"<br>• "My salt isn't dissolving," then he added more warm water | Identify criteria/constraint within design.<br>• S says "its bad" while spooning, and dropping mixture back into bowl (dripping)—its melts<br>• T says is it soft—yes, is it grainy—yes, S then also adds "and it's not stick"<br>• S identifies that it is sticking—"not good criteria to have."<br>• S: "I think they probably put too much water and flour; sticky playdough in the story" |
| Investigate properties and uses materials | Identifies a property of a material<br>• Describes playdough verbally/AAC as "slimy," "glooby green," "sticky"<br>• Put hands up to paraprofessional like a monster—notices "sticky" texture of playdough<br>• while washing hands—said "stuck (playdough) to my hands"<br>• testing "usability" of playdough made on Days 1, 2, and 3—marking their criteria list (e.g., stuck to cutter, easy to flatten) | Compares materials by identifying properties<br>• S says slimy, very sticky and grainy. T—asks him to explain what he means—S says, "you feel salt"<br>• S says "it came out easily" testing usability/ compared with other playdoughs<br>• S touch high quality versus low quality when asked<br>• S indicates "yes, dissolved with warm water, not cold, now just a liquid" | Selects a material to use based on knowledge of attributes<br>• S identifies what to add—based on current attributes (chooses based on knowledge of attributes of water, flour, salt)<br>• S tells peers "add water—too dry"<br>• S tells peers "its crumbly"—then adds more water |
| Persist and learn from failure | Identify something didn't work or could work better<br>• "didn't work—not enough solar" (T told them, S noted when identifying how their solar oven worked)<br>• T asks if it is high quality playdough—did it work. Yells out no—too sticky<br>• "look—look" showing teacher pencil with playdough stuck to it | Initiate/communicate that something needs to change<br>• S indicates to improve with "less water"<br>• S adds more water<br>• add "warm water"—makes it better (the playdough)—disappear<br>• T introduces "If . . . Then." S says "if too grainy—then add more water" | Does something different (change); tries new material or new way of using materials<br>• S identifies mixture needs more flour—adds on own<br>• Mixture is still sticky—T "want more flour"—"yes please." Seven students raise hand to ask for more<br>• S adds more flour—until consistency is right |

*Note.* HoM = habits of mind; S = students; T = teacher; AAC = augmentative alternative communication.

research team also met weekly to discuss lesson implementation, unit progress, and the next week's lesson plan implementation.

The control group did not receive an intervention, rather data at pretest for both groups and for the control group throughout the study were "business as usual" (1.5 hr per week of mandated science instruction). Based on the state mandated standards, all students were to engage in science and technology practices, which aligned with the three HoM this study sought to measure. During all observational assessment probes, it was assured that all students had at least one opportunity to exhibit each EHoM at each of the three levels of depth, either independently (i.e., student initiated) or with teacher direction.

*The EiE Curriculum.* The EiE curriculum consists of three components: a teacher guide, storybook, and materials kit. Each unit of work includes an EiE teacher guide, including detailed lesson plans, useful tips for lesson prep, background content, learning goals, unit-specific vocabulary lists, student planning worksheets, data collection worksheets, reflection worksheets, and assessment sheets. Each EiE unit starts with a storybook about a child who solves a real-world problem through engineering. The storybooks integrate literacy and social studies to help students understand how STEM subjects are relevant to their lives. For example, in the storybook associated with the unit on solar ovens, a young girl who lives in Africa would like to find a more sustainable way to cook, using the sun's energy.

