Engineering for All

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Introduction

The National Science Education Standards (NSES) provided educators with priorities and a framework for science education, with the release of the Common Core State Standards (CCSS; National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010) in English and mathematics. Next, a national call for updated science standards was met in 2012, with the NRC's development of a conceptual framework to guide the next set of science standards. A specific focus of the *Framework for K-12 Science Education* (NRC, 2012) was on the development of science education that cultivated student engagement in experiencing science, with the emphasis away from "scientific inquiry" (NRC, 1996) towards "engagement in scientific and engineering practices" (NRC, 2012). From this new framework came the development of the *Next Generation Science Standards* (NGSS; Achieve, Inc., 2013) providing learning progressions that break down the content and practices across the K-12 grade span. The NGSS Framework identified the following eight scientific practices essential for all students to acquire: (1) asking questions, (2) developing and using models, (3) planning and carrying out investigations, (4) analysing and interpreting data, (5) using mathematics and computational thinking, (6) constructing explanations, (7) engaging in argument from evidence, and (8) obtaining, evaluating and communicating information (NRC, 2012).

Science Instruction and Disability

Whilst the research literature on teaching science to students with severe disabilities was growing (Spooner, Knight, Browder, Jimenez, & DiBiase, 2011) this new set of standards introduced a new 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 disabilities; however, the literature on teaching science practices is still limited and engineering practices non-existent. In the most recent review of the literature by Knight et al., (2019) synthesising the recent research for teaching science to students with intellectual disability/autism, only twelve methodologically sound studies were located. Differing from previous literature reviews focused on science content (Courtade, Spooner, and Browder, 2007), this review of the literature sought to determine the evidence for teaching science practices (e.g., asking questions, communicating findings). Although Knight et al. 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 et al., 2013). Additionally, while 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, analyse/interpret data, construct explanations, argue from evidence, and obtain, evaluate, and communicate information.

Although all eight science practices were identified across the twelve studies found in Knight et al., the level in which students exhibited science habits of mind (HoM) were somewhat limited. For example, some of the ways in which students engaged in science practices 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, 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 STEM related outcomes. Heinrich et al. (2016), investigated the effects of systematic instruction to teach STEM content to three secondary students with moderate intellectual disability. Students were taught geometric figures, science vocabulary, or use of technology to publish and chained tasks, such as Punnett square from a peer or teacher assistant. Along with the need for further development and depth of application of science practices for students with intellectual disability and ASD, Knight et al., also comment that additional research is needed on the teaching of engineering practices, 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” (p. 5; Cunningham & Carlseon, 2014). Scientific problems may be “solved” through the development of evidence and data to support a general knowledge claim, 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 maths, to solve practical problems, even without deep disciplinary understanding (Cunningham & Carlson, 2014). Hence, engineering problems and design challenges can be developed that are challenging and productive, while accessible to young learners (Levy, 2012). 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 (e.g., investigating factors that affect spring length in mechanical systems; Schauble, Klopfer, & Raghavan, 1991). In science, we begin with conceptual models; whilst engineering typically ends with something real, concrete and usable. Addressing engineering’s relevance to helping people may engage students with intellectual disability and ASD. While socially directed, engineering capitalises on the personal relevance (Trela & Jimenez, 2012) of science and math curriculum, through engineering design challenges situated within real-life contexts.

Engineering is Elementary. One specific research-based curriculum focused on engineering education for young children is the Engineering is Elementary (EiE)® program. EiE is a curriculum that introduces primary school-aged children to principles of engineering and technology. The impact of EiE has been evaluated and data suggests that EiE materials are engaging for girls, children of colour, children from low socioeconomic groups, and children with disabilities (i.e., learning disabilities and ADHD) and have resulted in learning gains related to both engineering and science (Gruber-Hine, 2018; Lottero-Perdue et al., 2011; Lottero-Perdue & Parry, 2017). In a 2011 study by Lachapelle, Cunningham, Jocz, Phadnis, et al., statistical analysis compared EiE student performance on post-assessments against the pre-assessment on five engineering units using t-tests and confidence intervals. Lachapelle et al. found that EiE students participating in all five units improved significantly on engineering questions ($p<0{,}001$) and science questions ($p<0{,}001$).

In the seminal work of Rutherford (1991), *Science for All Americans* defined "habits of mind" as "the values, attitudes, and skills that shape our outlook on knowledge and learning." Based upon the National Academy of Engineering's six 'ways of thinking' (1) systems thinking, 2) creativity, 3) optimism, 4) collaboration, 5) communication, and 6) ethical considerations; 2009). The developers of EiE have identified sixteen EHoM (e.g., develop and use processes to solve problems, construct models and prototypes, make evidence-based decisions, investigate properties and uses of materials) embedded within and throughout all EiE units.

