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Project-based learning (PBL) in Science, Technology, Engineering and Mathematics (STEM): Perspectives of Students with Special Education Needs (SENs)

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Abstract

This study analyzes the engagement of students with SENs when a STEM Project Based Learning (STEM PBL) method of teaching was implemented. Qualitative and quantitative data were collected to ascertain students' and the teacher's perspectives of STEM subjects, understanding and engagement in a STEM PBL approach, and changes in STEM skills. The results revealed that students had improved perceptions of some STEM subjects after the study. Results also showed that students were academically successful, engaged, and enjoyed the STEM PBL environment. Some STEM skills, both the teacher and students, improved throughout the study. The teacher showed improvements in some perceptions related to STEM and his ability to teach using STEM PBL, despite not having prior experience. This study demonstrated the positive impacts of using a STEM PBL approach when teaching students with SENs, and the possibilities for teacher development when employing this technique.

Keywords and Abbreviations

ADHD	Attention deficit hyperactivity disorder
ASD	Autism Spectrum Disorder
BSCS	Biological Sciences Curriculum Study
GCSE	General Certificate of Secondary Education
IEP	Individual Education Plans
IPRC	Identification, Placement, and Review Committee
IBL	Inquiry-Based learning
PBL	Project-Based learning
SENs	Special Education Needs
STEM	Science, Technology, Engineering and Mathematics

Summary For Lay Audience

The study conducted focused on using a teaching approach whereby Science, Technology, Engineering and Mathematics (STEM) fields are integrated in a Project-Based learning (PBL) framework. The students in the study have special education needs (SENs); most with anxiety. The teacher was not familiar with the STEM PBL approach. In this approach, students are given projects with well defined outcomes and tasks that can be accomplished in a variety of ways. Students are creative in their approach and learn important real world skills while completing activities and learning content. This study collected different data including student work, class observations, surveys, interviews, and attendance. The study found that students were successful when learning in a STEM PBL format. They enjoyed themselves more and worked harder in class. The teacher was successful teaching through this method and due to the success, he intends to use it again. Students and the teacher improved their STEM skills, and students improved some of their perceptions of STEM subjects. Moving forward, more schools and teachers can be confident in the various benefits for teaching students through a progressive approach, specifically STEM PBL.

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Introduction

Having skills related to science, technology, engineering and mathematics (STEM) are considered critical in the current globalised economy (Langdon, Beede, & Doms, 2011), and having technological and mathematics literacy skills is becoming increasingly important when relating to a variety of different jobs in the 21st century (Decoito, 2016). STEM literacy is fundamental for individuals to have successful work and social lives (Bybee, 2010), however students who have special educational needs (SENs) often struggle in these contexts and are not given the support to help them succeed, especially at the high school level (Schneider, Krajcik, Marx, & Soloway, 2002).

There is a global problem regarding STEM education, and it is difficult to determine best practices in a variety of different contexts. Educational systems globally have not been able to address the societal changes regarding STEM skills and the necessity of changing current teaching pedagogies, especially when relating to students with SENs. STEM-based educational reforms have become more prominent in schools, and rethinking the separated-subjects approach is often a point of focus (Capraro, Capraro, & Morgan, 2013). The types of teaching pedagogies employed in STEM reform often revolves around student-centred approaches, with a focus on creativity and skill development (Glennie & Mason, 2016). The overarching goals of these reforms are to increase general STEM literacy for all people and increase post-secondary enrollment leading to careers in STEM fields (Decoito, 2016). These goals are often presented without changes in the curriculum, which may facilitate student development. The onus for change is often expected from teachers, individual schools, or school boards. Specifics regarding the implementation of these alternative teaching methods are addressed in a more local context

(Sinay, Jaipal-Jamani, Nahornick, & Douglin, 2016). Consequently, there are also issues regarding the enactment of more holistic STEM education, especially in terms of the inclusion of all students.

Students with SENs may struggle to fit into traditional educational environments because they may have a different understanding of social interactions or subject content. Thus, strategies must be employed that will provide opportunities for students to succeed (Green, 2014). The Government of Ontario believes all people should have access to an excellent educational system, as illustrated in their mission statement: "Our education system will be characterized by high expectations and success for all" (Ontario Ministry of Education, 2014b, p.1). To achieve this success, curriculum and policy need to accurately reflect the struggles and concerns that teachers and students face daily.

There are a variety of issues related to STEM education and students with SENs. These issues include teacher preparation, content knowledge, pedagogies, and the ability for teachers to differentiate for a multiplicity of SENs in students. Added to the aforementioned challenges is the fact that mathematics and science teachers require more specific skills and content knowledge which limits the success of STEM programs in a variety of contexts (DeCoito & Myszkal, 2018; National Research Council, 2010). Not all STEM teachers are qualified for teaching students with SENs, which likely impacts the effectiveness of pedagogies implemented with these students.

Canada currently lacks specific policy regarding STEM education and is not producing enough STEM graduates, especially when considering diversity (DeCoito, 2016). Ontario should strive to be a leader in effective progressive education in STEM fields while being inclusive of students with SENs. Kohn (2008) explains that progressive education does not have a specific definition but holds specific values. These values include: attending to the whole child, community, collaboration, social justice, intrinsic motivation, deep understanding, active learning, and taking kids seriously. The values and concepts of progressive education are just as crucial as the pedagogies used to implement such models.

Progressive education

Past research (Scheider, Krajcik, Marx, & Soloway, 2002) has shown positive effects of more progressive and alternative teaching methods when compared to traditional methods, especially regarding students with SENs (Han, Capraro, & Capraro, 2015). Teachers can sometimes struggle while teaching subject matter with numerous learning objectives to students with SENs. Developing and testing resources and methods that facilitate teaching these subjects to students with SENs would help equip educators in their practice.

In Canada, there is a gap in educational research exploring teaching strategies, and the relationship to student learning in STEM fields. This gap is exacerbated when looking at students with SENs. Inquiry-based learning (IBL) (Carlone, Haun-Frank, & Webb, 2011) with a focus on project-based learning (PBL) (Gültekin, 2005) is shown to increase proficiency and engagement in students across subjects. These findings have been observed on a broad spectrum to improve achievement in students with SENs more than students without, but specifics regarding these SENs and the relationships have not been examined (Han, Capraro, & Capraro, 2015). PBL is a progressive teaching method organized around learning through projects and is currently being used in a variety of schools (Thomas, 2000). It has been successful in facilitating the retention of knowledge while students learn skills and develop projects. Thomas (2000) amalgamated a definition of projects as complex tasks based on challenging problems. These tasks allow students to design, problem-solve, investigate, and make decisions, thus developing student autonomy. PBL also focuses on the process of completing the projects, not only the final product.

Teachers have additional struggles when employing new teaching methods. In addition to understanding and implementing curriculum, they may also be faced with additional requirements when considering private schools with authority to grant credits (Ontario Ministry of Education, 2013). Introducing new methods can cause additional concern to specialized private schools who wish to integrate a variety of pedagogies into their program, while still meeting additional standards required by the government. For example, the traditional teaching methods in single STEM subjects are typically didactic, especially for science and mathematics. This includes teachers explaining concepts to students who memorize and regurgitate the information. Student-centred teaching and learning approaches encompass a variety of different progressive teaching pedagogies. As well, many progressive teaching pedagogies allow for assessment in alternative ways that may increase success for students with SENs. Effective STEM education can be taught through student-centred approaches which shifts the onus of knowledge from the teacher to the student and can include a variety of teaching methods such as IBL, emergent education, universally designed lessons, and PBL, to name a few. This type of pedagogy has been shown to increase content retention and critical thinking skills (Han, Capraro, & Capraro, 2015).

Progressive education is often challenging to implement effectively in classrooms as a result of the lack of alignment in teacher education programs and professional development initiatives. Providing teachers with training, resources, and curriculum that maximizes available time may help them optimize the educational partnership between students and teachers (Kokotsaki, Menzies, & Wiggins, 2016). As mentioned previously, PBL is a progressive approach to teaching and learning that helps students experience and engage in the learning process (Thomas, 2000).

STEM PBL

STEM PBL involves an integrated approach to teaching STEM subjects through PBL pedagogies (Capraro, Capraro, & Morgan, 2013). This means that the project involves more than one of the STEM subjects to help students solve a problem. A basic framework behind the creation of STEM PBL is using a well-defined outcome as a goal while students explore an ill-defined task (Han, Capraro, & Capraro, 2014). Students should reach goals at the end of their project, but the specifics of what they create are not defined. STEM is often difficult for students with SENs because they may not possess traditional learning skills, may have issues with authority, or may struggle with anxiety or other factors that limit their learning (Green, 2014). Since STEM PBL is successful and engaging for the majority of students, it is worth exploring how students with SENs relate to a PBL focused curriculum.

Scope, Context and Purpose of the Study

Scope. This descriptive case study aimed to examine the perspectives of students with SENs and their teachers' experiences and perspectives related to STEM PBL pedagogies. The study also sought to explore student skill development in a variety of STEM fields. In the case of students, the goal was to assess the impact of STEM PBL on students' perspectives and skills in STEM. For the teacher, the goal was to understand the growth, development and perspectives related to their experience while implementing and assessing STEM PBL. This research utilized a case study in order to assess the impact of STEM PBL on students with SENs.

Context. The research study occurred in a private school, with a focus on enrichment and support for students, in South Western Ontario. The school has been authorized to provide credits towards the Ontario Secondary School Graduation Diploma. Their mission is to inspire intellectual curiosity in students and integrate current knowledge, technology and opportunities to help students build skills for the future. They customize learning and strengthen skills in a creative and collaborative environment while providing small class size environments.

Specific characteristics of the school made it conducive for this study, including the types of students, the class sizes, and the duration of a term. The school’s population is comprised of Grade 7-12 students, most of whom left public school due to lack of success in previous schooling environments. The school's student population align with both the age category and demographics I was interested in exploring, given much of the literacy and current practices around using an integrative and progressive approach to learning is focused on a younger demographic. Students at this school are enrolled in all academic classes. Many of the students are from low socioeconomic backgrounds and have low numeracy, scientific, and English literacy skills. This school also has a higher Indigenous population compared to other schools within the area. Statistically, Indigenous peoples have a lower rate of participation in STEM fields compared to other groups in Ontario and Canada (Statistics Canada, 2016). Indigenous students commute to and from their reservation via a school bus as there is no public transportation from their homes. If they miss the school bus they either miss the school day or are transported by a family member.

The school has small class sizes which vary from three to ten students, with an average size of five students. Students also consecutively enrol in one class thus fulfilling Ministry requirements of 110 hours. The term length means that for approximately one month, students are studying only one subject all day. This is unique and preferred as this allows teachers to ensure they relate to the individual needs of each student. In addition, students at this school have individual plans; thus, in-depth knowledge of each student in the study is attainable. Together, these features of the school and students provide an ideal model as it will allow for lengthy periods of time for students to develop their projects in the study.

The aforementioned features of the school directly align with the values espoused in progressive education and integrate well with a STEM PBL framework. Challenges to implementation involve the integration of STEM subjects in the school, given the orientation of courses in the Ontario science curriculum. The curriculum documents encourage teachers to use an integrative approach (Ontario Ministry of Education, 2008a, b), but as the specific curriculum documents are not integrated and there is no alternative model which allows for integration, it is challenging to track required documentation in a way that is conducive to the Ministry's specifications. It is noteworthy to mention that in the current Ontario science curriculum document, a specific integrated approach is non-existent, and all STEM subjects are taught separately, with their specific objectives (Ontario Ministry of Education, 2008a, b). Although there are some connections between STEM subjects for specific objectives, these are quite limited.

PBL has the potential for success at this school as students are not restricted by a short amount of consecutive class time and by learning multiple subjects concurrently. Additionally, the reorganization of student timetables is often cumbersome in traditional schools because students have different schedules, and such a study would require that they forfeit time in different classes to facilitate long enough periods for inquiry and experimentation.

Finally, students within this school have high levels of anxiety in many social situations and while completing assessments. Most of the students at the school have Individual Education Plans (IEPs) that include an anxiety disorder. Through volunteering at the school, I learned that students generally feel less anxious when doing a project compared to a test, and many of the teachers currently require students to complete final projects.

In summary, there is currently a wealth of knowledge around the effectiveness of STEM PBL for students. Unfortunately, this concern has not been extended to students with SENs. This research aimed to address areas in the literature where there are gaps related to this student population. Additionally, the teachers' changing perspectives while implementing STEM PBL pedagogy and personal perspectives throughout the study were explored. The findings aim to provide a better understanding of how to effectively implement STEM PBL with SENs student populations.

Statement of problem.

Teachers can sometimes struggle with teaching students with SENs, especially when the teachers are not comfortable teaching STEM content (DeCoito & Myskzal, 2018; Nadelson, Callahan, Pyke, Dance, & Pfiester, 2013). There has been little research regarding STEM PBL and students with SENs. The existing research does not expand on the types of SENs, despite addressing SENs (Han, Capraro, & Capraro, 2015).

The following research questions explored the influence of a STEM PBL pedagogical approach on students and their classroom teacher:

1. a) What perspectives do students and their teacher have of PBL in STEM?

   b) Do these perspectives change over time? If so, why do they change? How are the changes manifested?

2. a) What is the teacher's understanding of PBL and assessment in STEM?

   b) Does the teacher's understanding change throughout the research study?

3. Do students' and the teacher's STEM skills change as a result of project-based learning? If so, how are the changes manifested?

Researcher Positionality

Creswell (2013) explains the importance of addressing the researcher's positionality and subjectivity. Researchers must be aware of their subjectivities, which they may bring to the research and try to counter this bias. The concerns around subjectivity are essential and can often be addressed through a sizeable detailed data pool and triangulation of the data.

It is also essential that a researcher reflects on their practices during the length of the study and consciously try to limit the effects of biases. The researcher is often recommended to provide information regarding their personal history, educational and work backgrounds, and the reason for their interest in the subject material they are exploring. Below is a description of my educational experiences and positionality related to the subject matter.

I started my post-secondary educational career with an undergraduate degree in Kinesiology from York University. As a high-level competitive athlete, sports allowed me to become invested in coaching at the age of 13. This love of coaching fueled my critical decision to enroll in education. During my Bachelor of Education program, I was a student of my current supervisor, Dr. Isha DeCoito.

After graduating with a Bachelor of Science and a Bachelor of Education with specialties in biology and science, I was eager to enter the teaching profession. I quickly learned of a waiting list to become a teacher in Toronto and decided to pursue my teaching career in the United Kingdom. Here I learned the differences in educational systems between countries and the impact on students and teachers. This facilitated my exploration of different educational models comparing my personal experiences between Ontario, England, and eventually exploring the systems of a multitude of provinces and countries.

I worked in London, England, for two years and noticed the focus of the schooling system on standardization and knowledge acquisition, rather than critical thinking skills or student understanding. This experience fuelled me to challenge how and why educational systems function. I was personally disappointed with the focus on products, the appearance of a focus on student progression, lack of innovative pedagogies, activities and authentic inquiry. The governmental pressures from the Office for Standards in Education known as OFSTED (Jeffrey & Woods, 1996) and the pressure from student General Certificate of Secondary Education (GCSE) success (Embse, Schoemann, Kilgus, Wicoff, & Bowler, 2017) caused me significant stress, in addition to being a new teacher at a new school.

I was confident in my teaching abilities and content knowledge, but struggled to teach using more traditional methods and classroom management strategies. In addition, many students did not respond positively to progressive pedagogies, as they felt uncomfortable in new situations, and other teachers did not employ the same strategies. Students wanted notes and ‘knowledge’ from the teacher, simply to pass their GCSEs and not because they were interested in classroom activities. Many parents felt similar and wanted to see their child’s notebooks filled with well-written notes. In my practice, I taught students with a variety of learning disabilities including dyspraxia, dyslexia, autism, and attention deficit hyperactivity disorder (ADHD), and witnessed firsthand how these students were excluded from subjects in STEM because of their perceived difficulty. Moreover, I felt that many teachers were not addressing students who were experiencing a variety of different challenges. Despite only having two years of teaching experience, I was able to engage in a variety of different after-school programs at the schools I taught. I was able to participate in lesson studies and curriculum development groups with experienced teachers. Many of these teachers wanted to employ different strategies, but these teachers were not usually within STEM fields.

In considering my teaching experience and personal education, I became extremely interested in genuine inquiry, subject integration, learning through projects, and bringing these strategies to classrooms in a variety of settings with students from diverse backgrounds. I have seen the effects of school-related anxiety on children. My sister was a school refuser based on anxiety and attended a variety of regular and alternative schools, most of which did not fit her needs. Even though some of the teachers did an outstanding job teaching students and had high levels of content knowledge, they did not teach skills that can potentially help students succeed outside of school. Progressive integrative teaching was not present in any of the schools where I worked. A combination of these reasons fuelled my decision to pursue a graduate program in education and to further my personal knowledge of more innovative pedagogies and how to engage a wide range of students with differing levels of ability.

The aforementioned reasons further fostered my interest in STEM PBL as a strategy for helping students with SENs learn STEM skills and content knowledge. The school in which I conducted my research focusing on students with SENs does not currently take an integrated approach to STEM subjects. I have volunteered in this school on a few occasions with different teachers, and I believe that this will limit the observer effect (Martella, Nelson, Morgan, & Marchand-Martella, 2013). In the study, I seek to develop a depth of understanding of each student and their interaction with STEM PBL.

Conceptual Framework

The conceptual framework which underpins my research study relies on a constructivist worldview. Participants will have some prior knowledge of STEM and a variety of STEM skills. Creswell (2013) explains that the constructivist worldview seeks to establish the meaning of a phenomenon from the viewpoints of the participants. He explains that within this worldview, it is essential to look at not only the data provided but also the behaviours of participants as they engage with activities. Within this framework, I seek to explore if there is a change in participants' worldview as it will allow me to understand the context in which they engage in knowledge construction. This exploration will also allow me to understand the teacher's personal growth, a component of my research. I will be using a few different lenses to inform my research. These concepts will be explored through the study of students' and the teacher's perspectives of STEM fields and PBL.

Jerome Bruner, an educational psychologist proposed that learners construct their own knowledge and do this by organizing and categorizing information using a coding system. Bruner was a proponent of constructivism and he explained four significant aspects related to constructivist theory (1966). First, he focused on the predisposition towards learning. Within this concept, I explored how both students and the teacher relate to concepts in the course and STEM fields as a whole through data related to the attitudes and growth of the teacher and students. Secondly, how knowledge was structured to facilitate student understanding of the content is explored through students' reaction to the teaching and learning of content knowledge through STEM PBL pedagogies. Constructivist theory also assesses if and how the material is presented in the most effective sequence. This assessment is achieved through anecdotal evidence of students' content knowledge before starting the projects, and the process students engaged in to complete the tasks. Finally, this model explored concepts involving reward, punishment, and motivation. In this study, additional rewards or punishment compared to the traditional classroom are not included. Changes in students' motivation may be due to the effects of PBL on student autonomy. There are alternative explanations relating to student autonomy, which will be discussed further in the analysis and conclusion sections.

Significance of the Study

There are currently gaps in the literature in terms of STEM PBL in general, PBL within a Canadian or Ontarian context, and relating to students with SENs. This study has the potential to derive significant findings for STEM education, especially related to students with SENs. The conclusions could inform further research on professional development initiatives around PBL, and strategies for incorporating different methods to facilitate effective learning of STEM for a variety of students.

Environments which help students with SENs often do not focus on the development of STEM skills which are integral in preparing these students for career aspirations in STEM. Students with SENs can struggle with STEM content at both the K-12 and post-secondary levels, thus decreasing the pool of students pursuing STEM careers (Basham & Marino, 2013). Students with a variety of SENs are often capable of learning content and skills but are not provided opportunities to learn these skills because of the lack of STEM teacher training in these contexts.

Theoretical Overview and the Literature

This section will explore literature related to STEM PBL pedagogies and students with SENs. The literature was taken from texts related to STEM education, the need for STEM educational reform, including students with SENs in STEM, and teacher self-efficacy around STEM and PBL. This section will conclude by looking at how previous research informed the research methodology in my study.

STEM Education Globally and in a Canadian Context

The importance of STEM. Understanding the concept of STEM and its importance in our current global-political climate will provide clarity in terms of the concepts outlined in this research. STEM education takes an interdisciplinary approach to teaching science, technology, engineering and mathematics, often using more progressive methods founded in IBL (Capraro, Capraro, & Morgan, 2013). STEM education aims to increase STEM literacy in students, increase the number of students entering university in STEM disciplines and subsequently entering the workforce in these fields (Decoito, 2016).

Using a STEM approach in a classroom involves integrating two or more STEM subjects (Capraro, Capraro, & Morgan, 2013). Examples of projects include building a bridge in a mathematics classroom using engineering skills or creating a computer program which can explain and demonstrate a scientific concept. STEM learning moves from a traditional form of education, where teachers have expert knowledge and 'transmit' this knowledge to the students, to a model that facilitates students' knowledge construction (Haugen, 2013).

The goal of a STEM framework is to expand on the ideas proposed within IBL and integrate them into multiple subjects. For example, Smarter Science, a Canadian organization promotes the inquiry process and dissects it into smaller steps so that both students and teachers can interact during a task (Smarter Science, Youth Science Canada, 2014). This method highlights the importance of engaging students, allowing them to explore through experimentation, and explaining and extending their knowledge. A STEM-based framework adds skills, creates environments which can connect to real-life situations, and expands knowledge in multiple ways (Timms, Moyle, Weldon, & Mitchell, 2018).

Students need critical thinking skills and STEM skills to be successful in today's society, regardless of the career they choose. A variety of soft skills and non-technical abilities can be obtained by learning through an integrated STEM approach. These soft skills are fundamental skills for successful employees in the 21st century, and include, but are not limited to, social skills, adaptability, and self-management (Kyllonen, 2013). Thus, learning STEM subjects through an integrated approach can increase retention and understanding of the material while promoting the development of both hard and soft skills (Eskrootchi & Oskrochi, 2010).