*Universal designed EiE curriculum.* The research team modified the two EiE units based upon the UDL guidelines outlined by CAST (2018). The team worked to stay true to the original EiE curriculum units, only modifying elements as needed to eliminate barriers for learning, communication, and engagement (e.g., adding images to the existing vocabulary list, adding additional key vocabulary students may need to describe a material). Research and evidence-based practices for teaching students with ID and ASD (Browder et al., 2014; Wong et al., 2014) were embedded throughout all units (see Figure 1). Specifically, explicit (e.g., model-lead-test, example/nonexample concept train-

| | Provide multiple means of **Engagement** *The WHY of learning* | Provide multiple means of **Representation** *The WHAT of learning* | Provide multiple means of **Action & Expression** *The HOW of learning* |
|---|---|---|---|
| **Access** | • Task analysis (order of lesson)<br>• Real life examples – engineering jobs, hands on materials<br>• Consideration given to length and content in each lesson<br>• Opportunities for hands on investigation | • Adapted texts (teacher to read)<br>• Pictures to illustrate book ideas<br>• Colour coded graphic organisers<br>• Consistent use of NSW Foundation Font<br>• Physical objects and models | • Basic sign language/ Key Word Signs<br>• Yes/no response cards<br>• iPad response boards<br>• Choral responding<br>• Scribing/tracing |
| **Build** | • Differentiated activities based on reading/writing ability (sentence starters/prompts)<br>• Constant Time Delay<br>• Modelled and guided questioning using prompts such as *I noticed... I wonder...*<br>• Peer tutors and mixed ability grouping | • Key vocabulary cards (word and multiple image representations)<br>• Descriptive language cards (word and image)<br>• Visual representation of Habits of Mind and Engineering Design Process<br>• Virtual manipulatives<br>• Video clips to support understanding of key vocabulary | • Key vocabulary cards<br>• Response boards<br>• Prompting hierarchy (Least Intrusive Prompting)<br>• Sentence starters<br>• Think alouds<br>• Example/non-example<br>• Habits of Mind (choral responding; visual) |
| **Internalise** | • Self-assessment using criteria<br>• Feedback from teacher (verbal, visual and/or basic sign language) | • Big ideas<br>• Repeated storylines<br>• Chapter summaries<br>• Cloze passages<br>• Pre-teaching key concepts/pivotal skills<br>• Example/non-example | • Graphic organisers<br>• Highlight objective of lesson using big ideas<br>• Criteria and reflection<br>• Teacher to use think-alouds<br>• Students share and explain their work<br>• Visual and verbal self-monitoring and reflection |

**Figure 1.** Universal design for learning framework for engineering.

ing) and systematic instruction (e.g., time delay, least intrusive prompts) were embedded to provide prompting and error correction.

The storybooks were shortened, and chapter summaries were added using repeated storylines to highlight key ideas shared in the chapters of the storybook. When appropriate, additional or earlier science concepts were added to the lessons (e.g., 15 min added to lesson to teach, or review, that the sun is in the sky during the day and provides heat).

Finally, while not a component of UDL, if a student needed an adjustment for their own communication or support needs, those were also planned for (e.g., overlay board with images of key description words for a student who uses an augmentative alternative communication [AAC] device). However, if it was possible to include those same words/images on the interactive Whiteboard for all students to use during the lesson, this was included as a universally designed method of expression and engagement.

*Implementation of UDL EiE curriculum.* Each of the two classrooms completed one unit (Term 2, solar ovens; Term 3, playdough process) over 10 weeks of school. In the solar oven unit, students were introduced to the concepts of thermal insulators and conductors, and tested different materials to find the best insulators. As green engineers, they designed and tested their solar ovens. In the playdough process unit, students used solids, liquid, and chemical engineering to improve and design a "better playdough." Lessons typically lasted between 60 and 90 min, and they were taught between 2 and 3 times per week. All lessons followed an eight-step task analysis: (a) introduction, (b) big idea, (c) key vocabulary, (d) story, (e) investigation, (f) respond, (g) question/sharing time, and (h) self-assessment. Both treatment classrooms taught the same lessons, using the same task analysis. Although the EiE curriculum is divided into four lessons plus an introductory lesson, our units were then subdivided (e.g., Lesson 3A, 3B, 3C) depending on the level of support students needed to complete investigations and/or the amount of additional science or math content embedded into the engineering design task. For example, to test the design of the solar ovens, students needed to collect data on the temperature of their oven over time. Many students did not know how to read a thermometer; therefore, additional math instruction was embedded into the lesson on how to use measurement tools. The solar oven unit consisted of seven lessons, and the playdough process unit was taught over 11 lessons. All lessons were videotaped for observation and coding. Teachers implemented the UDL

EiE units in whole class groups (12 or less students), with many of the investigation steps of the task analysis occurring in small groups of two to four students. Teachers could choose to repeat whole or parts of lessons depending on the pace and understanding of the group.