To date, several studies indicate positive outcomes for the use of the EiE curriculum in primary classrooms; however, no research exists to support its use with students with intellectual disability. Even more specifically, no research exists to support engineering curriculum and/or Engineering habits of mind (EHoM) with this population of students.

Purpose of this Study

The purpose of this study was to investigate the impact of engineering curriculum on building the EHoM of primary students with intellectual disability and autism. We also had a strong interest in exploring the use of research- and evidence-based practice to support universally designed engineering curriculum. Universal Design for Learning (UDL is a framework for planning, teaching and assessing that offers all students equal opportunities to learn (Hall, Meyer & Rose, 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 framework 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" (National Center on Universal Design for Learning, 2012).

Our research team sought to use a model of pre-planning Universally Designed engineering curriculum using the EiE program, rather than retro actively adjusting, lessons and activities that take into consideration potential barriers students may have to access the content (e.g., reading skills, prior knowledge, level of vocabulary), '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), or engage in the learning task (e.g., attention, previous successes in content area, organisation skills).

Through this research study, three research questions were addressed:

1. What is the effect of universally designed engineering curriculum on the EHoM of primary students with intellectual disability and autism?

2. What is needed to universally design the Engineering for All curriculum to provide accessibility to all students using the Universal Design for Learning framework?
3. What is the effect of the use of the EiE program on special education teacher ability to teach high quality engineering curriculum to students with intellectual disability and autism?

Method

This study utilised a quasi-experimental control group design. Students with intellectual disability and autism were assigned into either a treatment or control group. All participants were pre-tested at the beginning of the academic year before treatment was implemented and post-tested 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 in Year 3/4 and two in Year 5/6) participated in the study. All student participants met the eligibility criteria that included the following: a) mild to moderate intellectual disability, with or without comorbid autism, b) enrolled in years 3-6, 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 curriculum with their classmates.

Description of Participants

The 43 student participants were enrolled in Years 4-6 at a school for students with an intellectual disability. All of the participants had intellectual disability 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 indicate no statistically significant differences ($p > .05$) between the control and experimental group for gender or ESL. T-Test analyses indicated a minor difference ($p < .05$) between the control and experimental group for age. Although minor differences were noted, all students were enrolled in grades 4,5, and 6. The students in the experimental group were actually younger (mean age 9.8) than their peers in the control group (mean age 10.9). Comparison of group differences at pre-test found no significant differences between the groups on any of the dependent variables (i.e., three EHom).

There was a significant difference between the experimental and control group for number of students with a mild versus moderate intellectual disability, the control group had double the number of students with a mild disability than the experimental. Additionally, the control group had more students with ASD ($n = 13$) than the experimental group ($n = 6$). Implications of these differences between the control and treatment groups will be discussed further in the discussion section of this report.

The four teachers who administered the control and experimental intervention, were all separate, primary, special education teachers. All four teachers had experience teaching science curriculum; however, none of the teachers had previously taught engineering curriculum.

Assignment of classes. Two teachers were initially identified to investigate the effect of engineering curriculum on their students' EHoM. The control group participants were then chosen based on the same age and year level. For example, the two experimental teachers taught students in Years 3-6. Therefore, the two control group teachers taught the other two Year 3-6 classes. This simple, sampling method was chosen because it was feasible to the logistics of the applied context. Further matching by type of disability, gender, or age was not feasible given the small sample size. Because of the small sample sizes in the group, statistical tests for examining the mean differences between the experimental and control groups on the pre-test measures were conducted. Initial statistical analyses indicated that both groups were equivalent for all pre-test 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 to focus outcomes on. The three EHoM chosen based consultation with an expert in elementary engineering and science education and the use of the EiE curriculum. Via her consultation, our research team chose three EHoM identified as essential to active and engaged participation in the units that would be taught. The three EHom were: 1) See themselves as engineers; problem solvers, 2) Investigate properties and uses of materials and 3) Persist and learn from failure. The dependent variables in this study included the *Engineering Habits of Mind Rubric of Behaviour* (see Table 4 for three levels of depth of application across the three EHoM), developed by the research team. The rubric was developed based upon the work of Cunningham and Lachapelle (2016) and the *Next Generation Science Standards* (NGSS, 2013).

The second dependent variable was an evaluation of the instructional strategies and supports needed to universally design the pre-existing EiE curriculum for accessibility of all students using the UDL Guidelines (Cast, 2018). Finally, using an open-ended interview structure and follow-up classroom observations, special education teachers' perceptions of and ability to generalise engineering curriculum programming was evaluated.