STEM skills for a global economy. Within the literature, research has shown that individuals with STEM skills increase economic growth and innovation in all places of work (Langdon, Beede, & Doms, 2011). STEM skills have a major role in much of the current economy and are essential for Canada to meet the demands required of the STEM labour force. Individuals with STEM degrees account for only 18% of the current labour force, and 41% of these individuals are immigrants (Statistics Canada, 2014a).

The lack of people with STEM degrees means that Canada is not currently inspiring enough students to engage with STEM subjects, resulting in a lack of self-efficacy in STEM and a desire to achieve a degree within these areas. Jobs in STEM fields are projected to continue to increase in number when compared to non-STEM fields (DeCoito, 2016). It is also more lucrative to earn a STEM degree or work within a STEM field as both have higher average earners compared to individuals without a STEM degree or working in a STEM occupation (Statistics Canada, 2014a).

In general, there is a shortage of STEM professionals within North America’s private sector. STEM fields, including computer science or engineering, are often in demand. However, this is not universally true as in some sectors there is a surplus of STEM professionals. There is underemployment for doctoral graduates seeking tenure track positions in a variety of fields in STEM. It is important to observe both the shortages and surpluses that are currently occurring in STEM fields (Xue & Larson, 2015). Having a higher number of STEM experts is not equivalent to providing the general workforce with a higher level of STEM hard and soft skills.

The importance of STEM skills and post-secondary education in STEM is present in a variety of contexts. The Council of Canadian Academics report show that supply and demand for STEM skills is currently balanced; however general STEM skills are lower, and there is currently room for improvement in this area (Council of Canadian Academics, 2015). The report also highlights the importance of STEM skills for innovation and productivity growth, but these skills must be accompanied by a variety of soft skills like leadership, creativity, and adaptability. Enhancing STEM skills, both hard and soft, can be addressed when teaching in a STEM PBL context.

Canadian STEM education concerns. As described above, there is concern that Canada, along with many other countries, is currently not inspiring enough students to pursue STEM studies and careers (DeCoito, 2016). Students are reluctant to enter STEM designations for a variety of reasons (Howard-Brown & Martinez, 2012). One of the most important issues addressed is the underrepresentation of minority and disadvantaged students.

Studying inequity is of paramount importance given that student demographics have been shown to moderate student interest in STEM fields (Bottia, Sterns, Mickelson, Moller, & Parker, 2015). The gaps related to economically disadvantaged and underrepresented minority groups have been shown to narrow when a school focuses on STEM education (Glennie & Mason, 2016).

Many students may not feel connected to STEM professionals as their demographics are not represented within the Ontario curriculum. The Ontario secondary STEM curriculum has little or no representation or mention of a variety of underperforming minority groups, which may further reduce student engagement (Lambie & DeCoito, 2017). There are few examples of non-white male STEM experts specifically listed in the curriculum. These underrepresented groups include women, people of colour, Indigenous peoples, and non-European peoples, which mirrors the underrepresentation within STEM fields. There is also concern that many STEM educational practices are not adapting to the innovation currently needed for student success. As discussed previously, the Ontario curriculum does mention the importance of integrating subjects but does not facilitate the integration. Many STEM teachers continue to use didactic pedagogies to teach STEM content, despite current literature demonstrating the success of progressive teaching methods in a variety of contexts (Kohn, 2008).

Finally, there is concern about the methods of evaluation in STEM when taking student anxiety into account. In the current study, almost all students in the school had moderate or high levels of anxiety, which often arose from larger social and stressful situations. The concept of test anxiety has been studied for over 50 years (Sarason & Mandler, 1952; Zeidner, 1998). STEM subjects are traditionally assessed through written testing and usually involve an exam at the end of the course. The focus on testing differs when compared to most other subjects, which allow students to create projects, essays, and presentations to demonstrate knowledge and understanding. The focus on testing increases anxiety for students who may be interested in these subjects. Moving away from a focus on testing knowledge via traditional formats to observation of student understanding and skill development could help reduce anxiety levels in students. This was particularly important to explore as high anxiety is one of the most prevalent SENs affecting students in the current research.

Students with learning disabilities in Canada

STEM fields are growing rapidly, and many students with learning disabilities may not feel comfortable or encouraged to enroll in these subjects. Given that STEM has been experiencing a lag in terms of graduates (DeCoito, 2016) it is vital to explore diverse student populations and employ different teaching strategies – for example, students with SENs in a STEM PBL environment.

Students with learning disabilities or mental illness are often not as easily identifiable as students with physical disabilities, and are also less likely to complete school (Statistics Canada, 2014a). Figure 1 explores missed opportunities and disadvantages individuals with these disabilities experience (Statistics Canada, 2014a, b), and further highlights the percentage of individuals from each group who complete post-secondary education, complete high school or do not complete high school. In summary, Figure 1 shows that non-disabled groups are more educated than those with mental health-related disabilities and even a considerable amount more than those with learning disabilities.

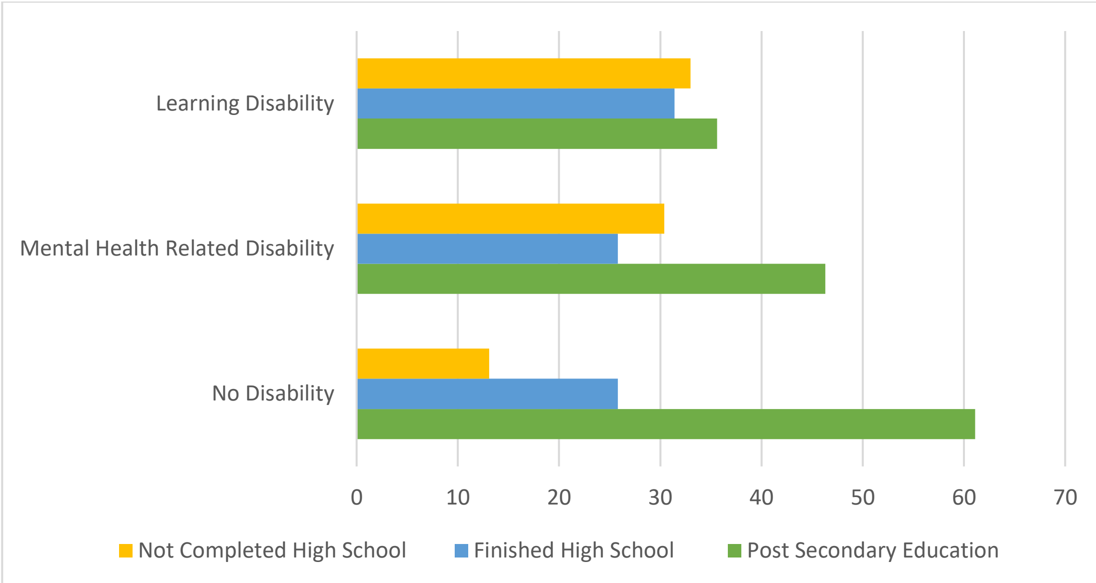

Figure 1. Educational attainment amongst individuals with mental health-related disability, learning disability, or people without disabilities (Adapted from Statistics Canada, 2014a).

Despite the disadvantages these students may face, they can succeed and pursue STEM careers in an environment that effectively facilitates their learning. Students who have autism spectrum disorder (ASD) enjoy working in STEM contexts and tend to go into these fields at a higher rate when choosing to attend university (Wei, Jennifer, Shattuck, McCracken, & Blackorby, 2013). However, there is a lower number of students with ASDs finishing high school and entering post-secondary education (Statistics Canada, 2014 b).

Teachers may struggle to differentiate instruction for a variety of student needs while learning and using new teaching methods. Using different methods to teach children with SENs may help students understand the content in a more meaningful way (Han, Capraro, & Capraro, 2015). Thus, ensuring that in-service and newly qualified teachers feel comfortable to teach using novel approaches is essential as these approaches have proven to be more successful, as discussed previously.

Students with SENs in Ontario. The study occurred in Ontario and focused on students with a variety of SENs. Therefore, understanding how students with SENs are accommodated and identified gives context to how the specific students in the study are accomodated in their school. The Education Act (Education Act, 1990) defines an exceptional pupil as 'one whose behavioural, communicational, intellectual, physical or multiple exceptionalities are such that he or she is considered to need placement in a special education program'. In this context, exceptionalities refer to a variety of students with SENs who are identified by one of five different categories, including behavioural, communication, intellectual, physical and multiple SENs (Ontario Ministry of Education, 2014a). Behavioural SENs include students who have an inability to maintain interpersonal relationships, have excessive fears or anxieties, tend to have compulsive relations or have an inability to learn that cannot be traced to other factors. Communicational SENs can include ASD, students who are deaf or hard of hearing, have a language impairment, speech impairment or learning disabilities which may be connected to processing, reading, writing, mathematics, learning skills, work habits or social interactions. Intellectual SENs can include students who are gifted, have mild intellectual disabilities or developmental disabilities. Physical SENs can include physical disability and students who have low vision. Multiple SENs include a combination of the SENs listed above. These students may need additional help from a variety of teachers who assist with a component of the student's SENs (Ontario Ministry of Education, 2014a).

The context of the school included a majority of students identified as having at least one SEN, and receiving accommodations in their classrooms. The school does not modify the curriculum requirements for students, as they are expected to achieve the objectives outlined in the curriculum documents. Instead, the school focuses on allowing all students to achieve an academic or university streamed education, and the principal of this school believes that students can achieve these standards through accommodations. This is because, in a different environment with additional supports, students can participate in schooling to a greater extent. In this school, students are in small class sizes, and teachers can interact with students on a one-to-one basis. SENs that are addressed at this school include high-anxiety, giftedness, ADHD, ASDs, dyslexia, dyspraxia, speech impairments, chromosomal developmental disabilities, social interaction difficulties, and students with a combination of several of these different SENs.

Students with SENs are identified by the Identification, Placement, and Review Committee (IPRC), comprised of at least three people, one being a principal or supervisory officer. The IPRC decides whether or not children are identified, types of SENs they have, appropriate placement for the child, and review of the identification each year. Students who are identified as having SENs have their strengths and needs outlined. Based on these strengths and needs students can be provided with academic accommodations and modifications to allow them to succeed in the educational system, including no accommodations or modifications, accommodations only, modified expectations (with or without accommodations) or alternative expectations/programs (with or without accommodations) (Ontario Ministry of Education, 2014a, 2017).

In Ontario, students with identified SENs are given IEPs. An IEP is a written plan that describes the unique educational program required by particular students based on assessments of the student's strengths and their needs. It involves a working plan which helps ensure that each student's learning is facilitated. It identifies alternative expectations and can be used as an accountability tool for students, parents, teachers and anyone else who is responsible under the plan for helping the student reach their goals (Ontario Ministry of Education, 2014a). Students in the study have IEPs including anxiety disorders, dyslexia, ADHD and ASDs. The students in this study are accomodated for their IEPs, but the curriculum expectations are not modified.

Exceptional students and invisible disabilities. Students can have a variety of SENs. Some are easily identifiable and can be addressed with minor adjustments such as providing hearing aids and printed slides of the teaching/learning material. Many SENs do not present themselves in a way that is readily identifiable to teachers. A student may seem lazy or uncooperative, but they may have an invisible disability. These are different types of anomalies that are life-limiting but not readily discernible to other people (Matthews & Harrington, 2000).

Many of the students that attended the school where my research occurred had invisible disabilities. Some examples of invisible disabilities include but are not limited to, oppositional defiant disorder, high functioning autism spectrum disorder, attention deficit disorder with/without hyperactivity, apraxia, dyspraxia, sensory processing disorder, anxiety, depression, learning disabilities, behaviour problems and a variety of other psychiatric or developmental disorders not listed above (Matthews & Harrington, 2000). When students have visible SENs in Western society, the necessary supports for those students are usually provided. Invisible disabilities can be challenging because they are often not recognized or acknowledged (Kaiser, 2018). This may make services for these students less forthcoming or easily accessed (Jahnukainen, 2011).

Many parents of students with SENs believe that private schools can address these challenges as private schools often have lower class sizes and may be able to address the concerns associated with invisible disabilities that both parents and students may face (Kaiser, 2018). The classroom in which my research was completed had seven students with a variety of SENs. The primary special educational need within this group of students was high levels of anxiety.

In addition to the number of students in the classroom, it is essential to focus on the general concept of inclusive education within the classroom, as elaborated upon by the Ministry of Education (2014a):

> [O]ne in which all students, parents, and other members of the school community are welcomed and respected, and every student is supported and inspired to succeed in a culture of high expectations for learning. (p. 53)

The focus on inclusive education is important when creating the STEM PBL curriculum, especially considering all students will have one or more SENs. The curriculum in my research study was informed by the classroom teacher and included accommodations for different students in the class. These accommodations included, but were not limited to different font styles for the student with dyslexia, alternative methods of presentation when students were not present, group size monitoring and management, technology use, and private spaces when students became too anxious or worried. Each student is considered in this inclusive education environment, and many of the lessons focused on universal design, which includes a variety of accommodations for the general lessons. Understanding more about SENs, specifically invisible disabilities, in the private sector of schooling inspired this work with students in this environment. There has been no research on exceptional students and STEM PBL in Ontario or Canada. An environment that focused on children with SENs was an optimal context for testing these ideas.

Understanding Progressive Education and STEM PBL

Learning through experiences. John Dewey (1938) explained the importance of experience-based learning and how students learn through participating in activities that are related to content. His concepts regarding progressive teaching influenced the educational profession for decades and continue to influence educators today. Traditional teaching and learning environments do not allow students to experience fully and learn the content required of STEM subjects. In general, students in these contexts learn from text or their teacher's explanations. Real world STEM experts often use experimentation, observation and testing to develop their ideas. Specifically, scientists are known to use the scientific method to observe and test phenomena, but this is also true in other areas of STEM. For example, a software developer uses their understandings of a programming language and can create a plan, observe any problems and bugs through testing, and then adapt and modify as necessary.

IBL is very similar to the scientific method as students explore to understand specific concepts and ideas. IBL was defined by the Ministry of Ontario (2013) using the work of Scardamalia (2002), as an:

> [A]pproach to teaching and learning that places students' questions, ideas and observations at the centre of the learning experience. Educators play an active role throughout the process by establishing a culture where ideas are respectfully challenged, tested, redefined, and viewed as improvable, moving children from a position of wondering to a position of enacted understanding and further questioning. (p.4)

IBL is a method in which students discover the content they are learning through activities, while PBL involves students fully exploring the knowledge through project creation. The ability to explore and connect content allows for the integration of different subjects into activities. Students can take their ideas and skills and use them to explore concepts to consolidate their understanding. For this reason, in particular, STEM learning fits well with PBL pedagogies.

In recent years, progressive pedagogies have become prominent when compared to more didactic methods of instruction. The impact of these pedagogies continues to be studied in a variety of different contexts. This study incorporated IBL and collaboration into aspects of the classroom curriculum, which facilitated knowledge acquisition. The teacher used a variety of different methods of instruction depending on the task and the course objectives. The purpose of this study was to explore if, and how students with SENs were affected by STEM PBL. Since students' prior knowledge included a working understanding of the concepts being explored in the projects, it was essential to identify the methods of instruction being used prior to the research study.

Why PBL? PBL was originally based on the work of William Kilpatrick (1918) and John Dewey (1938). They defined students as active participants in their learning rather than passive recipients of knowledge from their teachers. They believed that allowing students to be empowered through their learning is a fundamental aspect of learning.

When students construct knowledge for themselves, they are more likely to succeed in educational environments. This concept has been demonstrated in a variety of studies as PBL increases student performance on a range of standardized tests. Some critical meta-analyses involving PBL provide a more complete landscape. For example, Thomas (2000) conducted a review of research involving PBL and showed that PBL increases students' quality of subject/content knowledge. In agreement, Kokotsaki, Menzies, and Wiggins (2016) found increased test scores when comparing PBL to didactic methods. They argue that most studies have been done in a quasi-experimental way, and it is difficult to determine if PBL is indeed the cause of the increase in test scores. PBL can also change students' attitudes toward science. Haugen (2013) explained that attitudes towards being a scientist vary considerably depending on the specific measure being explored and the participants' age, ethnicity, and gender.

Why STEM PBL? PBL has grown in popularity and has been used within the educational community for many years. PBL is often confused with problem-based learning and project assessments, but they are not synonymous concepts. Capraro, Capraro, and Morgan (2013) explain that PBL is broader and is often composed of a variety of different problems that students explore. PBL brings authentic experiences that allow for the integration of concepts from a variety of subjects while engaging higher level thinking skills. The authors also detail how to develop successful PBL for classrooms and the specifics involving criteria and constraints. In my research study, the PBL learning projects were modelled and created in consultation with and informed by the literature focusing on PBL (Capraro, Capraro, & Morgan, 2013; Haugen, 2013).

There are several essential components when creating successful PBL, including a project design brief with constraints and criteria, self and peer reflections, and rubrics for both students and teachers. Within the project design brief, students should be given specifics which their projects should address. These include tasks the student needs to complete successfully in their project, and constraints in terms of the time frame, group size, documentation of work, and restrictions regarding the creation of the project. Self and peer evaluation help students measure their engagement levels and move the onus of responsibility for their actions onto themselves.

Students may complete personal logs and reports which measure the effectiveness of their time management. This helps students who may struggle with staying on task and will allow them to become aware of the inefficiencies in the use of their time.

There is also a need for rubrics that measure a variety of skills in PBL. The rubrics allow students, who may not succeed in the production of their projects, to succeed in the class if they learned the content required and engaged with the material. Having structure around an ill-defined task allows students to achieve well-defined outcomes successfully. These components all work together to create a framework that scaffolds environments that are advantageous to PBL. PBL often follows the Biological Sciences Curriculum Study (BSCS) 5E model (Bybee, Taylor, Gardener, Van, Powell, Westbrook, & Knapp, 2006) which helps create a structured environment for student learning. Figure 2 (DeCoito, 2015) illustrates the 5E model and a description of each phase as it relates to STEM integrated instruction.

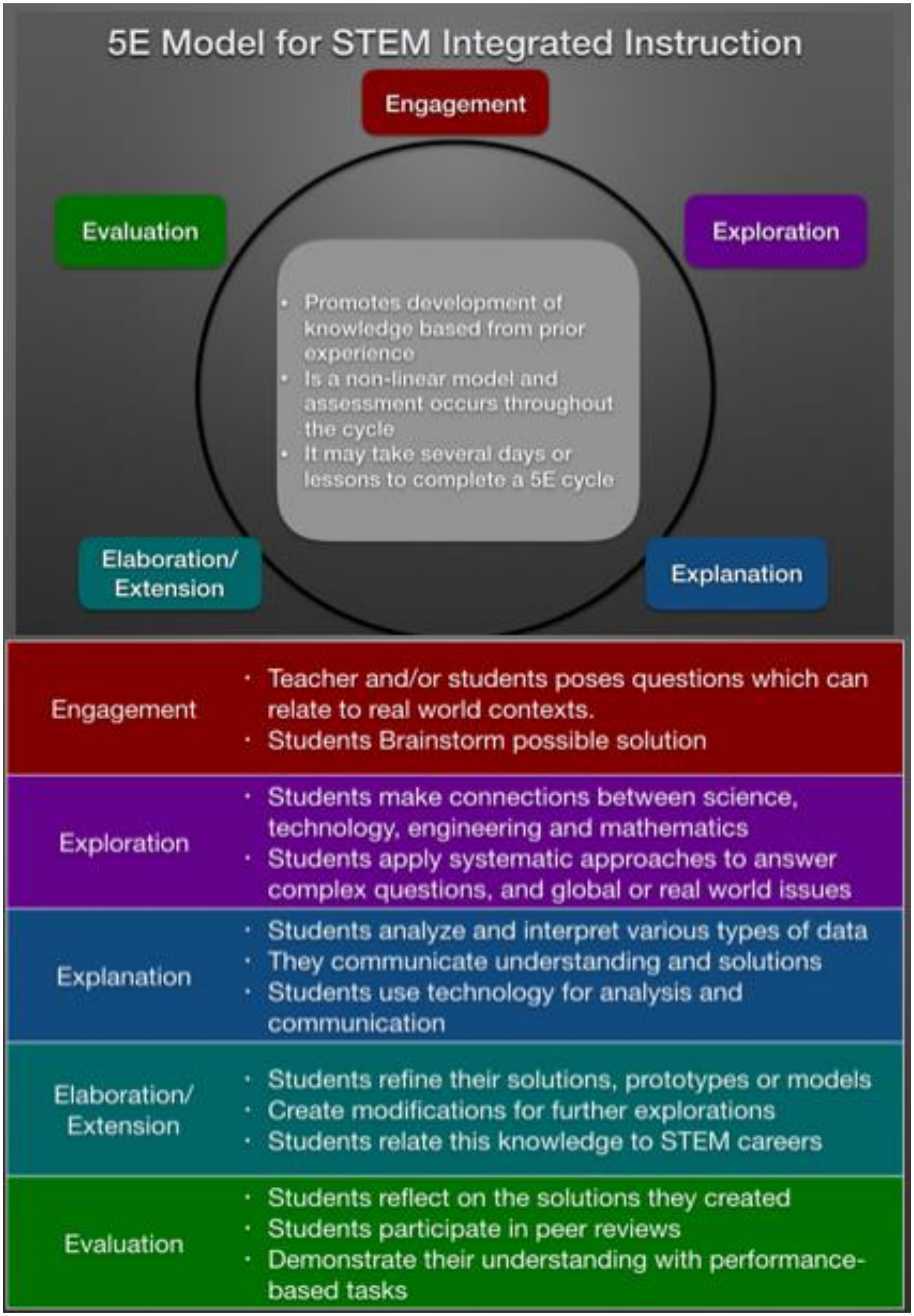

Figure 2. Alignment of the 5E Model with STEM learning (DeCoito, 2015).