## Analytic Techniques

*Coding of Videos.* All engineering lessons were videotaped using an iPad and uploaded onto a secure digital platform. The first author viewed each video (40–90 min lesson) a minimum of 3 times to code all behaviors identified as an EHoM, based on the *Engineering Habits of Mind Rubric of Behavior* (see Table 2 for reference to the three levels of application per HoM). With up to 12 students in one class, the researcher would watch two to three students at a time and code their behaviors, then repeat watching the same lesson coding for two to three more students. This was repeated until all student behaviors were observed.

A rubric was completed for each student in the control and treatment group. All behaviors were coded on an Excel spreadsheet, identified by lesson number, and time stamped. The behavior was coded based upon level of application, as well as if it was teacher directed, student self-directed or if the student did not respond or exhibit the behavior at any point during the unit of work. During one unit of work, multiple videos were coded. Therefore, to summarize a student score for the unit, the deepest level of EHoM application exhibited during the unit was then used for further statistical analysis (e.g., Level 2, student directed vs. Level 3, teacher directed). Although it is assumed that a Level 3 application is a deeper application than a Level 2, we did not weight the scores: as we could not assume that a Level 3 application was 3 times as hard/deep than a Level 1. Therefore, the research team coded each level individually, reporting an overall EHoM score, as well as a growth score for each level of application. Descriptive statistics were used to investigate student outcomes across each of the HoM, levels, and student initiation.

*Inter-observer agreement (IOA).* IOA was taken by another member of the research team on 20% of the lessons from both the control and treatment groups across pre- and postmeasures. Based upon the behaviors coded by the first author, IOA was conducted on 20% of those behaviors. The second coder watched a randomly selected 15 to 20 min portion of each lesson and identified which EHoM the student exhibited, the level of application (Levels 1, 2, 3), and if it was teacher or student directed. IOA was 98% agreement.

*Statistical Analysis.* The analysis was conducted using a Wilcoxon–Mann–Whitney test in Stata (Version 15.1). The Wilcoxon–Mann–Whitney test is a nonparametric analogue to the independent samples *t* test and can be used when you do not assume that the dependent variable is a normally distributed interval variable (we only assumed that the variable is at least ordinal). The repeated measures were obtained at different time points (pretest, after Unit 1 and after Unit 2) across both the control and treatment groups. We constructed a new variable for each level and pair of time points that was a participant's difference in score between the two time points: then analyzed whether the rank of these differences in score was significantly different between treatment and control groups. We wanted to test if the change in score is different between treatment and control groups, separately for each pair of time points. For example, we wanted to determine if there was a statistical difference between the control and treatment groups in each of the three EHoM that we investigated (i.e., problem-solving, investigation of properties and uses of materials, persist and learn from failure).

In addition, we also wanted to determine if the same level of differences would be found across all three levels of student depth of application, in which a student may exhibit each EHoM. Because the primary purpose of this study was to examine a differential effect between the treatment and control groups, the statistical tests of interest were the interaction terms. It was hypothesized that the students in the treatment group would have greater gains (i.e., greater mean differences from pretest to posttest) than the gains of the control group resulting in an interaction.

# Results

All 21 students in the treatment group increased their displays of EHoM from pretest to final observation. A statistically significant difference was found between the control and treatment groups across all three EHoM. In addition, students in the treatment group were able to demonstrate depth of application of EHoM across all three levels, including both student- and teacher-directed behaviors.