The control group did not receive an intervention, rather data at baseline for both groups and for the control group throughout the study was "business as usual". Based on the state curriculum, all students were to engage in Science and Technology practices, which aligned with the three HoM this study sought to identify within students' behaviours. 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 directed) or with teacher direction.

Intervention

The independent variable in this study was the use of the Engineering is Elementary (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. The two units of work were chosen from the twenty 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 year/stage levels of the participating students. The two classroom teachers of the intervention group participants were also part of the research team; therefore, receiving ongoing classroom consultation with the other two research team members, to ensure procedural fidelity.

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 developed the two Universally Designed EiE units. 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, as needed (e.g., adding images to the existing vocabulary list, and adding additional key vocabulary students may need to describe a material). Research- and evidence-based practice (e.g., task analysis, least to most prompting, constant time delay) for teaching students with intellectual disability and autism (Browder, Wood, Thompson, & Ribuffo, 2014; Wong et al., 2013) were specifically embedded throughout all units (see Figure 2). The storybooks were shortened, and chapter summaries were added using repeated storylines to highlight key ideas shared in the chapters of the storybook. If appropriate, additional science information (often early science topics) were added to the lessons, based on student prior knowledge (e.g., fifteen-minute section added to lesson to teach, or review, that the sun is in the sky during the day and it helps to warm us up). Finally, whilst not a component of UDL, if a student needed an adjustment for their own communication or support needs, those were plans for (e.g., overlay board with images of key description words for a student who uses an augmentative alternative communication (AAC) devices. However, if it was possible to also include those same words/images on the smartboard 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 EiE Curriculum Unit (Term Two, Solar Ovens; Term Three, PlayDough Process) over ten weeks of school. Lessons typically lasted between 60-90 minutes and were taught between two-three times per week. All lessons followed an eight-step task analysis; 1) Introduction, 2) Big idea, 3) Key vocabulary, 4) Story, 5) Investigation, 6) Respond, 7)

Question/sharing time, and 8) Self-assessment. Both of the intervention classrooms taught the same lessons, using the same task analysis. Whilst the EiE Curriculum is divided into four lessons plus an introductory lesson, our units were often then subdivided (e.g., Lesson 3A, 3B, 3C) depending on the level of support students may have needed to complete investigations and/or the amount of additional science or maths 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 of our 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 eleven lessons. All lessons were videotaped for observation and coding. Teachers implemented the UDL EiE Units in whole class groups (twelve or less students), with much of the investigation step of the task analysis occurring in small groups of two-four students. Teacher could choose to repeat whole or parts of lessons depending on the pace and understanding of the group.

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 minute lesson) a minimum of three times to code all behaviours that could be identified as an EHom, based on the *Engineering Habits of Mind Rubric of Behaviour* (see Figure 1). With up to twelve students in one class, the researcher would watch two-three students at a time and code their behaviours, then repeat watching the same lesson coding for two-three more students. This was repeated until all students within a class were observed and their EHoM were coded for.

A rubric was completed for each student in the control and treatment groups. All behaviours were coded on an excel spreadsheet, identified by lesson number, and timestamped. The behaviour was scored for the level of application, as well as if it was teacher directed (1) or student self-directed (2). If the student did not respond or exhibit the behaviour at any point during the unit of work, a score of 0 was coded. During one unit of work, multiple videos were coded. Therefore, to summarise a student score for the unit of work, the highest level of behaviour exhibited during the unit was then used for further statistical analysis (e.g., level 2, student directed or level 3, teacher directed). Although it is assumed that a level 3 behaviour is a deeper application than a level 2 or 3, we did not weight the scores; as we could not assume that a level 3 application was three times as hard/deep than a level 1. Therefore, the research team coded each level individually, reporting an overall HoM score, as well as a growth score for each level of application. Additionally, descriptive statistics were used to investigate student outcomes across each of the HoM, levels and student initiation.

Inter-observer agreement. IOA was taken by another member of the research team. IOA was taken on 20% of the lessons from both the control and treatment groups. Then from those lessons, 20% of the behaviours coded by the first author were then coded for IOA. The second coder watched a randomly selected portion of a lesson (i.e., video number and timestamp) and identified which EHoM the student exhibited, the level of application (level 1,2,3), and if it was teacher or student directed. IOA was 98% agreement.