Integration of STEM PBL into the classroom. Within STEM PBL, it is vital to identify how PBL will be integrated and the extent to which it will be used within the classroom. In exploring the relationship between the learning process and classroom and school setting, Capraro, Caparo, and Morgan (2013) provide a framework for contextualizing curriculum development and learning environments required to implement a particular curriculum effectively. Bonnstetter (1998) explains inquiry as an evolutionary process, with different levels within this model. In the first level of this model is a traditional hands-on verification of facts at the lowest level of inquiry, where the teacher creates all of the resources and tasks. The second level, the novice level, occurs when teachers create the outcomes and the majority of the resources, but students can define the specifics of the outcomes and artifacts which they create. The third level is the informed novice whereby students define the specifics of the outcomes, the artifacts, and the procedures. In this level, the teacher prescribes the task to be completed. The fourth is the expert level, where students create the task which they will be completing in addition to everything else listed previously. The final level is the researcher, in which students develop everything, including the topic they choose to study. This level is where the creation of new knowledge and conceptual frameworks occur.

In my research study, students worked at the informed novice level whereby the teacher created the standards, topics, tasks, and resources. Students and their teacher worked together in the procedure and design process, and students created the artifacts and outcome of the work. This level was chosen as students have limited experience within a PBL framework. The teacher provided support, but students were able to work through potential problems that they faced during the project.

Capraro, Capraro, and Morgan (2013) maintain that there is a continuum of PBL which looks at the level of integration within the classroom. For my research, the level of PBL integration is level 2, which is a themed unit. The teacher had no ability to move beyond the context of the specific course because of the format of the lessons and structure of the courses, as well as curriculum expectations. This level generally involves single classroom instruction where students work within small groups or individually to create their projects, and the teacher assumes the role of experts and not the sole provider of knowledge. The integration of STEM PBL into classrooms has been studied and will be explored in the following section.

Effects of PBL on diverse student populations. It is important to consider a variety of factors that affect educational performance in children and to take those into account when looking at PBL. Han, Capraro, and Capraro (2015) explain that throughout their study, groups who participated in PBL improved their scores on the Texas Assessment of Knowledge and Skills test. Less successful students initially showed significant improvements, which facilitated closing the gap between disadvantaged students. The study also explored student populations from low socio-economic status and found that PBL negatively impacted these students. However, those who came from minority ethnicities, ESL backgrounds, those in special education and at-risk students had significant increases in their test scores. This signals the importance of providing appropriate scaffolding for students from low socio-economic backgrounds. This paralles the trends observed in my study as several of the students are from different disadvantaged groups including low-socioecomic backgrounds, and SENs.

Students are generally more successful in smaller class sizes (Smith & Glass, 1980) and progressive education (Friesen & Scott, 2013). This is shown to be true regarding students with anxiety disorders (Kearney & Diliberto, 2013). Students diagnosed with anxiety disorders experience anxiety from a variety of situations. For example, many students normally experience situational anxiety at school including during presentations and during testing (Huberty, 2009). Anxiety disorders have been previously shown to have a negative impact on students' school performance and social interactions (Toro, Cervera, Osejo, & Salamero, 1992). Students with SENs are more likely to experience higher levels of anxiety compared to their peers without SENs (Stein & Hoover, 1989). Students with anxiety have also shown to be more responsive to progressive teaching stratagies including PBL (Kearney & Diliberto, 2013). There is currently no research involving the specifics of students with anxiety disorders learning in a STEM PBL environment. The students in my study have higher levels of anxiety and most have a diagnosed anxiety-disorder. Thus, findings from my study will address the gaps in research related to SENs and STEM PBL.

Teaching Students through STEM PBL. STEM teachers must be sufficiently prepared to teach through integrative, progressive STEM pedagogies, while at the same time having the content knowledge required to understand these content-heavy subjects. Many science, mathematics and technology teachers need better preparation to be effective educators (National Research Council, 2010). This lack of preparation is especially true with elementary-level teachers as few are trained in STEM subjects and they may skip over content which they do not fully understand or feel comfortable teaching (DeCoito & Myszkal, 2018). In my research study, the teacher participant had high levels of science and mathematical knowledge, but did not have prior knowledge related to PBL or integration of STEM curriculum.

Resources that allow teachers to engage students through inquiry and PBL are often not available in low-income areas and elementary schools. Many of these resources are expensive kits that schools may not be able to afford. Classrooms with insufficient materials or environments which are not favourable for active participation limits the teacher's ability to use these methods. The ability to take children outside for activities is also restricted in Canada, as a vast majority of school days occur during seasons in which the weather may be restrictive for activities. Without resources, space and preparation, teachers feel they are not able to successfully implement STEM teaching methods in practice, thus resulting in missed opportunities that could potentially inspire students to continue pursuing STEM education and careers.

Research evidence shows the importance of support and preparation for teachers seeking to incorporate PBL in their classrooms (Thomas, 2000). Teachers who do not have the support of their school, principal or peers struggle to successfully implement these approaches in their practice. Many teachers do not understand the difference between students completing projects and teachers using a PBL approach to teaching. In the former, projects are usually completed without collaboration with the teacher; where studens create work that is assessed by the teacher. The projects created are usually the same among all students within the class and do not reflect real-world environments or problems. Students are not given the opportunity to make decisions or choices regarding their project, and both the task and the outcomes are well defined. Students are assessed only on the final project and not on the development of the products created.

An additional important aspect that was considered when conceptualizing implementation in the current educational model was the number of learning objectives in the curriculum. Many progressive teaching methods are thought to increase the time taken to cover concepts, which make teachers less likely to use them in their classrooms. Mitchell, Foulger, Wetzel, and Rathkey (2009) illustrate how teachers can cover all learning objectives while using a PBL approach in the same amount of instructional time. In their study the teachers focused on student interests and connecting those to the learning objectives and the standards. Having more research exploring how numerous curriculum objectives can be incorporated into PBL approaches has the potential to overcome some of the perceived barriers that teachers encounter while starting to use more progressive teaching methods.

As stated previously, PBL involves an ill-defined task with a well-defined outcome (Capraro, Capraro, & Morgan, 2013). The teacher facilitates student learning and creation throughout the project, and there is a focus on process rather than the final product. Students are assessed based on a variety of different factors which may include self, peer and teacher evaluation. Projects in PBL should relate to real life situations and include skills that students learn while completing their projects (Pecore, 2015). Teachers must fundamentally understand the difference between these two concepts when thinking about incorporating PBL into their classrooms. Teachers must also be able to relinquish control to students and allow them to discover and explore the concepts while facilitating their understanding. The release of control requires patience and providing sufficient time for students to understand the concept and develop a plan related to the project they are creating (Capraro, Capraro, & Morgan, 2013). Sharing control in the classroom is not a simple task for many teachers, as they are used to providing information and being in control. Teachers must rely on the independence and motivation of students to complete the project and request assistance, as needed.

STEM PBL involves the same aspects mentioned above, and can be expanded upon to provide an interdisciplinary approach. Capraro, Capraro and Morgan (2013) explain the importance of using personal logs and self-reflection to allow students to assume control of their motivation. The authors provide a series of rubrics and checklists, which teachers can use and modify to increase students' responsibility and time management. They also provide a rubric and checklist which allows the teacher to assess their own STEM PBL. The rubric includes ensuring that the teacher understands the objectives, connections, outcomes and explanation behind their projects. They also provide a checklist to ensure that the projects are standards-based. In my study, these resources were utilized to ensure that the projects were well designed and based on recommendations from the literature.

Special education teachers help address the concerns of a variety of students with SENs. Some classrooms have teachers who are not experienced teaching these students and may not know how to address their needs effectively. Students may unnecessarily struggle in school because they do not receive a type of education that can meet their specific needs. In Ontario, in 2009, there were just over 350,000 students with SENs (Bennett, Dworet, Gallagher & Somma, 2019). This population requires teachers who can differentiate instruction to address the needs of these students. Many teachers try to incorporate methods that can help these students, and often, teachers try to differentiate course materials for students. Some teachers also try to create universally designed lessons, through which all students can engage, while taking SENs into consideration. Challenges to creating universally designed lessons include time and resources. Creating universally designed lessons that take into consideration the needs of all students, while ensuring successful teaching of the specific objectives is more difficult for teachers to create than traditional lessons (Basham, 2013). Teachers who have exceptional children in their classrooms must be aware and be adaptive to help these students integrate successfully into traditional classrooms. This integration can be difficult for many students and some students may not be able to integrate into a conventional classroom. Universally designed lessons create an environment that naturally includes all students and promotes success regardless of their needs. When students lack an environment that promotes their success, they, or their parents, may seek alternative schooling environments, including both alternative public and private schools (Tomlinson, 2012).

As stated previously, PBL has been shown to work broadly with students with learning disabilities (Han, Capraro & Capraro, 2015) but the types of SENs and reasons for success have not been examined. Conducting a case study in an environment with a variety of students with SENs can potentially shed light on the reasons behind the success of PBL for these students, as is the case in my study – students are gifted, and have anxiety disorders accompanied by ASDs and dyslexia. All students in the school have not succeeded in a traditional schooling environment, and because of this, many students are currently below their grade level for English and STEM literacy.

There are several strategies for teaching learners with SENs. Green (2014) explains the importance of including people with disabilities in STEM education to help alleviate the shortage of STEM professionals. The ideas presented by Green informed the development of the STEM PBL curriculum, and explain the importance of creating universally designed lessons that are i) inclusive of all learners, ii) relevant to students, iii) technology enhanced to facilitate learning, and iv) inclusive of parents and families, if possible (pg. 59). The use of PBL also allows teachers to differentiate for a multiplicity of students. Students are encouraged to build upon the strengths of one another and develop self-confidence in their skills. Green (2014) mirrors the perspectives of Capraro, Capraro and Morgan (2013) who explain the importance of self-monitoring to help children with emotional and behavioural disorders or problems (pg. 71), including students with mild to extreme cases of anxiety, disruption, or consistent off-task behaviours. According to Green (2014), “students on the autism spectrum often succeed in STEM subjects because of their inherent structure. It is crucial for teachers to monitor whether these students possess the skills to accomplish daily living tasks and simple tasks within the classroom. Teachers of students with ASDs understand the skill sets and struggles these students experience, and also help in the social development of these students, which is critical in their development" (pg. 89). Strategies to support these students include self-monitoring, teaching fundamental skills, monitoring progress and following up on ideas. Green discusses six steps to help students advance these strategies: i) developing background knowledge, ii) discussing the knowledge, iii) modelling the knowledge, iv) memorizing the knowledge, v) giving students support during the process, and vi) allowing them to perform the concepts and skills independently. These strategies parallel those adopted in my study in a STEM PBL environment.

Gaps in the literature. Research in Canadian contexts on PBL is currently in its infancy, and more research needs to be done to uncover the effects of PBL relating to students with special needs. Within the body of literature (DeCoito, 2016; Hasni et al., 2016), few articles engaged with any topics related to PBL in Canada. One study explored teachers' attitudes towards PBL (Macmath, Sivia, & Brittonand, 2017), and another compared various progressive teaching styles related to engineering (Habash & Suurtamm, 2010). The information gleaned from these studies allows for a specific Canadian perspective. For example, DeCoito (2016) conducted a knowledge synthesis of STEM initiatives across Canada in the past ten years, which resulted in a breadth of studies in STEM education. Overall, the studies did not explore student results, how students engaged with content, or whether there were attitudinal changes in students.

Currently, there are gaps in the knowledge base regarding PBL, especially related to students with SENs. Thomas (2000) explains that most teachers have limited experience with PBL and that this has an impact on how PBL is taught and learned in classrooms. Many students struggle with learning through PBL as students need to be taught how to inquire and may struggle with open-ended inquiry, highlighting the need for longitudinal studies looking at school-wide PBL and assessing potential benefits. The comparison between classroom PBL and school-wide PBL is an important topic to explore further. Thomas (2000) explains that information and practices in PBL are not being shared with teachers and classrooms in meaningful ways. This topic was also discussed by Dewey (1938), who maintained that educators need support for their learning so that they can be effective teachers while reflecting on their practice. This concept is essential given Kokotsaki, Menzies, and Wiggins' (2016) recommendation that students should have access to support and guidance during the process. The acquisition of teaching skills in STEM PBL has not been studied, and is currently being addressed in this study through research questions 2 and 3.

Globally, there are gaps in PBL when comparing attitudes related to learning, student outcomes, and differences between marginalized students. Within STEM PBL, there are several gaps in the current literature, especially in a Canadian context. An integrated approach to teaching PBL was employed for the study; meaning the content is taught through all STEM subjects. There is limited research looking at teaching PBL through all aspects of STEM education and understanding teacher acquisition of pedagogical knowledge. The most substantial gap in the research is regarding the effects of STEM PBL on students with SENs. There is sparse research looking at specific SENs and how different types of students are affected by PBL teaching methods. Currently, there is no research looking at the impacts of STEM PBL on students with specific SENs.

Methodology

I utilized a qualitative case study design (Creswell, 2013) for my research study. The study employed mixed method techniques but the small sample size and descriptive nature of the data classified this study as qualitative. In the following sections, I explain the rationale for the chosen methodology. This includes a description of the participants, the methods used, a description of the resources created, and the data analysis.

Research Design

Qualitative case study methodology

Choosing a case-study. Due to the paucity of research in the field, a case study provides detailed information on a small number of students from which learnings can be studied in a larger population. A descriptive case study was chosen based on the nature of participants and the contextual information related to the study. The context is unique, and a case study can potentially highlight the impact of STEM PBL as a teaching strategy on students with SENs. The small cohort of students in the case study allowed me to become immersed in the environment and witness how STEM PBL impacted each student and the classroom teacher.

Case studies are a type of qualitative research which can use both qualitative and quantitative data in their analysis (Creswell, 2013). The sample size and context are essential to this type of research and even when only quantitative data is collected, the results are not expandable to a larger population. The use of multiple data sources is commonly found in high-quality case studies as it enhances credibility within the study (Yin, 2003). Data sources can include documentation, interviews, artifacts, observations, results, surveys and quizzes.

Stake (1995) and Yin (2003) explain the importance of having a constructivist paradigm as this is essential for a successful case study. Fundamentally, there is a component of subjectivity, but this does not disregard the importance of objectivity. Yin (2003) describes important reasons behind the selection of a case study. These include the focus of the study relying on how and why questions, where behaviour is not manipulated by the observer, where context is critical, and boundaries regarding phenomenon and context are not clear.

My research study was situated well within these parameters and focus on how and why students with SENs, in an alternative private school, are impacted when STEM education is implemented in the context of PBL pedagogies. The context of the study and the phenomenon are fundamentally connected, as these boundaries are difficult to separate. I contend that attitude and interest will be affected by the teacher-student interaction and the integration of PBL pedagogies.

Yin (2003) defines a variety of case study types. I utilized a descriptive case study as this type of case study can be used to describe a program and the real-life contexts surrounding the program and the population. Case studies follow the collection and analysis of other qualitative studies that happen concurrently (Baxter & Jack, 2008). Yin (2003) explains the specific steps of data analysis and the importance of reflection during this process. It is essential to understand the data holistically and not just the sum of its parts. Within this context, some assumptions must be considered. It was assumed that the participants answered the questions honestly. Triangulation of the data was conceptualized prior to the study. Triangulation refers to how multiple different data sources assess the same criteria to add depth to the data pool. In this study a variety of different data sources were used to ensure internal validity and confirm reliability.

Recruitment of participants

Data collection for the research study lasted approximately one month. I had the opportunity to volunteer at the school prior to conducting research for my study. I was invited to help perform dissections, speak as an expert on politics, and teach students basic coding using Scratch programming language. This is a smaller school, and through my volunteering, these interactions have allowed me to develop relationships within the school, specifically with students, and teachers. Creswell (2013) explains the importance of the researcher understanding factors involved in the study and limiting the observer effect. Compared to other students, students with high anxiety or other SENs may react more so to a researcher who is unfamiliar to them. This effect may be amplified because of the small class sizes within the school. Hence, my volunteering at this school potentially limited these effects. By understanding the context of the environment and participants, the researcher can strive to minimize any foreseeable disruptions.

The participants in the study included a teacher and seven students in a private school in Southern Ontario. The school has small class sizes, four teachers, and one principal. Ethical approval for the study was obtained through the Western University Non-Medical Research Ethics Board (NMREB). Each participant within the study received a formal letter that provided an outline of the study, its objectives, procedures and purposes related to the research (Appendix E-i). The letter also explained that consent could be withdrawn by participants at any stage of the research process. I ensured that all students, school administrators, and parents understood that interviews, surveys, and collection of student work was voluntary. Students and teachers were able to withdraw their consent to participate in the study at any time.

Prior to the study, consent from the teacher, parents, and students were obtained. During the study, students participated in school lunches and upon completion of the study, students were compensated with a $10 gift card for their participation.

Participants

This section includes the context of the students' educational and personal backgrounds to increase the understanding of how specific students interacted with the STEM PBL framework. Within this case study, six students were included because they consistently in attendance, and one student was excluded due to lack of attendance. This was due to factors out of the control of the schooling environment and relating to the student's family life, and was given multiple accomodations related to their lack of attendance. When this student did attend school, he was active in the class and was able to participate. The six students in this study were given non-related pseudonyms (Vincent, Michelle, Lex, Oscar, Olivia, and Emily) to protect condifentiality and anonymity (Table 1). The students in this study have been attending the school for over a year, with many attending starting from Grade 8.

Table 1

Student Profiles.

Student Name	**Student Grade**	**SENs**	**Gender**
Vincent	11	Autism, Anxiety	Male
Michelle	10	Gifted, Anxiety	Female
Lex	11	Social Anxiety	Male
Oscar	12	ADHD, Dyslexia	Male
Olivia	11	Depression	Female
Emily	12	Low literacy, Anger	Female

Vincent is a Grade 11 student who has autism. He also experiences high levels of anxiety in many situations involving schooling, and occasionally needs to be given a space to work alone to reduce his anxiety. He often has trouble with large tasks. He is comfortable with his teacher, and the teacher has a variety of tools which he uses to help him relax. Vincent gets extremely anxious during tests and exams and is provided additional time to complete these tasks.

Michelle is Vincent's sister and has skipped a grade as she was previously in the gifted stream. She is a Grade 10 aged student in Grade 11. She also has high levels of anxiety and is often triggered by the anxiety of her brother. She understands concepts quickly but can occasionally get caught up in a specific concept and believes that she does not understand it. She is also often bothered by issues which occur outside of the classroom. Throughout the school year, she had issues with significant others and friend groups, and may stop working for hours at a time because of her anxiety regarding these situations.

Lex is a Grade 11 student who struggles with school pressures and socialization. He was previously a school refuser and stopped going to public school because of the anxiety behind social interactions within school. He was less likely to refuse going to school with the smaller class sizes, which is also seen in previous research (Kearney & Diliberto, 2013). His teacher explained that he has high levels of social anxiety but usually tries not to exhibit this because it causes him to be more socially anxious. Lex is known to do less work than he is capable of and has a "I just want a 50%" attitude. He has the potential to be more successful, more creative and create interesting work when given the opportunity.

Oscar is a Grade 12 student who has been diagnosed with ADHD and dyslexia. The teachers suspect he also may be suffering from other mental health disorders. He is extremely interested in vehicles but has limited interest in schooling. He had very little success in public schools previously, and he is usually able to succeed in the classes in which he is enrolled.

Olivia has an Indigenous family and is related to the school's principal. The principal was not involved in the study except during the recruitment process, did not give special treatment to Olivia, and did not check in on the class during the study. She is a Grade 11 student who failed most of her Grade 10 courses the previous year. She was often influenced by social pressures to skip school and engage in behaviours which have been detrimental to her educational progress. Olivia realized that she would not pass high school if she did not make a change and requested to attend the school in this study. She has been diagnosed with depression and has extreme aversion to anything related to mathematics.

Emily is an Indigenous student who currently lives on Indigenous lands and takes a bus every day to the school. She is a Grade 12 student, and her younger brothers also attend this school. She is motivated to finish schooling but has had a difficult home life and educational experience. She occasionally has trouble understanding material due to lower literacy rate. She also has anger management problems, but the teacher has been working to help her succeed. She often has trouble with male authority figures, and it has taken the teacher a long time to develop a level of trust with her.

Procedures for conducting the study

A STEM PBL curriculum was utilized in the study in order to explore the research questions. In the following section, each aspect of the curriculum is explained.

STEM PBL curriculum

In consultation with a science teacher at the school, curriculum for the Grade 11 Academic Biology Course (SBI3U), was created based on the principles discussed earlier. The specific assessments included assessments “for”, “as” and “of” learning. Each of these assessments allowed the teacher to glean specific types of information about their students’ current progress from activities and work they produced. Assessment “for” learning focuses on diagnostic tests which assess the student’s current levels and allow the teacher to implement scaffolding to higher levels. Assessment “as” learning allows students to learn as they are completing a task. This is the fundamental component of PBL as students are learning and experimenting while they complete their project. Assessment “of” learning is based on the work students submit or any situation where the student receives a grade. The basic structure of the course involved a variety of activities and assessments to help introduce and teach topics to the students, as outlined below. Students at this school completed one course at a time, each term was approximately one month long and students worked on only one subject for the duration of the term.

1. Rubrics which lists the lesson number, activity name, learning objectives, types of assessment (for, as, of) to be used in the four categories – initiating and planning, performing and recording, analyzing and interpreting, and communication. The teacher used these guidelines to track student progress during the course and assess each activity completed by the students. These are listed in Appendices A and B.