## EHoM

*Wilcoxon–Mann–Whitney.* First, the dependent variables were examined for accuracy of data entry and missing values. Table 3 reports the difference in EHoM between treatment and control groups across each of the three HoM separately for each pair of time points. Statistical significance was found across the total scores for each of the three HoM:

**Table 3.** Difference in Engineering HoM Between Treatment and Control Groups for Each Pair of Time Points.

| | Prob >\|z\| | | |
|---|---|---|---|
| HoM | Pretest vs. mid | Mid vs. final | Pretest vs. final |
| Problem solve | | | |
| Level 1 | 0.0872 | 0.2000 | **0.0002** |
| Level 2 | 1.0000 | 0.3488 | 0.2468 |
| Level 3 | **0.0426** | **0.0012** | **0.0002** |
| Total | **0.0418** | **0.0000** | **0.0292** |
| Investigate | | | |
| Level 1 | 0.7063 | **0.0118** | **0.0000** |
| Level 2 | **0.0025** | 0.1664 | **0.0002** |
| Level 3 | **0.0053** | 0.0512 | **0.0000** |
| Total | 0.1937 | **0.0087** | **0.0000** |
| Persist and learn | | | |
| Level 1 | **0.0004** | **0.0274** | **0.0000** |
| Level 2 | **0.0002** | 0.1317 | **0.0000** |
| Level 3 | **0.0002** | 0.0943 | **0.0000** |
| Total | **0.0004** | 0.0658 | **0.0000** |

*Note.* Significance at a level of .05 is bolded. HoM = Habit of Mind.

problem-solving ($p = .029$), investigating properties ($p = .00$), and persist and learn ($p = .00$). When looking at each of the HoM and the levels of depth of application, the only area in which a statistical difference was not found was problem-solving, Level 2 (pose questions). This is likely due to pretest difference found only within this one HoM and level of application between the control (zero students) and the treatment groups (four students) exhibiting this behavior.

*Descriptive Statistics.* During pretest, most students in both the control and treatment groups demonstrated no response across each of the three EHoM and three levels of application. However, after engineering instruction, all students in the treatment group progressed from no responses during pretest to either a teacher or student directed response after the second unit (i.e., posttest, final). This means that there was not a single student in the treatment group who did not show growth across at least one EHoM.

*Sees self as a problem solver.* In the control group, two less students demonstrated a Level 1 application from pretest to posttest, and there was only an increase by one student for Level 2 application. However, in the treatment group, there was an increase by 15 students in Level 1 application, by eight students in Level 2 application, and by 11 students in Level 3 application.

*Investigate properties and uses of materials.* In the control group, nine students increased in Level 1 application; however, no students demonstrated a growth in Levels 2 and 3 application of this HoM. In the treatment group, there was an increase in EHoM outcomes with all 21 students exhibiting this behavior at a Level 1 application, 11 students at Level 2, and 14 students at Level 3.

*Persist and learn from failure.* In the control group, one less student demonstrated a Level 1 application from pretest to posttest, and there was no increase in Level 2 and 3 applications. However, in the treatment group, there was an increase by 18 students in Level 1 application, 17 students in Level 2 application, and 19 students in Level 3 application. Table 4 shows the outcomes for the treatment group across each HoM and level of application. It should be noted that during pretest no students exhibited the most complex level of application across the three HoM. After engaging in the engineering units, eight students demonstrated teacher directed and three students self-initiated *Problem-Solving* at the most complex levels. Similarly, 14 students exhibited teacher directed *Investigation of Properties and Uses of Materials* and 19 students demonstrated the behaviors of *Persist and Learn from Failure* at the most complex level. Due to the unique nature of ways in which students could exhibit (e.g., actions, verbally) each of the three HoM across the three levels of application, a wide range of behaviors were coded across the two engineering units. Table 2 provides EHoM example behaviors from the playdough process unit.