Analytic Techniques

The analysis was conducted using a Wilcoxon-Mann-Whitney test in Stata (version 15.1). The Wilcoxon-Mann-Whitney test is a non-parametric analogue to the independent samples t-test and can be 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 (baseline, after Unit 1 and after Unit 2) across both the control and experimental 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 analysed 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/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 group in each of the three Engineering HoM that we investigated (i.e., problem solving, investigation of properties and uses of materials, persist and learn from failure).

Additionally, we also wanted to determine if the same level of differences would be found across all three levels (see Figure 1) of student depth of application, in which a student may exhibit the 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 pre-test to post-test) than the gains of the control group resulting in an interaction.

Results

All 21 students in the treatment group increased their exhibits of EHoM from baseline to final. A statistically significant difference between the control and treatment groups across all three EHoM. Additionally, students in the treatment group were able to demonstrate depth of application of EHoM across all three levels, including both student and teacher directed behaviours.

Engineering Habits of Mind

Wilcoxon-Mann-Whitney. First, the dependent variables were examined for accuracy of data entry and missing values. Table 2 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 is found across the total scores for each of the three HoM; Problem Solving ($p = 0.029$), Investigating Properties ($p=0.00$) and Persist and Learn (p=0.00). 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 baseline difference found only within this one HoM and level of application between the control (zero students) and the treatment group (four students) exhibiting this behaviour.

Descriptive statistics. During baseline, most students in both the control and treatment groups demonstrated no response across each of the three HoM and three levels of application. However, after the Engineering Units all students in the treatment group progressed from no responses during baseline (pre-test) to either a teacher or student directed response after the second unit (i.e., post-test, final). This means that there was not a single student in the treatment group that didn't show growth across at least one HoM.

Sees self as a problem-solver. In the control group, two less students demonstrated a level 1 application from pre-test to post-test, and there was only an increase by one student for level 2 application. However, in the treatment group there was an increase by fifteen students in level 1 application, eight students in level 2 application, and eleven 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 by eighteen students exhibiting this behaviour at a level 1 application, eleven students at level 2, and fourteen students at level 3.

Persist and learn from failure. In the control group, one less student demonstrated a level 1 application from pre-test to post-test, and there was no increase in level 2 and 3 applications. However, in the treatment group there was an increase by 19 students in level 1 application, 17 students in level 2 application, and 19 students in level 3 application.

Table 3 shows the outcomes for the experimental group across each HoM and level of application. It should be noted that during baseline no students exhibited the most complex level of application across the three HoM. After engaging in the engineering units of work, eight students demonstrated teacher directed and three students self-initiated *Problem Solving* at the most complex levels. Similarly, fourteen students exhibited teacher directed *Investigation of Properties and Uses of Materials* and nineteen students demonstrated the behaviours 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 behaviours were coded across the two engineering units. Table 4 provides examples of EHoM Behaviours from the Playdough Process unit.

Universally Designed Engineering Units

The second dependent variable in this study was to identify what elements of Universal Design for Learning were needed in order to remove barriers to learning for all students using the Engineering is Elementary (EiE) program. The specific research and evidence-based strategies used to universally design engineering curriculum are outlines in Figure 2, based upon the UDL Guidelines. Specifically, explicit (e.g., model-lead-test, example/non example concept training) and systematic instruction (e.g., time delay, least intrusive prompts) was embedded throughout all lessons to provide student prompting and error correction.

Teachers Implementation of Engineering Education

The third dependent variable of this study was teacher's ability and self-perceptions of teaching engineering curriculum to students with intellectual disability, with or without comorbid ASD. Both teachers who taught students in the experimental treatment 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 2).

Teacher perceptions and social validity. Both teachers participated in post intervention 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", 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 them with opportunities to develop these skills, through the curriculum and other academic and social opportunities. Solving real world problems was mentioned multiple times by both teachers, emphasising that students will also 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 learnings 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 the 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 & Learn) are 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, Engineering curriculum can grow this in students, linking to so many practical applications across other subject areas (e.g., maths, and literacy) as well as the community.

Discussion

Major Findings

This study found that students with intellectual disability 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 verses those who did not. Through the use of Universal Design for Learning guidelines, teachers were able to develop curriculum 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 behaviours, the teachers in this study serving students with intellectual disability and ASD found it possible and socially important to develop and implement high quality engineering curriculum to their students.

Differences in Control and Treatment Groups. It should be noted that even though the experimental group had more students with moderate intellectual disabilities than the control; the findings of this study showed that the treatment group far out performed the control group. This demonstrates that there may be less of a connection between the severity of the disability; than the opportunity to learn and engage in engineering curriculum and problem solving.