2. General lessons during the course were developed following the Ministry of Ontario guidelines and objectives. The teacher used these as a guideline to teach STEM content. They were flexible to allow differentiation for students. Having activity guidelines allowed the teacher to prepare lessons after reflecting on student learning from the previous day. It is important that the students were taught the required material and that the teacher was able to determine if

students did not understand a concept and structure their teaching accordingly. The lessons can be found in Appendices A and B.

3. Details about the projects that were used for the STEM PBL segment of the course are included. Concepts from the assignments and rubrics created by Dr. Isha DeCoito were used in the creation of the STEM PBL (DeCoito, 2014, 2016). Documents include teacher and student debriefing forms and rubrics (Appendix D). Each project followed the model that was discussed previously (Capraro, Capraro & Morgan, 2013), including a description explaining the real-world applications of each of the projects. Students acted as scientists, researchers, and technology experts as they worked on their projects. Within this description, there were a series of measurable criteria that students could achieve. These objectives could be achieved through multiple avenues depending on how the students chose to address the projects. The student debriefing forms informed students as to how they were progressing during the projects and helped to inform their assessment.

As well, constraints related to resources are included, and within many of the sample project descriptions there are explanations regarding vocabulary that should be used, the time allowed during the project, constraints regarding its creation, completion of the project, and a rubric to measure success. These projects were assessed by the researcher to ensure their validity. The general rubrics (Appendix B) and assessment rubrics completed for each project were adopted and adapted from Capraro, Capraro and Morgan (2013). The teacher incorporated modifications to ensure the needs of the students were met. For these reasons, when using PBL methods, there is a significant component of work to be done before the implementation of the projects.

Data Sources

The case study involved data in the form of personal curriculum reflections, student attendance, interviews, student project artifacts, surveys, student notes, teacher observations of students, and personal classroom observations. A variety of approaches to data collection were used to ensure triangulation. Before the study began, I was able to speak with the teacher and students and created basic student profiles.

Prior to and during the study, I reflected on how the teacher was using and adapting the curriculum and kept a journal of our interactions. Pre-post student surveys were administered; once before and once after the implementation of STEM PBL. The Teacher Efficacy and Attitudes Towards STEM (T-STEM) and Student Attitudes toward STEM (S-STEM) surveys (the surveys can be obtained from the Friday Institute for Educational Innovation website, see references) which have been validated (Unfried, Faber, Stanhope, & Wiebe, 2015) were utilized in the study. Three interviews with the teacher were conducted; once before, during, and after the study. I collected student grades, student projects, and the teacher’s assessment of student progress during the unit; these were considered student artifacts. This included student notes that were completed during the unit, as well as quantitative and qualitative observational notes of classroom interactions and activities during the study.

Student profiles. Profiles of the students are described in the results section to add additional context and how their background may influence how they learn. The information from these profiles were obtained from student interviews, students’ in-class interactions during the study, and the teacher. The students’ names used in the study are pseudonyms, as is the school name and location in order to ensure anonymity.

Reflections on curriculum creation. This section of data involved personal reflections related to the creation and implementation of the curriculum. This involved my opinions regarding curriculum implementation and the teacher's prior knowledge of teaching in a STEM PBL environment. This section was only descriptively analyzed from journal entries.

Assessment, artifacts and student notes. In addition, data were collected including self, peer and teacher assessment. The collection of this data was important to interpret how students completed work and were assessed in a STEM PBL format. As discussed previously, having a variety of assessment types allow students to take responsibility for their actions and is vital in the implementation of PBL.

Photographs were taken during the study, and some online data sources from the projects created by the students were recorded. The pictures taken in the classroom did not include identifiable images of students, and most included only the products created by the students. Student notes were collected during the study — these informed sections of the artifact and further analysis. Most of the students wrote few notes during the study, but these were collected and analyzed nonetheless.

The research study obtained all assessment data given by the teacher during or after completion of the study. Collection of artifacts for the projects were in the form of, but not limited to, pictures taken of the environmental projects, document files including Microsoft Office files, online Google documents, YouTube videos, PowToon creations, posted Scratch programs, students' physical notes and assessment results. The results derived from these data sources involved explanations of the projects and artifacts created by the students. The data included some of the images of the individual projects. As a result, I was able to take the specifics of the artifacts and link them to the individual research questions. For this subset of data, the analysis completed were descriptive in nature.

Interviews.

The objective behind conducting interviews was to explore the unique perspectives, thoughts and voices of each participant. I conducted in-class interviews with students (Appendix Ci) and the teacher (Appendix Cii). The methodology followed was based on *"Interviewing as qualitative research: A guide for researchers in education and the social sciences"* (Seidman, 2006). Student interviews varied in length between five and fifteen minutes, depending on the engagement level and length of responses from students. Some students enjoyed the interviews and were willing to expand on their answers, whereas others answered questions minimally even when provided prompts to open-ended questions. It was important that students did not feel pressured to answer more than what they were comfortable with, and that they were not overwhelmed by the length of the interviews. Some students needed more time to formulate their thoughts, thus the interview data may appear miniscule when compared to the duration of the interview. The teacher interviews ranged between ten and twenty minutes. The teacher was asked additional questions, and provided more indepth responses when compared to students' interview responses. He elaborated on his answers, giving details about his experiences in and out of the classroom.

The recommended time between interviews should range between three days to three weeks, depending on the length of the study (Seidman, 2006, pg. 24). All interviews occurred during the first week, the end of the second or start of the third, and the end of the study. Interview questions were open-ended, so participants could adequately explain their experiences and ideas. The most distinguishing feature of this type of interview technique is that it involves collecting three separate participant interviews.

In my study, the student and teacher interviews were similar but explored differences in their histories and experiences. The initial student interviews focused on their educational history, their connection to PBL and STEM, and why they were currently attending the school. The second interview explored student attitudes related to learning styles, their connection to PBL and STEM, and their opinions about the course. The final interview allowed students to reflect on their experiences in the classroom, their connection to PBL and STEM, and their successes/challenges with this pedagogy. The following is a sample student interview question:

> *Given what you said previously about learning science concepts, how does learning through integrated STEM PBL change how or what you learned?*

The sample interview question is designed to shift the focus to understanding students' current and prior experiences.

The three interviews with the teacher focused on different aspects, reflecting the complexities of the teacher. The first interview focused on the teacher's life history and gave a depth of history to the context around the teacher's prior knowledge, and his perceptions of teaching, STEM education, and PBL. The second interview explored details of the experience involving teaching and learning through STEM PBL. This interview included the relationships revolving around teacher-student interactions, parents, administrators, and the wider community. Interview three reflected on the teacher's experiences during the study. This involved the intellectual and emotional connections between the teacher's work and their life.

All interview transcripts underwent qualitative analysis, and will be described in the data analysis section.

Observational data. Observational data collection tools were used to obtain holistic data involving daily activities and interactions (Cotton, Stokes, & Cotton, 2010). These included the teacher's observations of students, which is a Ministry requirement, and my observation of classroom interactions, both qualitatively and quantitatively. Teacher observations were generally used to inform observational research data. I observed the ways in which students engaged in the classroom during each of the activities, how the teacher interacted with teaching the content, and student behaviours while engaging in STEM PBL.

The qualitative collection encompassed written reflections, usually twice a day, and explored student attitudes towards learning, perceptions related to STEM, attitudes towards assessments, ability to complete tasks, and STEM skills displayed. A component of the observational data were daily class descriptions, which provided a summative assessment of how the class interacted that day, mentioning the specifics listed above. There were also daily personal observations about each student, which provided information related to how the student followed the patterns of the class. This section was analyzed through qualitative analysis, and will be described in the qualitative observational data analysis section.

There was also quantitative observational data collection which involved daily scoring of student engagement level and attitude, adapted from Jones (2009). Three types of observations of students were measured on a 5-point Likert-type scale and averaged each day. These included observations, perceptions, and independence and teamwork, as well as a section for overall engagement and comments. Observations included body language, consistent focus, verbal participation, student confidence, and fun and excitement. Perceptions included individual attention, clarity of learning, meaningful work, rigorous thinking, and performance orientation. Independence and teamwork included personal drive, grit, co-operation, and leadership.

The researcher also included daily general classroom observations, taking into consideration student-student and student-teacher interpersonal relationships. This data set was thoroughly analyzed through quantitative analysis, which will be described in the quantitative observational data analysis section. The researcher was the only coder and recorder for the study.

As discussed, participants tend to be influenced by an observer within the classroom, and given the fact that I have previously volunteered within the school, perhaps the effects will be mitigated to a certain extent.

Surveys. This study utilized the T-STEM survey and the S-STEM (Friday Institute for Educational Innovation, 2012) which were previously validated (Unfried, Faber, Stanhope, & Wiebe, 2015), and add a comparative quantitative data component to the study. These surveys measure the efficacy and attitudes towards STEM subjects. Due to the sample size, it is essential to mention that the results are not generalizable to the population. Students completed the S-STEM survey, which explores student attitude towards STEM. The teacher completed the T-STEM survey before and after the STEM PBL implementation.

These sections were thoroughly analyzed through quantitative analysis, which will be described in the data analysis section. Most data did not meet the normality requirements for analysis. However, those that did achieve normality (2) were compared using a paired t-test. Most of the analysis done for this study display the means of the data collected, complete non-parametric tests for comparison and some paired t-test. Due to the confounding variables discussed in following sections, extrapolation of these results to other populations must be done with caution.

Attendance data. Students attendance data was collected from the researcher's notes and confirmed with the school records. Student attendance from previous terms was also collected to determine if there were changes in student attendance during the study. This data was collected, and the averages for attendance during each of the courses was illustrated. This section was not analyzed further than the averages due to the high number of confounding variables which may have influenced the differences related to attendance.

Data Analysis

Across the different data sets a variety of data analysis tools were used for qualitative and quanititive data. Qualitative data were analysed in NVivo 12 software with emphasis on coding, and quantitative data were analysed using SPSS software. Figure 3 illustrates the data flow framework utilized during analysis.

In this section, the data sources, streams and the process of data analysis are briefly reviewed. There are four sources of qualitative data and three sources of quantitative data collected in this study. The first data source are student profiles, which provided contextual information about the students. The second data source included student artifacts and projects. The third data source are my reflections on the creation and implementation of the curriculum. This included a journal of reflections on the creation, implementation, and meetings with the teacher. This section of data was presented as descriptions of finished products by students and the processes that students wrote about in their workbooks. The fourth data source are the interview and observational data collected from both the teacher and students. This included a daily observational summary about the class as a whole and each student. The fifth data source is the quantitative section of the observational data. Each day students were given a score of 1-5 on a series of criteria related to their engagement during the day. The sixth source compared attendance data from previous courses to that of the course during the study. The seventh source included survey responses collected from the S-STEM and T-STEM. As previously discussed, due to the small sample size, much of the data collected were not normally distributed and as such, were assessed using non-parametric tests.

Qualitative data analysis involved an amalgamation of lexical, semantic (Bolden, & Moscarola, 2000) and pragmatic coding. The lexical analysis involved looking at specific word counts and comparing these in different situations. This allows for a broad interperation of the

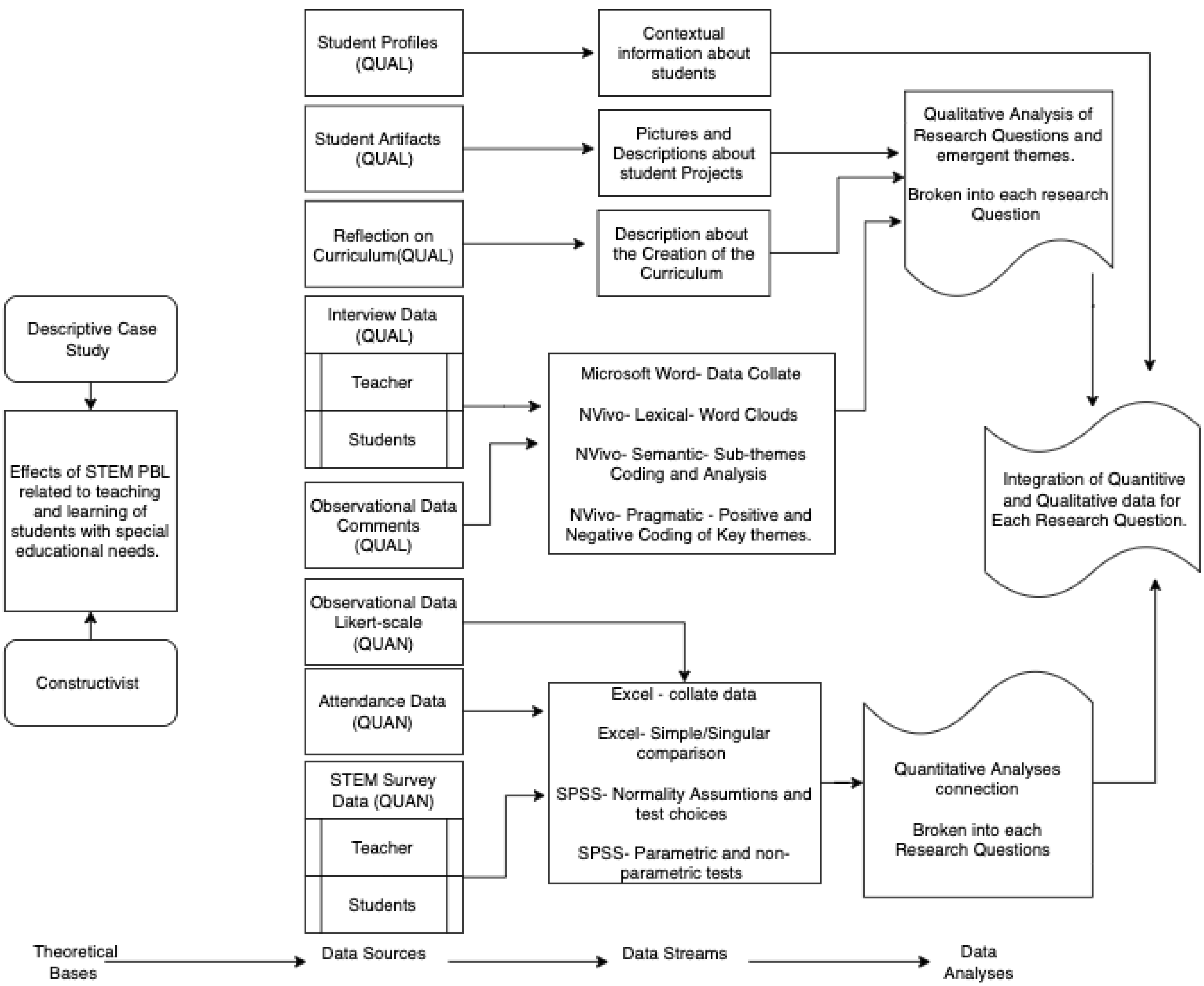

Figure 3. Data flow framework during analysis.

data. The semantic analysis involved checking the sections of key themes and subthemes. This was completed to understand the broader context of the data from a subjective view. Finally, the pragmatic section was developed by positively and negatively coding key themes and words explored in the lexical and pragmatic sections.

This allowed for more robust analysis of the data. In summary, initial themes were derived from Word Clouds and word counts in the lexical analysis (Bolden, & Moscarola, 2000). Following these, specifics about the semantics were analyzed to create sub-themes. These themes were then related to the research questions, and concepts were positively, neutrally, and negatively coded to highlight changes over time between the observation and interview data. A full explanation of the functionality of these three analyses will be discussed in the coding section.

Quantitative data analysis included descriptive statistics, parametric tests (t-tests) and non-parametric tests (Wilcoxon Signed-ranks tests, Friedman tests). These were undertaken to explore the changes that occurred during the study and highlight collected data with limited potential for researcher bias. If the information collected from these sources confirms what was found in the qualitative section of the study, it will strengthen or support the conclusions.

Coding

Saldaña (2013) explains the process of coding, whereby researches can identify the relationships between text, images and any other sources of data. Coding was used to understand the main themes while analyzing the various sources of data in this study. Initially, data were collected individually and further analyzed through their respective methods. Coding was completed using NVivo 12 software by looking at word counts represented, emergent themes, and patterns prevalent in the data. Coding started at the lexical level with word counts, and complied the types of words used during interviews when looking at the results from all students. This analysis counted stemmed words in the same category (e.g., talk, talking, talked) and after the initial analysis, unimportant words were omitted(e.g., very, get, really, just, way). The second step was semantic analyses which included looking at key themes and sub-themes gleaned from the data.

Lastly, the data was pragmatically examined by positively and negatively coding, with key themes elicited from each of the sections. These sections were coded by hand and confirmed using a word search in NVivo 12 for qualitative analysis. Following the initial analysis, I reviewed the context around each of the selected words and identified links between context and meaning. Analyzing a topic involved checking the situational context around words and confirming that the word was used in the context assumed by the researcher and that it is not over or under-reported. Analyzing a topic like student work means exploring the context around how the students were working and if the lexical and semantic analyses provided a rounded perspective on these topics. During the analyses, themes were coded using positive, neutral, negative and excluded coding. Examples of positively coded statements are: *"The group worked well together and had a fully costed plan,"* and *"______ was extremely excited with her finished work"*. These involved the word 'work' and a distinctly positive tone. Examples of neutrally coded statements are: *"Students continued the work from the lung capacity activity and moved onto the sphygmomanometer,"* and *"The teacher spoke to _____ and tried to help the situation and she finished some other work which she missed in the morning"*. These involved a statement where students completed work, but there were no specific positive or negative connotations regarding the work they completed or if they completed it. Examples of negatively coded statements are: *"She was almost doing no work and was constantly going upstairs or going into* *other rooms,"* and *"Many of the students were distracted and were not able to finish the required work."* These statements illustrate a negative context around work. Some instances of words were excluded as they were not explicitly related to the context or included as a subsection of another word. Examples were "homework," "she worked on temperature and garbage," and "who also works at the school." The analyses were completed on a weekly basis, comparing the scaffolding day to the project days. Following this analysis, summary analyses were completed.

Quantitative data included survey responses, observations and attendance, and analysis was initially conducted in Excel and analyzed in SPSS, as necessary. Before analysis of the data, tests for normality were completed, and significance was found at a p-value of <0.05. The types of tests performed depended on the types of variables explored and if they met the assumptions for testing. Most of the situations did not meet the requirements for parametric testing, and non-parametric tests or descriptive statistics were highlighted.

Findings

The purpose of this case study was to explore the perceptions and impacts of a STEM PBL approach on students with SENs and their teacher. The study addressed the following research questions:

1. a) What are students' and the teacher attitudes towards and views of PBL as a pedagogical approach in teaching and learning STEM?

   b) Do these attitudes and views change over time? If so, why do they change? How are the changes manifested?

2. a) What is the teacher's understanding of PBL and assessment in STEM?

   b) Does the teacher's understanding change throughout the research study?

3. Do students' and the teacher's STEM skills change as a result of project-based learning? If so, how are the changes manifested?

Qualitative Findings

Student Projects Artifacts

In this section, the types of projects that the students completed and some of the opinions they held during the project are presented. This also includes a variety of artifacts from the projects.

Descriptions and Summary of Student Artifacts. The following sections explore student artifacts collected.

Unit 1 – Organ systems. For this project, the students were divided into two different groups. The goals of this project were focused on the engineering, and math disciplines in STEM as students had to create budgets for bulk orders of their prototypes that they built. As a company, they would be given additional money if they were able to incorporate a specific drug from a company showing that their medication was effective in treating specific disorders.

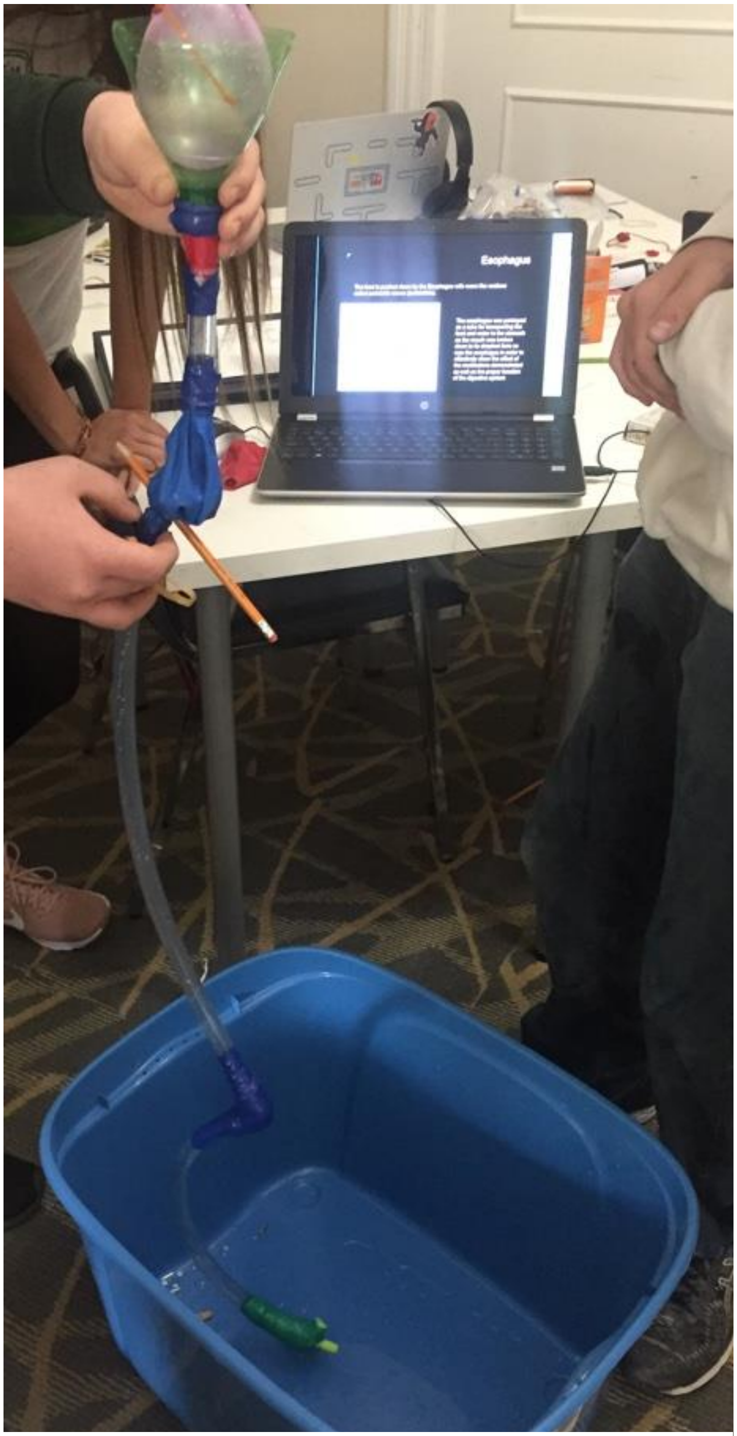

Figure 4. Group 1 scale model of the digestive system.