## Teachers Implementation of Engineering Education

The second dependent variable of this study was teacher ability and self-perceptions of teaching engineering curriculum to students with ID. Both teachers in the treatment

**Table 4.** Pre/Postoutcomes for Treatment Group Across HoM, Levels, and Initiation.

| HoM | Level 1 (Less complex) | Level 2 | Level 3 (Most complex) |
|---|---|---|---|
| Sees self as a problem solver | | | |
| Pretest | 17 no response<br>2 T directed<br>2 S directed | 17 no response<br>4 S directed | 21 no response |
| Final posttest | 2 no response<br>19 T directed | 9 no response<br>11 T directed<br>1 S directed | 10 no response<br>8 T directed<br>3 S directed |
| Investigate properties and uses of materials | | | |
| Pretest | 17 no response<br>2 T directed<br>2 S directed | 21 no response | 21 no response |
| Final posttest | 0 no response<br>7 T directed<br>14 T directed | 10 no response<br>10 T directed<br>1 S directed | 7 no response<br>14 T directed |
| Persist and learn from failure | | | |
| Pretest | 19 no response<br>2 T directed | 21 no response | 21 no response |
| Final posttest | 1 no response<br>14 T directed<br>6 S directed | 4 no response<br>16 T directed<br>1 S directed | 2 no response<br>19 T directed |

*Note.* HoM = Habit of Mind; T = Teacher; S = Student.

group had not engaged in engineering curriculum prior to this study. During classroom observations, both teachers were able to use the engineering task analysis with 100% procedural fidelity across all lessons, as well as implement all components of the UDL EiE lessons, as planned based upon the UDL guidelines (CAST, 2018; see Figure 1).

*Teacher Perceptions and Social Validity.* Both teachers participated in postintervention interviews. When asked how they felt engineering curriculum was important to their students, they indicated that it "created opportunities to build skills that can be used academically, socially, and in future work situations." Noting that the curriculum provided "authentic real-life problems" and that through their students learning EHoM, they gained "thinking strategies important to everyday life," such as how to "investigate ideas and materials," students "create and test ideas," and this "encourages persistence and creativity." Teachers were also asked what the most important component of engineering learning was in the primary classroom. Both educators talked about the need for "explicitly teaching students to problem solve," "to be persistent and investigate," then providing opportunities for students to develop these skills through the curriculum and other academic/social opportunities. Solving real-world problems was mentioned multiple times, with both teachers emphasizing students need to learn scientific facts, and engineering strategies to guide thinking. One teacher mentioned that the engineering design process outlined within the lessons and used through all lessons and units "gave students a structure to follow."

Both teachers found UDL a key element of planning, instruction, and assessment because it "allowed us not to have to do things 'differently' for one kid," mentioning "multiple response modes were used across all lessons, such as response cards, physical objects and pictures to select." One teacher mentioned the need to still adjust the lessons based on specific communication needs when necessary (e.g., AAC). When asked how they think these UDL EiE lessons would support students without disability, they both agreed that the lessons and response modes are appropriate for all learners to increase engagement and support the learning in any classroom.

The teachers were asked to reflect upon their own growth as an engineering curriculum teacher. They noted that they were limited in their original understanding of what engineering was, how it was different from science education, and they were not familiar with the EHoM. They also noted that their original focus in instruction was on content, rather than teaching students how to problem solve, communicate, or exhibit HoM. However, after participating in this study, they felt they had a strong understanding and both educators wanted to support their colleagues to also build these HoM within their teaching. One teacher said, "I now understand and am a strong advocate for how important they [HoM] are for my students' whole life development and growth living in our society today and into the future beyond school life." Finally, both teachers echoed that HoM (i.e., persist and learn) was important not only for education in the classroom but also in future life within the community. One teacher noted that some students already have questioning skills—but they are limited, and engineering curriculum can grow this in students, linking to so many practical applications across other subject areas (e.g., math, literacy) as well as the community.

## Discussion

The purpose of this study was to explore the impact of universally designed engineering instruction on the EHoM of students with extensive support needs. This study found that students with ID and ASD can build their EHoM across multiple lessons and units of work. Specifically, there was a statistically significant difference of these HoM between students who engaged in engineering curriculum versus those who did not. Through the use of the UDL guidelines, teachers were able to develop engineering units that removed potential barriers for their students, such as prior knowledge, limited receptive and expressive communication skills. Just as important to the feasibility and maintenance of these learning behaviors, the teachers in this study serving students with ID found it possible and socially important to develop and implement quality engineering curriculum to their students.