Finally, The control group did have significantly more student with ASD (n=13) than the experimental group (n=6). It is not known how this may have affected the outcome of students' growth within demonstrating the 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 in which 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.

Summary

Prior research in STEM for this population of students has significantly lacked in the area of behaviours 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; 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, Collins, Knight, and Spriggs, 2016).

Prior research studies in the field of engineering curriculum for students without intellectual disability has primarily focused student interest in and self-perceptions of engineering and STEM education. Additionally, 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 habits of mind across time using a quantitative research design. Additionally, it is the only study to investigate the development of habits of mind for students with intellectual disability and ASD. The significance of this study is large, 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 in order to develop meaningful curriculum for all students, including those with extensive support needs, Universal Design for Learning may provide educators a framework and guidelines to reduce barriers; therefor building important student learning dispositions.

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Table 1
Description of Experimental and Control Groups

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

Note: ESL – English as a Second Language, LBOTE-Language Background other than English
N = number of participants, M = Mean

Table 2
Difference in EHoM between treatment and control groups for each pair of time points.

		Prob > |z|		
		Baseline vs mid	Mid vs final	Baseline 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 0.05 is bolded.

Table 3.
Pre/Post outcomes for treatment group across HoM, levels and initiation.

		Level 1 (Less Complex)	Level 2	Level 3 (Most Complex)
Sees Self as a Problem Solver	Baseline Pretest	18 no response 2 T directed 2 S directed	18 no response 4 S directed	22 no response
	Final Posttest	3 no response 19 T directed	10 no response 11 T directed 1 S directed	11 no responses 8 T directed 3 S directed
Investigate Properties and Uses of Materials	Baseline Pretest	18 no response 2 T directed 2 S directed	22 no response	22 no response
	Final Posttest	0 no response 7 T directed 15 T directed	11 no response 10 T directed 1 S directed	8 no responses 14 T directed
Persist and Learn From Failure	Baseline Pretest	20 no response 2 T directed	22 no response	22 no response
	Final Posttest	1 no response 15 T directed 6 S directed	5 no response 16 T directed 1 S directed	3 no responses 19 T directed

S = student, T = teacher

Table 4

Engineering Habits of Mind: Example of Behaviours 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.** ○ S asked 'what happens with hot/cold water' – while stirring mixture ○ S indicates 'too sticky – need to make high quality	**Pose questions on own.** ○ "when you use pink sand (mixing chocolate) - the liquid might be pink" (referring to mixture colour) ○ "I wonder what (the mixture) it would taste like" ○ what if we mixed water first, then flour, then salt. ○ "if we put more flour it will be less sticky - if we put warm water, it will stop the grainy" ○ S says 'my salt isn't dissolving' – then he adds more warm water	**Identify criteria/ constraint within design.** ○ S says 'its bad ' while spooning, and dropping mixture back into bowl (dripping) - its melts ○ T says is it soft - yes, is it grainy - yes, S then also adds "and it's not stick" ○ S identifies that it is sticking – "not good criteria to have". ○ 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** ○ Describes playdough verbally/AAC as 'slimy', 'glooby green', 'sticky' ○ Put hands up to TA like a monster - "notices 'sticky' texture" ○ while washing hands – said 'stuck to my hands' ○ testing 'usability' of playdough 1,2,3 - then marking their criteria list (e.g., stuck to cutter, easy to flatten)	**Compares materials by identifying properties** ○ slimy, very sticky and grainy. T - asks him to explain what he means - she says, 'you feel salt' ○ "it came out easily" testing usability/ compared to other playdoughs ○ Touch high quality vs. low quality when asked ○ S indicates "yes, dissolved with warm water, not cold, now just a liquid"	**Selects a material to use based on knowledge of attributes** ○ S identifies what to add - based on current attributes (chooses based on knowledge of attributes of water, flour, salt) ○ S tells peers 'add water - too dry' ○ S tells peers 'its crumbly – add more water'
Persist and learn from failure	**Identify something didn't work or could work better** ○ "didn't work - not enough solar" (T told them, S noted when identifying how their solar oven worked) ○ T asks if it is high quality playdough - did it work. Yells out no - too sticky ○ "look - look' showing teacher pencil with playdough stuck to it	**Initiate /communicate that something needs to change** ○ S indicates to 'improve with 'less water' ○ S adds more water ○ add 'warm water - makes it better (the playdough) – disappear ○ 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** ○ S identifies mixture needs more flour - adds on own ○ Mixture is still sticky - T 'want more flour' – "yes please". Seven students raise hand to ask for more ○ S adds more flour- until consistency is right

T= teacher, S= student

Figure 1.
Universal Design for Learning Framework for Engineering

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