Groups 1 and 2 chose to focus on the digestive and respiratory systems, respectively. The two groups presented their prototypes with their plan for implementation to their teacher. Group 1 created a full-scale model of the digestive system and focused on the functionality of the system. They created a full list of resources necessary before building, created a budget for making these on a large scale and chose a disease and product that they could treat. The group was able to meet all of the well-defined goals within this project. They were able to create different components to act as the different parts of the digestive system (Figure 4). They worked well as a group for the most part, with some concerns arising when one student felt excluded from the group. The teacher was able to address this concern, and all students helped with the completion of the project.

They were also able to explain what each part represented and how it resembled and functioned like the corresponding part of the body. They wrote about changes that they would have made to their prototype with additional time.

The students included an additional optional component which involved showing a demonstration of how a specific drug would work in the digestive system. They decided to show the effects of highly acidic foods on the stomach lining and how antacids could help reduce the pain associated with it.

Finally, the students were able to create a budget for 100,000 units of their model. They also calculated how much money they would recover as profit by comparing the cost of buying the materials to selling their prototype.

Group 2 created a scale model of the respiratory system and strived for a more realistic version of the lungs than the classical models usually shown in classrooms. They decided to add lung shaped sponges inside of the balloons to allow full inflation, and created stents inside of the sponge to allow the shape of the lung to be maintained while still showing the growth of the lung with pressure changes.

This group encountered many more challenges compared to the other group. The teacher reviewed the specific methods around testing and engineering projects, which helped students arrive at solutions to the problems. The students needed some help with motivation during this section, but were able to develop ideas on their own. The teacher mentioned that the solutions were different from the ones he was thinking of, but they were interestering and they worked.

This group created a PowerPoint containing a larger volume of knowledge, as one of the group members focused on collecting information about the respiratory system. They linked the concepts within the unit to their project and a real world context. This group was also able to create a plan that analyzed the specific budget for 100,000 units. The group called organizations to see if they could bargain for lower prices for higher numbers of units. This was interesting as most of the students were too nervous to call. The teacher mentioned that they could pretend to be a business, and one of the students in this group was able to call and negotiate, which was a big step for this student who had high anxiety.

Group members also decided to complete an additional section and showed the process of a tracheotomy with their project. The group performed the “surgery” themselves during the presentation and showed how it would work in real life by having one person performing it on the prototype and another showing the locations of the incision on a real person.

Both groups were able to explain the processes to the other group as well as create an activity to test the other team’s knowledge.

Unit 2 – Evolution. For this project, students were instructed to work individually as the project involved digital storytelling focusing on the concepts central to evolution. Students were familiarized with the importance of storytelling for First Nations, Metis and Inuit (FNMI) communities. Students could incorporate evolutionary concepts from different perspectives to create a more Indigenous-focused project. This project also allowed for the incorporation of a variety of new technologies that the students had not previously used. Most students chose different types of stories and used different types of digital storytelling media. This included: creating online book software, Powtoons, Microsoft Word, online comic creators, audio recording, and digital reading. Many students were able to incorporate aspects from Indigenous ways of knowing into their projects.

Emily was able to create a story that incorporated the concepts from the units into a storybook format and was able to incorporate her style of artwork and writing into this unit. Her Indigenous background had an impact on the way the story was written and how she related the content to her own life.

Michelle decided to take a different and longer approach to this project and wrote a short story. She incorporated the feelings of specific key terms into the personalities of the characters. These characters interacted with each other to show other specific concepts in evolution. She included characters from a variety of locations, and she created an Indigenous history for several of the characters. She created chapter covers online for her digital section of the project, but focused more on content and writing.

Olivia created a simple story that focused on critical elements. Although she is from an Indigenous background, she chose not to include a significant focus on Indigenous knowledge. She was more interested in adding the definitions compared to creating a well-developed story.

Lex decided on a comic strip format and used his creativity a lot in this project. It took him a little while to get started, but once he understood and could explain the story of evolution in different ways, he was able to have fun with it. His story involved the magical journey of a pig and his experiences through the history of evolution.

Oscar had trouble writing, and settled on creating a script for a TV show. He used an online storyboard creator to help him cover the content. It took more time to help him get started than the other students. He was self-conscious about his writing abilities and struggled to come up with an idea that incorporated a variety of sections from the evolution unit in the context of a story. Both Lex and Oscar focused on the content aspect and did not relate the content to Indigenous knowledge.

Observing Vincent during this project was extremely interesting, as he showed much growth during the creation of his book using an online tool. He originally wrote a series of facts about evolution, and the teacher explained that the project was to create a fictional story. It took several hours to allow him to work with the teacher to help him understand that fictional stories can be based on scientific facts. Once he understood that he could personify the animals, he started to create his story. He eventually decided on creating a story about frogs going through cryogenesis and evolving along with other creatures. He incorporated a variety of different key terms in his story. It took him a long time to create the initial storyboard and he worked on the digital book at home. He finished his book in class and was extremely excited about how his story turned out. His book was made on an online book building website, and he was able to get his book printed in hardcover after its completion.

Unit 3 – Genetics. This project involved students learning the fundamentals of coding and creating a focused genetics game (DeCoito & Briona, 2019). It was recommended that students use Scratch for their programs as it is a simple program to learn and use. One student in the class had previous experience coding, whereas all others had little to no knowledge of coding or coding software. Students created simple to complex programs, involving multiple scripts of many types of codes.

Emily was able to create a simple program despite having no experience coding, and limited knowledge pertaining to genetics. Figure 5 showcases screenshots from the program she created. The premise of the game was to identify and teach what the words genotype and phenotype mean and how to identify them. The character, Pico, moves around the screen and follows the mouse. Before starting, he explains the goal of each level. The player selects the right answers and continues, or the wrong ones and is redirected to the “Lose” screen. If all levels are completed, Pico says “YAY, u win! Go home.”

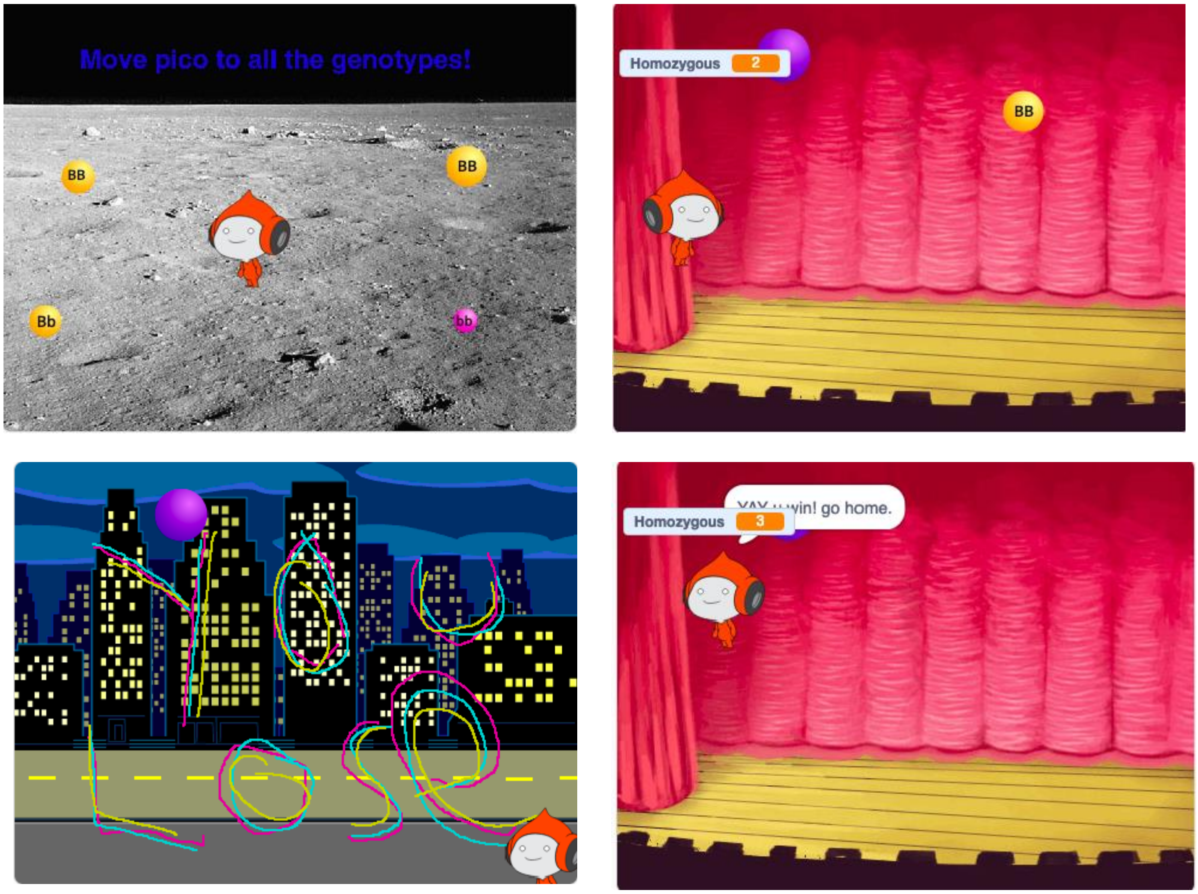

Figure 5. Screenshots from Emily’s game creation.

Lex created a question-answer style game with questions focusing on genetics. He included some hidden elements in his project for fun and enjoyment. These did not impact the game or the content, but he found them funny and increased his overall engagement with the project.

Michelle created an extremely complicated game. She had worked with Scratch before at a basic level, but needed additional assistance to allow her to complete the project in a way that was aligned with her original plans for this assignment. The teacher did not possess knowledge of coding and occasionally was not able to answer specific questions about how to troubleshoot her project. During lunch breaks, I was able to explain some higher-level concepts in Scratch to her. She had the most interactive and complex game by far, involving multiple game styles that allowed the player to collect the individual alleles and create genotypes. These were then entered into a Punnett square; the cross results were displayed as a phenotype and genotype. This allowed students to continue the game, with new alleles.

Oscar has a coding background and was extremely excited to work on this project. He created a game that was complicated in its design, and he was unable to finish it. He decided to use a different platform than Scratch, which had better graphics and higher-level instructions since Scratch did not allow him to perform all the functions he wanted. He did create a skeleton version in the form of a flow chart and a simple version in Scratch. He was disappointed that he did not have time to complete a functional version of the game, but the teacher explained that his grade would be based, in part, on the flow chart and his ability to explain his proposed game. He would therefore not lose marks because he did not complete the game. STEM PBL focuses on the process and the ability to explain concepts, not just the finished project.

Olivia decided on a storytelling video with coding. There were a few characters that interacted with one another to explain the concepts of evolution. Olivia was frustrated with debugging her program but was helped by Michelle and the teacher. She had a lot of timing involved in her program; many different scripts were needed to interact successfully with each other, and the neccessity of a specific start coding. She eventually finished but did not include all of the specifics she wanted.

Students had the opportunity to play each other's games and give feedback about playability, how the concepts were included, and enjoyment. Some students chose to incorporate feedback and modify their games accordingly.

Unit 4– Plants and Diversity Pond Study. This project was longer compared to the others and incorporated technology, math, and engineering. Students had to work in small groups to collect a variety of data relating to the diversity of plants and animals. Students used Google docs to share information class-wide, and the teacher ensured that all students had access to the document. This allowed the students to create plans for the collection of data, the locations explored for the project, and share the data to develop the final version of their project.

Students planned the entire project, the locations of data collection, types of data to be collected, methods of collection, and who will be collecting each type of data. Michelle and Oscar were tasked with the role of leaders during the planning phases, and two locations were chosen for observation. Data collected included variables like pH, temperature, amount of garbage in an area (counted through quadrants), types of animals and plants observed, light pollution levels, and air quality. Students decided to go to a conservation area in the city zone, and near the local river in a public park. Most students were engaged during data collection. If not, they were distracted by things outside the context of the class.

For presentations, two groups of students decided to present in the form of a website. The final projects were completed and well-constructed, but were lacking in detail. Students wanted to finish a little early, so they had time to study for their final content exams.

Student Interview Data

The interview data analysis comprised four sections: i) descriptions from the collated data, ii) lexical analysis of words, iii) semantic analysis based on sub-themes, and iv) a pragmatic analysis based on positive and negative coding.

Description of Students Interview Data. The data collected from the interviews were transcribed and input into the NVivo 12 qualitative analysis software. This section includes in-depth information on students' educational background and their feelings about learning in a STEM PBL format. The three interviews explored student experiences before, during, and after the study.

The initial interviews highlighted a variety of differences regarding why the students were in the school and their relationship with STEM subjects and education. Michelle and Vincent were very positive about both, Emily and Olivia felt like education was essential but not always something easy for a variety of different reasons, and Oscar and Lex were indifferent about how and why they were in this program and had slightly positive views of science.

The second interview explored the initial perspectives of the students in STEM PBL. All of the students generally perceived PBL positively when compared to other methods used in their educational histories. The students felt that PBL impacted their anxiety level in a positive manner, if they were initially anxious. Few students noticed the connection between the other STEM subjects and what they were doing in the projects, even though they demonstrated that they were learning new skills in these areas.

The third interview explored how students responded to their success and feelings about PBL. One student was not present when the third interview was conducted, and as such, there was no third interview data for her. Attempts were made at alternative times, but she declined to be interviewed as the proposed time slots would interfere with her lunch periods or after school. All students, except Lex and Oscar, felt more successful learning in STEM PBL. These students did state that they received higher grades in this class compared to other classes, but they found it less challenging than a test. This made them feel as though they were less successful than in other courses. This was interesting because they also mentioned that in some of the projects, they felt they did more work than in other courses. Follow up questions were asked regarding this, and students did not want to comment on why this was the case. This disconnect would be interesting to explore further given the interview continued to show that students were happier, less anxious, and enjoyed learning through this method.

Lexical Analysis of Student interviews. This section, exploring the different interviews, is divided into a summary analysis and a comparative analysis.

Summary Lexical Analysis. The initial lexical analysis looked at the types of words used during the interviews across all students. The summary showed the types of words (and their occurrences) used during the interviews (Figure 6). The most frequently used words were projects (n=85), think (n=60), feel (n=60), and science (n=57). There were also a few specific words related to the research questions which had high counts; learn (n=47), math (n=40), make (n=36), differently (n=34), technology (n=34), engineering (n=23), tests (n=23), easier (n=19), understand, (n=18) and successful (n=16).

Comparative Lexical Analysis. The three interviews (prior to the study, during the study, and after the study) provided different views of how the students interacted with the educational system and their perspectives on STEM PBL. The first set of interviews focused on student backgrounds, their preferred learning styles, what they know about STEM and why they were attending the school. The second set of interviews focused on how the students were learning in their class, how they felt about PBL and STEM, and their current progress. The third set of interviews explored how students felt during the course, if they were successful, and the effectiveness of learning through this method.

Figure 6. Comparative Word Clouds of three student interviews, shown respectively.

Semantic analysis of Student interviews. After coding this section of the data, the sub-themes which emerged are student co-operation, context anxiety, social anxiety, learning style preferences, post-secondary aspirations, SEN, student success, perspectives on STEM, and student work ethics. The themes created are briefly explained in the following sections.

Co-operation. Students in the study typically had trouble working in groups, and all who mentioned groupwork preferred working independently. Many students also have social anxiety about working in large groups. Michelle mentioned how the "atmosphere as a whole was pretty different" and how she "learned how to work as a team." When students worked together, they preferred the route of delegation rather than collaboration. The students decided on the components that they would complete based on their preferences and abilities. Emily felt that she was not able to work with other students as she felt that they "don't listen to [her]" and that she did not feel "smart enough" to work with other students. Male students had fewer reservations towards working in groups when compared to female students.

Context anxiety. Several students struggled with demonstrating their knowledge, and there was also concern related to the increased number of learning objectives and content compared to previous years. All students who expressed feelings of anxiety in test settings felt that the projects were associated with less anxiety compared to completing tests.

> "Studying really stresses me out and like the fear of not studying enough but being able to show my knowledge through a project, I don't know, it makes me feel more comfortable." (Interview with Michelle)

> "The projects, for me, were easier to complete than the final exam because I didn't have to make study notes … and tests give me more anxiety." (Interview with Vincent)

Emily and Vincent struggled with the amount of content learned in this course, and Emily felt like she was not smart enough at the start of the class. Vincent was usually overwhelmed by larger ideas and moving to a new concept, which occasionally caused him to struggle with content. This is demonstrated in the following exchange:

> Interviewer: What was your feeling about how [Teacher] was teaching? Did it feel different than the other courses?
>
> Vincent: Yes, because I stressed out a little because I didn't really understand what he was talking about in the first place.
>
> Interviewer: Were you able to understand in the end?
>
> Vincent: Most of the pieces of information that he spoke about, such as mitosis.
>
> Interviewer: What made it harder?
>
> Vincent: Newer concepts, like those that never existed in Grade 10.

Social anxiety. As mentioned, most of the students struggle to work in large social settings, and this is one of the reasons why they are attending this school. Students mentioned the "chaotic environment" of public schools and how they "work better" in smaller class sizes. One student mentioned that in her previous public school, she "really slacked off and … didn't get that many credits because [she] was more intrigued with [her] social life". Students did not speak about the social anxiety they had while working in groups in this context. This is most likely due to the small class sizes currently at this school.

Learning Preferences. Students had a variety of different perspectives related to enjoyment of learning and what worked best for them. Lex explained: "public schools were not teaching me much; they were moving too fast and not going over anything." He also explained that he felt "more comfortable making [project] than writing a test."

Oscar preferred "learning in a hands-on way." He also mentioned that there should be more experiences and activities so "students can learn more skills and stuff in different ways." He also found the projects to be easier compared to writing tests and exams, and mentioned that he did not like completing tests because occasionally, he couldn't do all of it on the computer. He did mention that he felt like he completed more work in the PBL format compared to 'regular' teaching, but did not enjoy the extra work he was doing despite getting higher grades. Oscar had not engaged in assignments as much in previous classes as in the research class, and was more motivated to finish the projects in biology.

Vincent felt less anxious during the creation of projects. He felt connected to specific content that he had learned in the context of biology. This may not have been the specific objective within the curriculum, but it allowed him to engage in learning the other necessary content.

Olivia explained that she "really enjoys the hands-on stuff." She also mentioned how her public-school education was not as good and that the way she was learning at the private school was much better for her education. When asked about PBL, she explained that “there is less stress packed into it” even though it was worth the same grade. She felt like the PBL format worked better with her learning style and mentioned that she prefers “watching people do stuff” and “ doing it after.” She liked the number of hands-on activities, that there was not an overwhelming amount of work to complete, and that there were opportunities for class discussions. Olivia created projects which did not go beyond the requirements of the assignments.

Michelle felt more comfortable learning in a PBL format. She enjoyed the amount of structure as it allowed her to be creative, but also achieved what was expected to succeed. She stated: “I actually have enjoyed [PBL] more than any other course that I have taken this year. I like having the projects”. She also spoke about the importance of the process of learning rather than the focus on the final product; how completing the work and working through problems was important in this method, not just having an ‘amazing’ final project.

Emily mentioned that she preferred science-based subjects because they involve less writing than non-STEM courses. She felt like she was doing better in PBL format in terms of her grade and that she is “learning a lot more than what [she] learns in a normal course.”

Post-secondary aspirations. Students had a variety of different opinions on where they would go after high school. Three students expressed that they would like to go into STEM subjects and post-secondary education. The others were either not interested in STEM or indifferent, and were not sure if they would pursue post-secondary education. The goals for these students ranged from getting the credit to doing the best that they could do. They did not change their opinions related to post-secondary aspirations.

Students with SENs. Little was mentioned regarding their SENs in the interviews. Most students spoke about their anxiety. The student with autism did not mention specifics relating to his autism and his learning. The student with ADHD and dyslexia mentioned a few things. He mainly spoke broadly about how his ADHD and dyslexia made him easily distracted in typical schooling contexts and that it affects his reading.

Student success. Students had different opinions on what success is and how it was manifested in their learning. Some students thought it was the grade in the course, some felt that it was the ability to complete something perceived as difficult, and others thought it related to how well they completed the work. Each of these opinions led students to have different perspectives of success in the PBL context.

Students generally had higher grades in this course, and as a result, some students felt that they were more successful. Some felt that they had a lower level of success because completing the projects was less difficult for them compared to completing a test. The two students who felt this way also mentioned that they worked harder to complete the projects compared to studying or doing assignments for another class. A few students mentioned that they felt more successful because they were able to complete work to a high standard. Some students also mentioned that they were able to retain and remember the information better in the PBL model, and this will give them more success in their next high school course.