Although noteworthy growth in the field of science education for students with ID has occurred over the past two decades, severe disabilities has not yet ventured into the world of STEM education holistically. As found in the review of the literature by Knight et al., what we call STEM is somewhat limited by a narrow view of science. Even innovative research teaching students with ID and ASD to follow task analysis to code robots (Knight et al., 2018) has limited depth into the practices outlined by NGSS. Potentially, the most important rationale for engineering education is to guide students to grow within their development of initiation, thinking, collaboration, and problem-solving skills (i.e., self-determination).

### Limitations and Future Research

Several limitations to this study suggest areas for future research. First, this study focused narrowly on the application of engineering curriculum in separate classrooms within a separate school for students with ID. Although this study provides one of the first investigations of EHoM for students with ID, including those with comorbid ASD, more research is needed to investigate the use of the UDL guidelines and EiE lessons within inclusive elementary and secondary classrooms, with more specificity to allow for replication. Similarly, there is a dearth of studies exploring engineering instruction for people with developmental disabilities in general, particularly individuals with complex communication challenges. Future researchers should continue to investigate what instructional supports are needed for students with ID to independently participate in engineering design challenges.

Second, the control group did have significantly more students with ASD ($n$ = 13) than the treatment group ($n$ = 6). It is not known if this affected the outcome of students' growth within demonstrating EHoM. Due to the nature of ASD, further research and analysis of data is needed to investigate specifically how ASD may or may not affect student development of EHoM. Specifically, initiation and communication are both skills that greatly impact students' engagement in engineering curriculum. As we know that these are often skills identified for development for this population of students, it would be important to identify if students with ASD need more support than their peers with other disabilities.

Third, the validity of the measure used to code student EHoM during the engineering lessons is limited. While the *Engineering Habits of Mind Rubric of Behavior* was developed using the expertise of a content expert (endowed STEM professor) and NGSS standards, the scoring rubric describes general, synthesized criteria that were witnessed across individual behaviors and, therefore, cannot feasibly account for the unique characteristics of every behavior (Moskal & Leydens, 2000). This study did try to control for the potential variability of interpretation of behaviors through IOA and transparency of what was coded (see Table 2). More attention is needed to develop and validate assessment rubrics that would allow researchers and educators alike to identify when/how students with complex communication and support needs exhibit EHoM. In addition, research is needed investigating what engineering behaviors look like expanding beyond the three HoM of this study.

Finally, it should be noted that even though the treatment group had more students with moderate ID than the control group (higher number of students with mild ID), the treatment group far out performed the control group, revealing that there may be less of a connection between the severity of the disability and the opportunity to learn and engage in universally designed engineering curriculum and problem-solving.

### Summary

Prior research in STEM for students with ID has significantly lacked in the area of behaviors of learning, specifically science and engineering HoM. The first outcome of this study was the level in which students who participate in engineering curriculum grew in their ability to engage in the science/engineering lessons. Students not only started to pose questions but also those questions grew in depth across units. Prior research in engineering for this population has focused on students coding robots using a task analysis (Knight et al., 2018) or identifying new vocabulary associated with STEM concepts (Heinrich et al., 2016).

Previous research studies in the field of engineering for students without disabilities has primarily focused on student interest in and self-perceptions of engineering and STEM education (e.g., Capobianco et al., 2011; Pantoya et al., 2015). A large majority of this research has been qualitative in nature, including case study analysis of young children working together in engineering type challenges (e.g., building a bridge). This study is the first of its kind to investigate the development of HoM across time using a quantitative research design. In addition, it is the only study to investigate the development of HoM for students with ID (with or without ASD). The significance of this study is sizable, as it challenges the notion of what high quality engineering curriculum can look like for students with limited expressive and communication skills, limited engagement, and problem-solving skills. This study sets forth the idea that to develop meaningful curriculum for all students—including those with extensive learning and communication needs—UDL may provide educators a framework and guidelines to reduce barriers, therefore building important student learning dispositions.

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