Perspectives on STEM. Students had a variety of perspectives on each stream of STEM. Students in this class enjoyed science, and a few students mentioned that they would specifically like to go into post-secondary science studies. One student explained that she enjoyed it, but had failed the current course last year. No one in this class had negative views of science or biology. Students were able to see the specific science-related skills that they were learning and incorporating. This may have been because it is specifically a science course and they were thinking about this moreso.

Students had mixed opinions about technology ranging from Oscar, who loves technology, to the majority of the class who was reasonably indifferent, to Emily, who only uses it to contact people and for social media. Students enjoyed completing the coding assignment, but many did not notice the different opportunities where they learned to use a variety of technologies. Students had a particular perspective of what is classified as technology. Most students did not consider researching online, using Microsoft Office, or photo and video editing as technological learning.

Most students did not feel that they incorporated engineering into their projects even when asked about construction. This is a similar issue as technology since students did not see themselves engaging in engineering practices. However, student engagement with engineering principles was evident from the teacher and researcher's perspectives. Students did not think about the ways in which they solved problems in the other assignments by using the BSCE model as an engineering solution. Students who did remember engineering enjoyed this section and felt like they learned skills during this exercise.

Mathematics was noticeable as being incorporated by a few students, or they actively tried to ignore it. There were small amounts of mathematics incorporated into all of the projects, but many students in the class did not enjoy math. Olivia went so far as to say that she "tried to block out" anything related to math in the course. Most students had completed Grade 11 math, and they were most likely looking for higher level math concepts. Most of the math was related to algebra, averages, standard deviation, data collection, and data representation.

Student work Ethic. Students in this class generally have a medium to low work ethic. This was explained prior to the course by their teachers. Vincent is the only student who consistently tried his hardest regardless of extenuating situations; this is the case in all of his classes. This does not mean that he can always work, but the intention is to do so. Many of the students in this study prefer to 'coast' in their classes and complete a minimal amount of work. Students explained that they had to work a little harder to complete the projects. Lex said that "It takes more work and thinking to do the projects than to just copy down and remember the information. You have to actually do stuff for projects, and it takes longer to finish." This sentiment demonstrates the general feeling related to the students completing work. Many students would prefer to do less work because they generally dislike doing any additional work and would prefer to coast through the courses. The STEM PBL environment motivated or gave them a reason to complete more work, which resulted in them doing better in the course.

Teacher Interview Data

The teacher interview data analysis is divided into four sections in the same format as the student interviews: i) descriptions from the collated data, ii) lexical analysis of words, iii) semantic analysis based on sub-themes, and iv) a pragmatic analysis based on positive and negative coding.

Description of Teacher Interview Data. The data collected from the interviews were transcribed and inputted into NVivo 12 for qualitative analysis. The information in this section represents an in-depth exploration into the teacher's views of incorporating STEM PBL into his classroom. There were three interviews that explored the richness of the teacher's experiences as he learned to teach in a STEM PBL environment. The first interview explored his history, the second his current experiences of teaching and learning, and the third his reflections on the course, and PBL.

The initial interview data explored his history and motivation for becoming a teacher. This provides some context in terms of his previous knowledge of education, PBL, STEM and students with learning disabilities. He had little knowledge of PBL and had not integrated STEM subjects into his prior teaching. He previously taught science as an individual subject, without integrating components of technology, engineering, or math. Prior to participating in the study, he was unaware of the process of assessment in PBL, but was able to learn about these practices prior to starting his assessments. His interview revealed that his love of teaching originated in childhood from his teachers and science classes. He is from a family where both of his parents did not have post-secondary education. He was always interested in the field of science, and he has a rich history in education with a focus on students with learning disabilities. He mentioned, “My parents weren’t overly science-y, but they did have a good regard for knowing things,” and “My mom, in terms of knowing natural things, was always a pretty natural gardener and would bring out the scientific side by measuring pH and stuff like that and I garnered stuff like that, but it was not from an institutional level”. He did not have any major role models in science except one of his science teachers; he mentioned: “he really passed on that enthusiasm in the classroom.” He also mentioned that most of the schools where he has taught have had a high percentage of students with learning disabilities, this included students with ADHD, ASDs, anxiety, dyslexia, and dyspraxia. He has taken professional courses related to teaching students with SENs while teaching at this school.

The second interview explored his current knowledge and experience teaching through this method during the course. Prior to this course, he assessed students with projects, but not through a PBL framework. When asked about teaching using this method for the first time, he said, "learning the strategy has been kind of like stretching an elastic band and reopening your brain and getting your head wrapped around it. It has been an experience, to say the least. It is interesting, and it is different, and it allows such a varied approach to completing content and assessment."

He was positive about how the course evolved during the study. There were some issues as he indicated that students "haven't experienced this type of learning before and they're Grade 11 students and generally you might consider them to be a little more stuck in their ways. They have opted in and really given it as good of a go as they can". There was also a focus on students improving STEM-related skills, not content related. He explained this through his interview: "Students have generally been able to integrate different skills into the project more easily … it really gives them the ability to either spruce up skills or learn a new skill and enjoy that as a new facet." He also mentioned that students were doing better in terms of their grades.

He expanded on the students with mental health issues and learning disabilities. He explained that he noticed positive effects on students with anxiety and that they "tended to be more okay with this because they have their own time and ability to plan and organize and get that straightened out." The student who has autism struggled with the freedom and found the work "too broad." He mentioned that the student with ADHD and dyslexia was positively affected by PBL.

The third interview explored his perceptions of STEM PBL and how it impacted his students. He explained that cross-curricular learning is essential and is becoming more of a focus. He mentioned that the removal of testing allowed students with anxiety to manage themselves better and "PBL and the ability to spend time with the content and process the content differently allows them to slow it down and incorporate it differently so when they do have to recall it all at once, it's all there at once." His success with this method depended on the individual projects, as he felt students struggled especially with those projects having a larger literacy component. However, overall, he mentioned that students "in terms of learning the material, and the actual science, [were] much more successful." This was based on the student's ability to learn and express their understanding of the content in the science course, compared to previous science courses he has taught.

He preferred teaching through PBL and plans to teach his next science course using this method. His STEM skills did not change substantially, but he learned the basics of coding through this course. He stated, "I think with the proper given time, PBL is much preferable." He added, "I think it is easier to teach when things are more fun, and you know if your students are doing well, you can take pride in that." He explained that he felt the students ended up learning "certain skills better" but learned content knowledge "to probably the same degree" but were able to "recall it better in terms of knowledge-based questions" and "synthesize better."

He also mentioned that the student with autism was most affected by this method. It allowed him to recall specifics related to certain events during that day. Generally, anxiety levels were lower, and "students that are high anxiety were able to, through this, kind of forget their anxieties and just pour in their ideas."

Lexical Analysis of Teacher Interviews. This section is divided into a summary analysis and a comparative analysis exploring the different interviews.

Summary Analysis. The initial lexical analysis looked at the types of words used during the interviews. The words mostly used were *students* (n=64), *learn* (n=41), *think* (n=36), and *teaching* (n=31). This varies over the course of the different interviews. There were also a few specific words related to the research questions which had high counts; *project* (n=7), *time* (n=22), *skills* (n=19), *differently* (n=19), *successful* (n=12), and *anxieties* (n=10). The frequency STEM subjects were mentioned; *science* (n=23), *math* (n=11), *engineering* (n=8), *technology* (n=7).

Comparative Lexical Analysis. The fidnings from three different interviews provided varying views of the teacher's interaction with teaching and learning (Figure 7). The initial interview explored the history of the teacher, and the focus was on his background and his teaching philosophy. Positive words associated with this interview included: *enjoy* (n=6), *good* (n=4), *help* (n=4), and *able* (n=3). There were no explicitly negative words.

The second interview explored the teacher's interaction with subject content that was taught. This was shown by the frequency of words used during the interviews. Findings indicate a shift in focus from *teaching* (n=23) to *student* (n=23) and *learning* (n=16). Positive words include *thinking* (n=11), *allow* (n=8), *content* (n=7), *good* (n=5), and *coaching* (n=5). The only negative word mentioned was *hard* (n=2).

In the final interview, the responses were aligned with a PBL approach. More frequently mentioned words include: *think* (n=23), *able* (n=11), and *skills* (n=9). Positive words include: *able* (n=11), *allow* (n=10), *successful* (n=10), *well* (n=9), *explain* (n=5) and *develop* (n=4). Figure 7 shows the Word Clouds for each of the interviews, respectively. There were no explicitly negative words.

Figure 7. Comparative Word Clouds of three teacher interviews, shown respectively.

Semantic Analysis of Teacher interviews. Throughout the interviews, there were a few themes that persisted: i) personal experience and growth of the teacher, ii) assessments and project relationships, and iii) how students with SENs engaged with projects, PBL, and developed STEM skills.

Personal Growth of the Teacher. The initial interview provided a snapshot of the teacher's strengths, including his teaching qualifications and experiences. He felt that he had experienced growth during his teaching career, and there was still room to grow. He was not familiar with PBL, but had used projects as assessments previously. He explained that he was more comfortable with STEM subjects.

The second interview highlighted struggle, but personal growth. The teacher expressed a similar sentiment multiple times, indicating that he did not feel "everything has gone perfectly, but that it has gone very well." He enjoyed the holistic and varied approaches to assessment. He also mentioned that he enjoyed when students experimented and arrived at their own conclusions, and felt that this aided their retention of content knowledge.

The third interview demonstrated his understanding of the importance of the cross-curricular nature of STEM PBL. His personal opinion of his success depended on the project; he focused on the problems which occurred during the second project, and how literacy levels impacted the completion of this project as it was more difficult and less enjoyable for him and the students. He also saw the opinions of some of the students change as they were exposed to different technological skills, like coding and website creation. He preferred the PBL method if he had enough time to prepare the content, and in-class time to implement this pedagogical approach. He also felt that the additional preparation work before the course would be worth the additional benefits in terms of student learning, as reflected in his interview:

> I think it is easier to teach when things are more fun, and you know if your students are doing well, you can take pride in that. You can say, Oh, my students are doing well, so I am doing well. It makes it easier to justify, I guess, putting in the extra effort to develop PBL or learn a new strategy, or to want sometimes to pass on knowledge or get students to develop their own sense of knowledge. (Teacher Interview)

He also explained that he is planning on implementing STEM PBL in a course later in the year. He said the learning curve for this method was pretty steep/long. He also mentioned that he would feel less comfortable teaching through this method if there was a standardized test which the students were required to complete or if he was in a ‘stringent’ environment. He indicated that students may learn more content but because students will have less practice with testing environments, they may not be as successful. The teacher explained that it is easier to teach in a way that you know students will achieve a grade, compared to taking a risk using a teaching method you are less familiar with, especially if your pay or job could be impacted if some students do not succeed.

Assessments and projects. In the initial interview, the teacher did not explain his approach to assessments. He admitted that he usually does not analyze his assessment practices in ways that he did for the PBL approach in the study. He explained that his focus was often on accommodations for students, and he was in a one stream mindset. The second interview expanded his views on assessments and he indicated that he had increased his strategies to assessments. He did mention that some of the students needed additional help with narrowing the possible choices for their projects. The students in his class were usually given specific tasks as an accommodation. Within STEM PBL, it is necessary to have an “ill-defined task” to allow students to explore the concept and develop the ideas themselves. He explained that this was especially difficult for the student with autism. Students who have autism do not need step by step instructions to succeed and many are able to work well with ill defined tasks. He expanded on his feeling about the student with autism learning in a STEM PBL framework:

> In this case, because of the changing nature you can have with PBL, I was able to help them and coach them so they could focus on certain parts a little easier and do the holistic approach. From my understanding, and past experience with students with autism, because of the way the brain functions they are thinking about everything all at once and are in need of that coaching aspect first, umm, and then once and this is what I feel to be a bit of a common misconception is that autistic students can’t do this or can’t do that, but if you give them or if you point them in the right direction then or point them in a direction they will ‘bite’. (Teacher Interview)

In the third interview he mentioned the projects were successful and focused on students’ ability to dedicate sufficient time to complete their work, given most students in these classes struggle with time management. He also mentioned that literacy levels were a hindrance for students, especially related to digital storytelling. Eventually, many of the students who struggled with literacy completed a project which included alternative ways of communication.

Students with SENs. In the initial interview, he explained his history as a science and math teacher working with students with SENs. He explained his previous approach focused on accommodations. In the second interview, he elaborated on the students' interaction with STEM PBL and the effect on their SENs. Regarding students with anxiety, he stated that the students were less anxious because "they have their time ability to plan and organize." He felt that the student with autism needed more direction than the other students initially because of the broad range of possibilities. The teacher maintained that the additional time and access to technology helped the student with dyslexia, thus he was not 'held back'. He also mentioned that it was easier to assess the student with dyslexia because the products assessed were not all written pieces. He used a higher percentage of marked conversations and observations because these assessments fit better with the STEM PBL framework. He also explained that the student with ADHD was more focused because he was personally interested in some of the projects before the course, specifically the first and third, and added, "giving them the space to do it, is actually beneficial, which allows them to almost hyperfocus."

The third interview was about time constraints and allowing students with anxiety to complete their work over an extended period of time, as it allowed the students to learn more "cohesively." He also mentioned that STEM PBL helped the students with anxiety to recall information in 'chunks' as they were less worried about recalling all information at a specific time. He mentioned that when he spoke to students, many explained that the projects 'went over more comfortably' and some students almost forgot their anxieties about science. This could indicate that their anxiety around science is related more to the method of instruction and assessment compared to the subject content. He indicated that the student with autism was able to remember and connect specific information to situations that occurred during the projects. The teacher heard his students speaking specifically about some of the projects while writing the final exams. He said it "took students that were previously not engaged and allowed them to be engaged, more able to accept that they were at school."

Observational Data

This section reflects the researcher's daily observations and explores student interaction with the STEM PBL format and STEM skills learnt during the study. The observational data were analyzed on a weekly basis, and comparative analysis was conducted on the scaffolding versus project days. Several key themes and sub-themes are explored in this section such as learning with SENs, anxiety, independence, content and material, hard and soft STEM skills.

Lexical Analyses of Qualitative Observational Data. This section is divided into a summary analysis and a comparative analysis exploring the different observations.

Summary Lexical Analysis. The initial lexical analysis looked at the types of words recorded (Figure 8). The observational data focused on *work* (n=195) and *students* (n=161). There were several other keywords related to the research questions: *finish* (n=89), *engage* (n=64), *activity* (n=49), and *struggle* (n=45).

Figure 8. Summary Word Clouds of observational data.

Comparative Lexical Analysis. More information recorded about the project days (total word count=3012) compared to the scaffolding days (total word count=1754). This difference makes it difficult to compare usage without it being represented as a percentage of the total words used. The exact value and the percentage are included to add context, in part because there was a higher percentage of project days compared to scaffolding days.

When analysing the project days there were differences in themes represented. The project components focused on *students* (n=74, 2.45%) *completing work* (n=119, 3.95%) but also had more of a focus on *projects* (n=72, 2.39%). The positive words in this section were diverse and focused more on the students completing work: *able* (n=63, 2.09%), *finish* or *complete* (n=55, 2.16%), *good* or *well* (n=74, 2.45%), *engage* (n=31, 1.03), *understand* (n=26, 0.86%), *created* (n=25, 0.83%), *explain* (n=24, 0.80%), *ideas* (n=22, 0.73), *focused* (n=18, 0.60%), *collect* (n=17, 0.56%), *help* (n=17, 0.56%), and *show* (n=16, 0.53%). The negative words included: *struggle* (n=23, 0.76%), and *distracted* (n=19, 0.63%). Additional words and representation of their counts are illustrated in Word Clouds (Figure 9).

During the scaffolding days, the observational comments show that *students* (n=80, 4.56%) *completing work* (n=68, 3.88%) were the most reported words. There were a series of positive words related to teaching and learning which were often recorded: *finish* or *complete* (n=35, 1.82%), *engage* (n=32, 1.82%), *able* (n=29, 1.82%), *good* or *well* (n=17, 0.97%), *explain* (n=7, 0.74), *learning* (n=10, 0.57%), and *interesting* (n=9, 0.51%). There were also some negative words associated with the scaffolding days: *struggle* (n=20, 1.14%) and *distracted* (n=13, 0.74%).

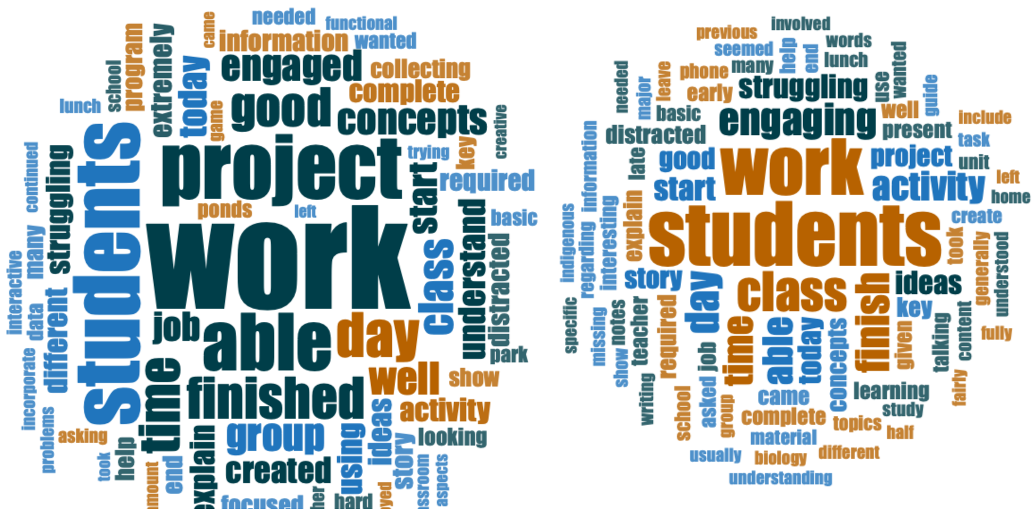

Figure 9. Word Clouds of observational data, comparing projects and scaffolding respectively.

Over the weeks, similar amounts of text were recorded for each week. Compensation for additional words found between the weeks was not included in the analysis. Week 1 focused on *student* (n=40), *work* (n=47) and *engagement* (n=28). It explored if *groups* (n=25) were *able* (n=17) to *finish* (n=25) their *projects* (n=17). It also included students *struggles* (n=8) and *helped* (n=8) to *start* (n=16) their projects and finish within the *time frame* (n=15). Positive words excluded above from this week include: *show* (n=9), *explain* (n=8), and *confidence* (n=4). The negative words not included are: *hard* (n=4) and *concerned* (n=4).

The second week focused on *student* (n=42) *work* (n=34) on their *story* (n=32). It also included if they were *able* (n=25) to complete their *project* (n=19) and how they represent their *ideas* (n=18) in digital storytelling. Students *struggled* (n=14) to *start* (n=14) and *finish* (n=13) this project more than the other projects. This project focused on incorporating *Indigenous* (n=13) ways of knowing. Positive words excluded from this week include: *understand* (n=12), *engaged* (n=8), *developed* (n=7), and *interesting* (n=5). The negative words not included are: *distracted* (n=7), and *hard* (n=3).

The third week focused on how *students* (n=37) *working* (n=50) on their *project* (n=34) which was *coding* (n=7) a *program* (n=22). Most students were *able* (n=24) to finish or *complete* (n=32) this in the allotted *time* (n=21). Students incorporated a variety of *concepts* (n=23) and *created* (n=15) different *games* (n=13) *using* (n=21) the Scratch program, even if some of them *struggled* (n=14). Positive words excluded above from this week include: *understand* (n=18), *engaged* (n=10), and *learned* (n=7). The negative word not included is *distracted* (n=12).

The fourth week focused on *students* (n=42) *working* (n=57) with their *class* (n=31) to *collect* (n=17) *data from parks* (n=12) and *ponds* (n=13). They were *able* (n=30) to finish or *complete* (n=32) their *projects* (n=21) in the *time period* (n=20). Students had a *good* (n=21) experience with *data* (n=13) collection and were *engaged* (n=18) throughout the *days* (n=27). Other positive words from this week are *explain* (n=7), *focused* (n=9), and *enjoyed* (n=7). Negative words were *distracted* (n=12), *struggle* (n=8) and *problem* (n=9). Word Clouds representing each week are illustrated in Figure 10.

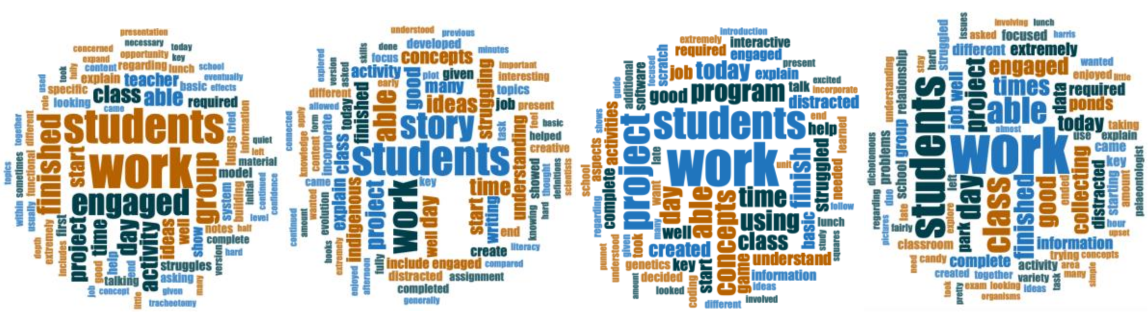

Figure 10. Comparative Word Clouds of observational data over four weeks, shown respectively.

Semantic Analysis. The semantic analysis looked holistically and comparatively between observation of students to draw sub-themes from the observational data collected. There were key sub-themes drawn from the data; some were detailed and divided into specific subsections: Students with SENs (Anxiety, Learning Disabilities), Students and Teachers (Independence from the teacher, content and materials), Hard STEM skills (Science Skills, Technology skills, Engineering skills, Technology skills), Soft STEM skills (Creativity, co-operation and leadership, time management), and Indigenous knowledge.

Students with SENs. Students in this study have a variety of different SENs, and their interactions with the STEM PBL framework are explored in the following sections: anxiety and other SENs.

Anxiety. Many students displayed anxiety during the study. This was to be expected because on a daily basis, it is not usual for many students to display anxiety. The anxiety was often not related to the content being learned in class nor to the completion of projects.

Michelle had several difficult days where she left and went to a different room because of her personal circumstances. There were six significant recordings where she left for a longer period or was unable to complete work at a high level. Even when these situations occurred, she was able to engage in activities or projects she saw as extremely important. She had a more difficult time engaging when specific concepts were being covered, or where there were activities on a smaller scale. Michelle had a significant role in the groups as she fulfilled the role of a leader. The one day when she was not present, her group had significant issues understanding all of the steps for the project.

Vincent had anxiety throughout the study for a variety of reasons. He was often upset about his behaviour relating to his emotions. He was unable to understand some of the projects because the tasks were not well defined; his group members and teacher were often able to help him. He struggled a lot with the creation of the story and displayed anxiety because he did not understand how to incorporate the way of Indigenous storytelling with biological definitions and concepts. He struggled several times when having to apply abstract concepts to specific points. He also had anxiety when the Scratch program was introduced. He later explained that this was due to the program looking too childish for him and he wanted to engage with the adult format.

Oscar was anxious while creating the ideas for his story because the thought of writing things down caused him anxiety. He explored a variety of different avenues for story creation and eventually was able to deal with this anxiety. He was agitated one day, and it was later discovered this was because of an issue with student relationships.

Emily had anxiety stemming from her low self-confidence which was directly connected to low literacy levels and complicated scientific vocabulary. She has issues with other students not including her in activities in a way that made her feel comfortable. In these situations, students were not excluding her, but not actively including her. She was not sharing her ideas with the group because of her low self-confidence. This caused her to feel excluded because she was often given tasks by the other group members, instead of coming up with tasks herself. She displayed no anxiety whenever the class went outdoors for data collection. She had a few terrible days because of her anxiety regarding issues not within the school context, which led to her being picked up from school.

Olivia and Lex displayed no visible signs of anxiety. Olivia occasionally did not pay attention as she was distracted by social media. When one of her devices was removed, she usually had an additional one; the teacher had to remove all electronics when she was being distracted.

Other SENs: Few of the students' specific learning disabilities directly impacted their learning during the study. This section will include related disabilities.

Vincent occasionally struggled with how broad topics were and his ability to incorporate all of his ideas into the project. He occasionally felt overwhelmed by the amount of information and the scale of the projects when initially assigned. The teacher occasionally divided the projects into smaller sections when he was feeling overwhelmed. Oscar struggled with digital storytelling because of his dyslexia and lower literacy levels. Emily did not encounter the same issues even though her literacy levels are significantly lower than Oscar's. The teacher explained that Oscar is very self-conscious about writing tasks, and Emily was interested in writing her story through an Indigenous voice with Indigenous based visuals. Oscar also had trouble understanding the concept of Punnett squares because of the uppercase versus lowercase letters. With the recommendation from his teacher, he was able to change the type of font on his computer for his project to make it easier for him to tell them apart.

Independence from teacher. Some students were able to take on leadership roles that they had not previously assumed and as a result, they displayed excellent leadership skills. The teacher explained that some of the students stepped up to tasks even if they did not have the leadership skills fully developed. For example, Michelle took on a variety of leadership roles and developed leadership and collaborative skills throughout the study. After a few projects, she was looking to her group members for answers as opposed to directing them to the teacher.

Most of the time, students needed help creating and adhering to timelines. The teacher helped the students ensure that their projects would be completed within the time period. This skill would have taken much more time to develop for all of the students as this is a persistent problem in their lives.

Vincent did an extraordinary amount of work on most of his projects, but needed a lot of additional assistance and clarification during his work. He was usually given clear, simple short tasks to ensure that he can complete them. He was able to extend his ability in the course, and the teacher explained that if he continued with this type of learning, he would develop a variety of essential skills for later in his life. He also explained that the time period was too short to make significant changes for most of the students.

Content and material. This section explores how students learned the concepts from the scaffolding lessons and displayed or expanded their knowledge during the projects.

Michelle and Lex consistently did a good job in class, while understanding and learning the content for the course. Oscar and Olivia occasionally struggled with technological distractions and subsequently did not fully understand the content being taught. Oscar used his computer to take notes because of his dyslexia, but this was a hindrance as he was often distracted. Olivia has at least a mild addiction to her device and felt anxious without it. The teacher usually confiscated her phone and electronic devices when she was distracted too much and could not complete her work.

Emily had many issues related to prior knowledge of general and scientific vocabulary. Her low scientific vocabulary caused her to struggle to understand some concepts, which was assumed to be prior knowledge such as hierarchy, dominant, and respire. She was more able to participate in the projects that involved new concepts without the use of higher-level vocabulary. She struggled to incorporate the new vocabulary she learned in science, and this was a factor in many of the struggles she faced with subject content knowledge.

Vincent struggled with understanding specific concepts and expanding them into abstract ideas. He was used to understanding and regurgitating material in previous science classes; however, the content in Grade 11 included more concepts and their application. He often struggled to learn the content within a short amount of time.

Hard STEM skills. This section explores the type of hard STEM skills the students learned and demonstrated during the course. This includes skills involving the specific subjects within STEM.

Science Skills. Within the course, the students were able to demonstrate a variety of different skills related to science. Students needed to recall their knowledge about independent and dependent variables in a few of the lessons. Students demonstrated their ability to plant tops of vegetables, like carrots, and measure the growth of plants while explaining the connection to subject content knowledge.

Students also learned explicitly about the difference between quantitative and qualitative measures. They learned how to collect data during the first day of class and continued to demonstrate this skill throughout the course. The students demonstrated their understanding in the final project as they had to choose the metrics, including quantitative and qualitative measures, that they would be studying in different environments.

Students also displayed their ability to use both electronic devices for recording specific measures such as total dissolved solids testers, and non-electronic technologies such as pH strips, thermometers, and rulers. Students exhibited their ability to record these measures in tables they created, and explained the importance of taking multiple measures to ensure the accuracy and validity of their data.

Students learned the different ways of displaying data in graphical forms. They were able to take the data collected and choose the type and best suited graphical representation. This is a skill that none of the students had previously demonstrated. Many of the students struggled initially with this and thought all data should be displayed in the same format. The students who were very comfortable with the idea of independent, dependent, and control variables encountered less challenges with this task.

Technology Skills. There were numerous technological skills that students used during this course; some were simple, and many involved higher level skills. Some of these skills were assumed to be familiar to the students, but many students needed to be taught basic computer skills. Most students were not able to use Microsoft Office or a comparable service for word processing successfully, data collection and analysis. At the end of the projects, all students showed, at a minimum, that they were able to use an online word processor and spreadsheet. Several of the students focused on the analysis of data and these students also learned how to convert data into different graphics. In addition, they learned how to compute a variety of variables in spreadsheets. Students also learned about research skills and how to effectively use a search engine to research useful information for their projects.

Students learned different skills, depending on the types of projects they decided to complete. When developing their digital story, each student explored a variety of different possible methods and chose the one they thought would be most appropriate for their project.

Students learned the fundamentals of coding during one of the projects. Only two of the students had ever used coding before, and their projects were much more extensive than the other student projects. At the end of the project, all students created a functional program which displayed some aspect of evolution. Some of the students could not build their full version of the project due to the size of their proposed project.

Students also worked in groups to create a website and explain how and why they created their websites in a certain format. Each of the students had a different role in the creation of the websites, but co-operation was important because they wanted to reduce the time to complete the final project.

Engineering Skills. Students demonstrated their engineering skills in the first project and used the approaches to help them work through their problems. Both groups had a few problems during construction of their prototypes and were able to work through problems with collaboration and perseverance. In each group, there was a clear leader. Some of the students were not as confident with their engineering skills, and usually, the more confident students were coming up with the central ideas.

Students also had the opportunity to use their engineering skills in the final project while collecting data. They were able to create devices to help them measure certain specific variables. One student created something to help test the depth of the water in different areas and another to test the temperature of the water closer to the middle of the pond.

Mathematics Skills. Students had a few different opportunities to use their math skills throughout the course. Several of the students in this classroom had an aversion to math, but were not usually worried about the integration of math in the projects. For example, in the first unit, there was a budget required and groups needed to plan for their total cost to be below a specified amount. Most groups designated one person to be in control of the budget. The student responsible for the budget needed to explain the total price breakdown to the other group members. The groups were creative in their ability to look for and purchase the cheapest versions of the materials in bulk form. The total cost and profits were included in their final presentation of their prototypes.

In the final project students calculated averages, analyzed and displayed data based on the type of data collected. Many of the groups were able to compare collected data to data from various online sources, through which they could determine the health of the areas studied.

Soft STEM skills. This section explores some of the soft STEM skills that students developed over the course.

Creativity. One of the soft skills which was clearly observed as students completed their projects is creativity. When viewing the data holistically, there was a trend in the observations where most of the students struggled initially with their projects and with creativity. Once the students were assisted and became motivated, most students had creative ideas for their projects. In the first project, both groups wanted to copy an idea from the Internet; it was specifically stated that the projects must be original, and both groups struggled at the beginning. Overall, creativity levels slightly increased over time, especially once students felt comfortable with their project.

Co-operation and Leadership. Some students struggled with co-operation during the course, but most were able to do so successfully. Emily struggled with group work and co-operation in many of the contexts where cooperation was central. She felt excluded from the first project and struggled with group work during that project. Vincent and Michelle occasionally struggled with co-operation because when Vincent is struggling with his anxiety levels, it also increases Michelle's anxiety. Most of my observations of co-operation involved students working well together and occasionally asking each other for help. Students still relied on the teacher to answer many questions, even though it was explained that students should try to work together to find answers to problems.

Time Management. Most, if not all, of the students in this class have poor time management skills. In these projects, students had more time to complete the projects than regular assignments. The students in the class did not change most of their time management skills. Many of the students needed to be reminded of how much time there was remaining to complete individual projects. Several students did not fully finish within the time requirement and took a few extra days at home afterwards to finish their project. The group projects were all completed within the required time. Students may have been more motivated because other students relied on them to help complete the work. The student who was gifted had an especially difficult time with her time management outside of group projects. She was usually focused, unless she had a specific issue that day outside of class. Her major problem with time management was because she often decided to create a project idea that was much too large to complete within the required time. Lex had better time management and also a higher level of completion for his projects. In his previous classes, he was known for completing the minimum possible work to achieve a passing grade. He often finished to a much higher standard during this course.

Indigenous knowledge. Some of the students included Indigenous ways of knowing in their projects, but only one of the Indigenous students created a project with this focus. Vincent struggled to understand how to incorporate the concepts learned into his story, as he was already having trouble incorporating content and the concept of fiction into his story. There were several opportunities during the course for students to engage with these ideas further, but few chose to do so.

Quantitative Findings

Observational Data. The observational tool was adapted from the *Student Engagement Teacher Handbook* (Jones, 2009). Observational data were collected by the researcher relating to the students in two different ways. There was a recording of the individual students based on a Likert-type scale of how the students were relating on a few different scales, as discussed in the Introduction. There was also a section for overall engagement and comments. The overall engagement amounted to the observed engagement of a student for a full day, and were taken specifically at the end of lunch and at the end of class.

The researcher noted how well each student compared to a statement connected to a topic. An example is the observation of body language, which is assessed by the following statement: Students exhibit body postures that indicate they are paying attention to the teacher and/or other students. The researcher would mark on a scale from 1-5 how well each student matched this description. Each day had a calculated average for each section, including an overall engagement and a mean of all subsections. These calculated scores are then compared weekly and during scaffolding days or project days.

This data was analyzed comparing scaffolding days and project days, and provides a general perspective on how engaged students were throughout the study.

Summary analysis. This section explores overall differences that students had around STEM PBL and whether students responded differently over time, and specifically when comparing individual projects. Analysis highlight student engagement and comfort level in a PBL format over a short period. This section also explores some of the reasons why specific students may have responded differently to specific projects when compared to others.

Before this initial analysis, general themes from specific students were observed. The students differed significantly from others based on their educational backgrounds when comparing the specific weeks of the study and the different projects. Many students showed changes when comparing the observational data over the weeks. Week 2 was an anomaly for most of the students either positively changing or negatively changing, compared to general trends of the weekly difference. Emily had higher scores compared to most other weeks. Oscar and Lex had scores that were much lower compared to other weeks. The other students in the class had similar or slightly lower scores during week 2. This was most likely due to the nature of the project. This project involved writing and had a focus on Indiginous ways of knowing, which appealed to Emily.

Most students had different results when compared on a weekly basis, but there was a small increase from week 1 to week 4. This is not consistent among all students. Table 2 highlights data relating to individual students and the averages and standard deviation. There was an increase in engagement scores when comparing most weeks to the following week, with week 2 being the exception for most students. Further tests were done to see if these results were significant.

Table 2

Weekly mean engagement for all students in each subsection.

Engagement Measure	Student	Week 1	Week 2	Week 3	Week 4
Observational Engagement	Michelle	4.08	3.6	4	3.67
	Vincent	3.24	3.52	3.48	3.93
	Oscar	3.24	2.76	3.56	3.53
	Emily	3.04	3.8	3.5	3.84
	Lex	3.36	2.6	3.44	3.9
	Olivia	3.48	3.1	3.2	3.67
	MEAN	**3.41**	**3.23**	**3.53**	**3.76**
Perceptional Engagement	Michelle	4.08	4	4.2	3.8
	Vincent	3.84	3.2	3.76	4.27
	Oscar	3.44	2.8	3.68	3.6
	Emily	2.96	4	3.5	4.08
	Lex	3.76	2.65	3.48	3.93
	Olivia	3.44	3.15	3.04	3.43
	MEAN	**3.59**	**3.3**	**3.61**	**3.85**
Independence and Team engagement	Michelle	3.7	3.65	4.1	3.54
	Vincent	3.1	3.3	3.95	4.08
	Oscar	3	2.75	3.7	3.42
	Emily	2.55	3.25	3.19	3.6
	Lex	3.25	2.44	3.35	4.04
	Olivia	3.52	2.88	2.95	3.5
	MEAN	**3.19**	**3.05**	**3.54**	**3.7**
Overall Engagement	Michelle	4.4	3.8	4.2	3.83
	Vincent	3.6	3.8	4	4.17
	Oscar	3.7	3	3.6	3.67
	Emily	2.8	3.5	3.63	3.8
	Lex	3.2	2.25	3.4	4
	Olivia	3.9	3	3.2	3.67
	MEAN	**3.6**	**3.23**	**3.67**	**3.86**
Mean of All engagement scores	Michelle	4.07	3.76	4.13	3.71
	Vincent	3.45	3.46	3.8	4.11
	Oscar	3.35	2.83	3.64	3.55
	Emily	2.84	3.64	3.45	3.83
	Lex	3.39	2.48	3.42	3.97
	Olivia	3.58	3.03	3.1	3.57
	MEAN	**3.45**	**3.2**	**3.59**	**3.79**

Assumptions were not met for parametric tests relating to the observational scores. Friedman tests were carried out and all were shown to be non-significant: Observational engagement ($\chi2$ (3) =6.6, p=0.86), perceptional engagement ($\chi2$ (3) =4.2, p=0.241), Independence and team engagement ($\chi2$ (3) =4.2, p=0.241), Overall Engagement ($\chi2$ (3) =7.6, p=0.55), Mean of all engagement scores ($\chi2$ (3) =5.4, p=0.145).

Project vs scaffolding days. This section explores the perceptions students had around STEM PBL and highlight whether students responded differently during class time to scaffolding versus project days. It was assumed that students had prior knowledge of fundamental concepts before starting the projects. This section showcases how student perspectives changed during the study and if they responded better to independently guided learning.

In addition, there was a class-wide observation every day, which allowed the researcher to take into account critical class-wide situations that were occurring or how students were interacting with each other during the study. Scaffolding concepts before allowing students to engage in project building is essential for the success of the projects. This section explores whether student engagement differed during scaffolding of course material compared to more free and exploratory time during the projects. The teacher assisted students when necessary, and tried to encourage students to think of creative solutions to the well-defined outcomes listed for each project. It is important to note that the scaffolding was done using a variety of different teaching methods, including inquiry-based learning, problem-solving, interactive activities, didactic teaching, think-pair-share, expert groups and more.

Before the initial analysis, general themes from specific students were observed. It was not clear that the specific students differed significantly from others based on their educational backgrounds when comparing scaffolding and project days. All students showed increases when comparing scaffolding to project means. Table 3 illustrates the difference between the observed engagement level of students learning content for scaffolding and for completing the projects, and is divided into observational, perceptional, and independence and team engagement.

Table 3 shows the mean engagement observed for all students during the scaffolding compared to the project days. The trends for observations, perceptions, and independence and team engagement were not normally distributed and were thus analyzed using non-parametric tests rather than a t-test. In contrast, the data collected from the overall engagement and the means of all engagement scores did meet assumption criteria and were analyzed using paired samples t-test.

All of the completed Friedman tests showed that there was a significant difference comparing the medians in the engagement levels when students were learning scaffolding material and completing projects. The tests explored if students were more engaged during the project component of the course. The first test indicated that there was a significant difference comparing scaffolding lessons (Mdn=3.12) to project time when looking at students' observations (Mdn=3.65), $Z = 21.00$, $p=0.028$. The second test indicated that there was a significant difference comparing scaffolding lessons (Mdn=3.06) to project time when looking at students' perceptions (Mdn=3.83), $Z = 21.00$, $p=0.028$. The third test indicated that there was a significant difference comparing scaffolding lessons (Mdn=2.85) to project time when looking at students' independence and team engagement (Mdn=3.56), $Z = 20.0$, $p=0.028$.

Two paired t-tests were completed for the overall engagement score and the mean of all engagement scores. This was completed to show an overall engagement score and measure if there was a difference when comparing the data holistically. This value was calculated by taking the means from each section and averaging them into a single value for participants. This allowed a larger question sample for each participant related to measuring engagement.

A paired-samples t-test was conducted for the first test to compare the overall engagement each day of students while learning scaffolding material or completing projects. There was a significant difference in the engagement of students during scaffolding (M=3.16, SD=0.32) and project time (M=3.86, SD=0.287) conditions; t(5)=-13.92, p<0.001.

A paired-samples t-test was conducted for the second test to compare the mean of all engagement each day of students while learning scaffolding material or completing projects. There was a significant difference in the engagement of students during scaffolding (M=3.07, SD=0.28) and project time (M=3.73, SD=0.19) conditions; t(5)=-10.87, p<0.001.

Table 3

Scaffolding and project mean engagement for all students in each subsection

	Scaffolding Averages *n=6*		Project Averages *n*=6	
STEM Attitudes	Mean	*SD*	Mean	*SD*
Observational Engagement	3.13	0.28	3.71	0.15
Perceptional Engagement	3.10	0.32	3.81	0.23
Independence and Team Engagement	2.92	0.28	3.69	0.25
Overall Engagement	3.14	0.32	3.81	0.29
Mean of All Engagement scores	3.04	0.03	3.74	0.05

These results suggest that students are more engaged while completing their projects compared to when they are learning the material needed to complete the projects.

S-STEM Findings. The analysis of the data followed recommendations by Unfried, Faber, Stanhope, and Wiebe (2015).

Analysis of S-STEM data. The survey data was collected and summarized from the first four constructs, namely attitudes towards math, science, engineering and technology. The survey has been validated at the construct level, and data analysis was completed at this level. This procedure resulted in the group scores for math attitudes, science attitudes, engineering attitudes, and technology attitudes. The means of the results are shown in Table 4, and suggest some differences between the groups, with attitudes increasing from pre to post surveys. Non-parametric tests were used to test significance levels between the pre and post data. A Wilcoxon Signed-ranks test was used for each of the four STEM attitude groupings. There was significance $p<0.05$ found for science attitudes and technology attitudes, the specifics for each will be shown below.

The results from the math construct indicated that there was no significant difference in math attitudes in the pre-survey data (Mdn=3.36) compared to post-survey data (Mdn=3.75), $Z = 18.50$, $p=0.093$. There was shown to be a trend as $p<0.1$, but it may not be related to the study.

The results from the science attitudes indicated that there was a significant difference in science attitudes in the pre-survey data (Mdn=3.78) compared to post-survey data (Mdn=3.94), $Z = 20.00$, $p=0.045$.

The results from the engineering attitudes indicated that there was no significant difference in engineering attitudes in the pre-survey data (Mdn=3.94) compared to post-survey data (Mdn=4.17), Z = 10.00, p=0.066. There was shown to be a trend as p<0.1, but it may not be related to the study.

The results from the technology attitudes indicated that there was a significant difference in technology attitudes in the pre-survey data (Mdn=3.68) compared to post-survey data (Mdn=3.90), Z = 0.00, p=0.026.

Table 4

Pre and post STEM PBL mean and standard deviation comparing STEM attitudes derived from middle/highschool S-STEM data.

	Pre-test Averages *n=6*		Post-test Averages *n*=6	
STEM Attitudes	Mean	*SD*	Mean	*SD*
Math Attitudes	3.00	1.13	3.27	1.01
Science Attitudes	3.74	0.45	4.02	0.45
Engineering Attitudes	4.00	0.34	4.28	0.35
Technology Attitudes	3.73	0.65	3.89	0.64

One section of the S-STEM data compared student's interest in future STEM focused jobs. Findings did not suggest an overall change (pre-survey (M=2.5, SD=0.38), post-survey (M=2.6, SD=0.36)) in students' career aspirations in STEM. Students were also asked to predict their performance for math, English, and science courses. Findings indicate that there were no differences in opinion in terms of predicting success in their English and math courses. There was a slight increase in their opinions about their predicted perform in their science classes (pre-test (M=2.5), (post-test (M=2.83)). This was not tested for significance, as these were singular questions and statistical data were not derived.

There were no changes in student opinion of post-secondary aspirations. In terms of knowing STEM specialists, two students knew a scientist in real life; this was most likely due to the classroom guest speaker from the archeological site. It is important to note that these changes occurred over a short period, and students may have remembered taking the survey previously, which could be a confounding variable impacting their responses.

T-STEM Findings. The T-STEM results are listed as means of each of the constructs along with the standard deviation. The results do not indicate a significant change between the pre/post tests. All but the efficacy and beliefs increased in the post-test averages, and the only data point, which was a moderate change, was student technology use. The STEM Career awareness was related to the teacher's knowledge of STEM careers, and may have increased due to him meeting the archeologist (Table 5).

Table 5

Pre and post STEM PBL mean from the T-STEM survey.

	Pre-test Averages *n=1*		Post-test Averages *n*=1	
Section of T-STEM	Mean	SD	Mean	SD
Science Teaching Efficacy and Beliefs	4.58	0.51	4.5	0.52
Science Teaching Outcome Expectancy	3.5	0.52	3.7	0.48
Student Technology Use	3.0	1.1	3.63	0.74
Science Instruction	2.8	0.65	3.0	0.76
21st Century Learning Attitudes/Skills	3.8	0.86	3.87	0.83
Teacher Leadership Attitudes	3.5	0.55	3.83	0.75
STEM Career Awareness	3.75	0.5	4.25	0.5

Attendance data

The attendance data was collected and analyzed to compare attendance during the course to previous courses, to determine if attendance was impacted. There were many confounding variables related to attendance data. The timing of the course in comparison to the rest of the year was of considerable concern. Certain courses occurred during the winter months when some students struggled to attend school due to snow; more students attended in the early semesters compared to later semesters. Another factor is students' willingness to come to class, as some students felt more comfortable with some teachers compared to others, especially students with high anxiety. Many students also have situations outside of their regular education, such as bus schedules, which affect their ability to attend class regularly.

The attendance data does, however, provide general insights into students' average attendance. Further analysis of the averages protects the anonymity of the students and the school. The students were compared individually and as a group, and two groups became apparent; students who were consistently late and those who were often absent. Other students were present and on time over 90% of the time, and only missing class due to illness (Figure 11)

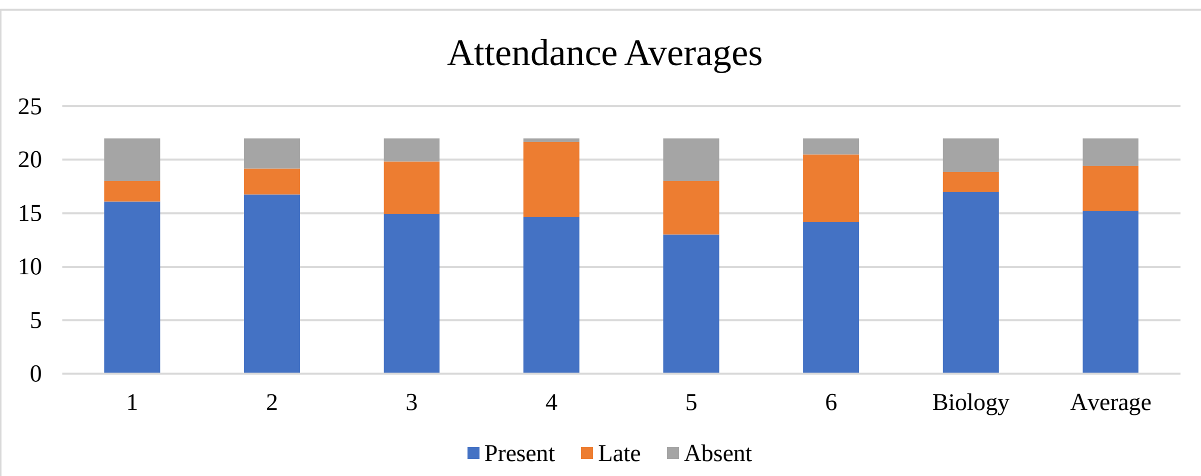

Figure 11. Comparative attendance averages of students over the school year.

Summary of Findings

Research Question 1.

1. a) What attitudes and perspectives do students, and the teacher have of PBL in STEM?

   b) Do these attitudes and perspectives change over time? If so, why do they change? How are the changes manifested?

Student attitudes and perspectives changed during the study as engagements and interest increased in students. Many students who struggled to complete projects and assessments were able to complete larger than normal projects. Students generally increased their comprehension level and were able to use STEM content information in their projects. Students also felt more personal success and better time management skills when completing the PBL. The teacher graded students' ability to think about the concepts, apply their understanding, and demonstrate their skills.

Key sub-themes connected to the aforementioned observations were i) STEM, ii) student struggles, iii) anxiety, iv) learning style preferences, v) PBL, vi) content, vii) SENs, and viii) personal growth of the teacher.

i) Students generally have a positive perspective of STEM subjects before, and experienced a small increase following the study. Negative aspects were related to previous opinions of subjects, such as students who had aversion to math. The teacher believed in the importance of incorporating STEM into the science curriculum and related this to soft skills. His opinion did not seem to change throughout the study.

ii) Student struggles related specifically to the learning of content, the completion of a project, and emotional struggles and anxiety not connected to the course or curriculum. Students were generally able to overcome struggles related to work, but issues relating to non-schooling concerns were more severe and some students were not able to continue attending class.

iii) Students displayed less anxiety by the end of the study, but this was not mentioned extensively in the interviews. There was one mention of a negative situation involving content where the student felt like the work in the course was ‘very hard’, causing him some anxiety. Students also had non-school anxiety about relationships, social situations during lunch, and menstruation issues. Students were unable to adapt to emotional struggles, and these situations concluded with students either going home, leaving the classroom for long periods, or complete disengagement. The first few weeks involved specific situations where students had emotional struggles. These involved one or two students and were semi-resolved by them going home or by them leaving the classroom and returning once they had ‘collected themselves’. The fourth week involved several substantial relationship and social issues.

iv) Students did not enjoying testing and this increased their anxiety. The ability to complete larger projects instead of completing tests reduced their anxiety. Students found that some projects worked better with their individual learning styles. Students enjoyed hands-on learning and engaged more, when compared to didactic teaching methods. Students did not enjoy using textbooks as much as learning the information from other sources. The teacher noted that many of the students aligned more the STEM PBL method of teaching and learning. He mentioned that student thinking and learning were at better levels compared to his previous method. Students learned information more thoroughly and could connect their learning to information in other contexts.

v) Students generally had very positive views of PBL and the negative comments from one student were in terms of how they felt about completing additional work. Students explained that they felt more efficient and focused while completing PBL. In each subsequent interview, students relayed their understanding and the fact that they were more comfortable with PBL.

Findings from the S-STEM indicate that some areas of STEM saw a considerable improvement based on students' pre- post survey responses. When compared individually, student math attitudes were a bit lower compared to science, technology, and engineering. Students significantly improved their perspectives regarding science and technology, but only slightly improved their perspectives related to math and engineering. Perhaps this is due to students completing more activities related to science and technology over the duration of this course, when compared to engineering and math. The amount of perceived exposure to subjects may have had a more significant impact on survey data and the timing of the projects, in relation to the completion of the survey. The focus of the final two projects was on science and technology, and because those were recently completed, the students may have had more favourable views of these subjects. Students were generally positive when speaking about their projects – from the reasoning behind them, pride from doing their work, and enjoyment and success with the project. Negative comments about their projects were connected to literacy.

Differences were noted when comparing both the weekly pattern and during the scaffolding versus project weeks. Week 1 and week 3 were similar, and these involved in-class projects and student creation. Week 2 was a struggle for several students, and this was related to the literacy component within this project. The final project was data collection in the outdoors, and all students seemed to respond well to this method. The teacher continued to exude more confidence with the incorporation of PBL into his teaching.

vi) Many students struggled with course content. Either students did not remember prerequisite knowledge, or they were struggling to understand the new material presented, and this in turn impacted their ability to work. There was a small decrease in struggles during the course. The initial struggles experienced in the first week was inevitable as students were starting their science course for the first time in a year. As the course progressed, there was not much difference between weeks 2-4, but week 4 had the lowest total struggles. There was a difference when comparing time during projects and scaffolding. Students had many more negative situations related to subject content knowledge during scaffoling when compared to the projects. Students were learning and recalling content during the scaffolding sessions and projects allowed them to use this knowledge, not just recall it.

vii) Students did not feel that their learning was impacted negatively by having a SEN. Students explained that their SENs did not impact their ability to learn in a PBL format and they showed a small improvement over the duration of the study. Students mentioned that they may have a difficult time completing the PBL in a larger class size. The positive situations were related to understanding and comfort level of students, and the negative to a situation where a student had increased stress due to the lack of structure involved in PBL.

viii) The teacher personally improved during the course of the study. He explained that he would like to use this method again, as he found it rewarding and more beneficial for students. He also felt more comfortable teaching through this method after the course had ended. His survey showed his views were generally more positive after the completion of the PBL.

Research Question 2.

2. a) What is the teacher's understanding of PBL and assessment in STEM?

   b) Does the teacher's understanding change throughout the research study?

The teacher started the study with a basic level of understanding in terms of the methods of assessment. His understanding was developed through his assistance during the creation of the curriculum. Prior to this development, he did not possess a good understanding of the differences between PBL and projects and the assessments available.

The teacher was able to incorporate the fundamentals found in *"Growing Success"* (Ontario Ministry of Education, 2010) and the PBL learning format. During the creation of the curriculum, he found that the conversational and observational component could be easily incorporated because students had the opportunity to engage in personal and peer reflections, conversations about how their project related to the content, and their rationale for engaging in specific tasks, not just focusing on the outcome. This led to his ability to assess the students' projects on process as opposed to exclusively on products. The rubrics allowed students to succeed even if they did not complete the project. An example of this occurred when Oscar could not finish the coding assignment but was able to explain his ideas about what would be included.

This allowed him to receive a good grade on the project without completing it the way he had originally intended. The teacher had not assessed students through this method before, and it allowed him to grade the students who understood the content but did not have time to finish a full version of the project.

This type of assessment allowed more time in class designated to assessment “as” and “for” learning. Students in this class require extended periods to complete tests, and most of them have accommodations for time. This is regularly employed for students with learning disabilities like dyslexia and those who have high levels of test anxiety. Several hours are often designated for students studying for and completing a test. The teacher explained that PBL allowed students to have more time to understand the material. This reduced anxiety in students as it took them less time to complete assessments. They were also more able to demonstrate their knowledge in this format compared to a test situation.

Key subthemes related to research question two include PBL assessments, and STEM incorporation. Students reacted more positively toward the type of assessments used in a STEM PBL format, as they had an easier time with the assessments and generally did a better job. It was mentioned that there were significant struggles when there was a literacy focus. Students did not mentioned the incorporation of STEM into the projects extensively. This may be due to the fact that the teacher was not personally thinking about the incorporation of STEM subjects into the course, but into the projects instead. It is also possible that because he is familiar with STEM integration, he was able to focus on the implementation of new strategies and approaches.

Research Question 3.

3. Do students’ and the teacher’s STEM skills change as a result of project-based learning? If so, how are the changes manifested?

Most of the students did not have a variety of specific STEM skills before this course, and as they completed their projects, they learned specific STEM skills. The majority of students did not have experience with many of the tools and measurements they were exposed to during this PBL (e.g., building a working model, using digital storytelling, coding, higher level Microsoft Office skills, measuring pH, population density). Students learned these skills during the course and were able to use them again later in the projects. Many projects involved students using a specific skill more than once; the teacher showed an example, and students had the opportunity to practice, demonstrate the skill, and apply it in their project.

Students were able to work better in group settings later in the course. Some of the issues (e.g., peer feedback) that initially occurred diminished over time. The teacher explained that initially, students struggled. Over time, as they realized the feedback was not focused on negative aspects and small amounts of feedback was given, students became more comfortable when the feedback was more informal and brief.

Key sub-themes include co-operation, student work ethic, independence, and STEM hard and soft skills. Co-operation falls under soft skills, and this is one of the few skills which students spoke about in the interviews. In the context of this class, it was interesting as many of the students do not like other people, and they have anxiety in a variety of social situations. Their ability to work together was a skill that some of the students developed during this course. This was mentioned in a few of the student's interviews.

Students commented more about how the additional work they were doing was not enjoyable because it was work, but they wanted to finish the project because it was interesting. Most of the mentions of work ethic were relatively neutral and did not expand on how the students' perspectives changed over time.

In terms of seeking additional help from their teacher and taking the initiative to help others instead of students asking the teacher, there was a difference noted when comparing the projects and scaffolding days. Results indicate that students were positively independent from their teacher during the project portion of the study, and not during scaffolding days. Students were more independent when given the opportunity to work on their projects, as this was based on their ideas and creativity.

Students mentioned STEM skills in a positive manner. There were several situations where students spoke about using STEM skills, but it was not clear if they learned them during the study. There was only one mention of the teacher feeling like his personal STEM skills improved, which was related to coding. He did mention the students' STEM skills positively, including coding, data collection, numeracy skills, and several soft skills. In terms of hard skills, there was a difference when comparing weeks; this is most likely due to the nature of the projects. The projects that were based on engineering, design, and physical skills demonstrated development of student skills, as there were more STEM skills observed during the projects. For example, week 1 had a distinct focus on the engineering aspect as students were expected to design and build a prototype. There were positive observations of students developing engineering skills. In week 2 students displayed skills in technology, and did not include many aspects of different STEM subjects into their projects. Week 3 showed significant use of technology, and this was the only time where students had negative interactions with STEM skills. Finally, week 4 focused on science skills but incorporated mathematics, engineering, and technology. These skills were directly used in the projects related to data collection in field research. The projects were the only time these skills were recorded in the observational data, as students were not seen developing skills during scaffolding lessons. The soft STEM skills that emerged were creativity, co-operation and leadership, and time management. Each of these skills were observed in different amounts during the weeks. Scaffolding days had little mention of soft STEM skills. Students showed less soft skill development during the coding project.

In week 1, students demonstrated time management abilities, some creativity, and co-operation and leadership. At the end of this unit, both groups struggled to finish within the time frame and a few times they asked the teacher for assistance without first asking their groups. Week 2 was stressful for some students; however, most were able to manage their time. In the end, a few students still struggled to hand in their projects on time. In week 3, students showed substantial amounts of creativity because of the nature of the project. Some students struggled at the start with their ideas, but once they developed them, they were able to complete their project. Several students did not finish within the time allotted in class and worked on their projects at home. All students finished the final projects, but they displayed less creativity than what was included in their original plan. This was to be expected as students collected data and worked together to finish their projects.

Discussion

Teacher and students' perspectives of PBL in STEM

The perspectives of students and the teacher did change regarding PBL in STEM. The students and the teacher were previously exposed to using projects in classes, but not the PBL approach. The findings indicate that both students and the teacher had no experience before this study regarding PBL, and after the study, they preferred using this method. Projects involving real-world situations, problem-solving, and creativity to solve problems created a different environment for the students and the teacher in this study.

This was manifested in students' ability to complete projects, their engagement levels, their connection to STEM subjects, their anxiety levels, and their knowledge of assessment practices. Thomas (2000) explained the importance of ensuring that teachers have enough support to facilitate their personal growth while learning how to teach PBL. This was reflected in this study as the teacher felt more confident and was supported throughout the course. This is an important finding as research has shown the lack of confidence teachers feel while teaching STEM subjects (DeCoito & Myskzal, 2018; Nadelson, Callahan, Pyke, Dance, & Pfiester, 2013) and using a PBL learning format can increase the confidence or perception of their ability to teach the subject.

An additional important aspect that was considered when conceptualizing implementation in the current educational model was the number of learning objectives in the curriculum. The teacher in this study was able to cover all key learning objectives required in the course while having the same amount of instructional time. The teacher explained that prior to experiencing and working through the STEM PBL framework, he would have been sceptical of the amount of time required and the students' ability to complete the larger projects. This reflects the findings from Mitchell, Foulger, Wetzel, and Rathkey (2009) where the perceived barriers related to timing seemed more difficult than the implementation. As the teacher explained, there are often concerns about the ability to teach all of the concepts in a progressive environment. The findings of this study mirrors that of previous research (Mitchell, Foulger, Wetzel, & Rathkey, 2009) indicating that progressive approaches, including STEM PBL, are able to cover all of the curriculum expectations while teaching in a more engaging method. This helps limit the potential concerns of implementing new teaching methods that teachers have not experienced or used previously.

Interview findings indicate that students and the teacher had little knowledge of PBL, and specifically STEM PBL before the course. Their ability to learn successfully through this method were similar to findings of Han, Capraro and Capraro (2015). Students enjoyed working in a PBL environment more when compared to completing regular projects or tests. Previous research has shown that PBL increases engagement in students (Gültekin, 2005) which was demonstrated in this study. The observational findings showed that students enjoyed activities that focused on interactive lessons, and a lesser focus on literacy skills. Several of the students had low reading levels and their ability to experiment and think about content helped them succeed. Previous research (Thomas, 2000) showed that students with low literacy levels or SENs demonstrated higher scores compared to other students, when PBL was implemented in the classroom. The findings of this study reinforce the fact that interactive projects that are situated in contexts that SEN students can relate to results in an increase in student enjoyment. This means that incorporating STEM PBL is beneficial for students with anxiety or SENs in terms of their engagement.

Students struggled initially to incorporate their ideas and creativity, but this skill was enhanced over the course. The artifacts that students created and the progression across their creation showed students' ability to self-reflect and incorporate feedback directly to their projects. The change in perspectives of STEM PBL were manifested in student explanations, and observational data of increased enjoyment and success through this method. My study findings reflect the concepts gleaned from Haugen (2013) whereby attitudes towards being a scientist and students' current perspectives were explored.

At the onset of the study, student perspectives related to all of the STEM subjects was high and slightly increased over the duration of the study. This was evident through findings derived from the S-STEM survey, student interviews, as well as the qualitative observations of the students. Students perspectives of science and technology significantly increased, as shown in the S-STEM survey. Student interviews indicated that few opinions changed around most of the STEM subjects, but many students felt more comfortable with specific technologies and some scientific tools. These changes could have materialized because students finished a science course with the integration of other STEM subjects. Attitudes of students prior to and after PBL have been explored previously and show that students perspectives improve after learning in a PBL learning environment (Tseng, Chang, Lou, & Chen, 2013). This study has shown that students with positive viewpoints of STEM can improve their perspectives related to STEM fields. Exploring this further with students with initial negative perspectives of STEM could show improvements in a PBL context. These are beneficial as the incorporation of STEM PBL teaching methods could increase student enjoyment while learning STEM subjects. This may impact students' aspirations to enrol in STEM subjects in post-secondary education.

Student perspectives and their ability to complete projects changed throughout the study, and this was manifested in student artifacts, interviews and observations. The artifacts demonstrate that students were able to complete projects, and findings from observations and interviews showed improvements in time management skills amongst some students. Capraro, Capraro and Morgan (2013) explained the importance of giving students the resources and time so that they can improve their time management skills. This study showed the implementation of STEM PBL could be used as a tool to help students develop their time management skills. Teachers can use STEM PBL to teach a variety of soft skills like time management, which are beneficial to students when entering the workforce in their future (Schulz, 2008).

Students spoke in interviews about doing more work to complete the projects than in their previous classes. The students' descriptions of their grades clearly demonstrated that students were more successful when they were more willing to complete a project or put in more work into their project. This is especially important with high-risk students who often do not finish projects or activities due to a variety of factors. These ideas connect to the performance and success of students who learn in STEM PBL environments (Han, Capraro & Capraro, 2015; Thomas, 2000). This idea is intuitive as students who do more work, will more likely be successful. However, the important aspect is many of the students in this study did not have any intrinsic desire to be very successful in school. The inclusion of STEM PBL learning increases the motivation for students to complete more work or complete it to a higher standard. Teachers often try to figure out ways to inspire students to want to do more work, and STEM PBL is a method which could positively impact and inspire students.

In terms of the perception of student engagement, there was evidence that students were more engaged while completing the projects. Student interviews demonstrated that they enjoyed the projects and were generally engaged during the study. Students who struggled were able to overcome issues related to projects and some problems related to content, but if there was an emotional struggle in the student's life this teaching method was not able to consistently re-engage the student. There was no specific prior research that explored the reasons for re-engagement related to STEM PBL when looking at the specific causes of disengagement in classes. If students are more able to deal with content related concerns while learning in a STEM PBL environment, there could also be positive impacts for students without anxiety or SENs. This was a concept that was explored after coding the data, and additional research should be completed to explore this further.

There was slightly higher attendance during this course when compared to other courses, which could have been related to student engagement. The changes manifested could be due to the individual student’s personal investment in the projects, their increased confidence related to content, the additional time given, or that they were doing activities which they had not attempted before. These factors could have created a unique environment that possibly increased engagement for a short period. Similar to findings in this study, attendance rates of students in PBL environments has been shown to increase in previous research (Smith & Cook, 2012). This research has shown the potential of STEM PBL to increase student enjoyment which may impact their attendance. Further studies can explore environments with low student attendance, and ascertain if STEM PBL can indeed impact student attendance.

Students’ anxiety levels in terms of their perspectives of a STEM PBL context also changed. Students demonstrated that their anxiety levels were lower, and also explained directly that their anxiety levels were lower when being assessed through this method, especially when compared to assessments based on testing. The teacher also indicated that student anxiety levels were lower in the PBL format. These results show the benefit of incorporating a STEM PBL approach to help reduce the anxieties students may have regarding STEM subjects.

Students' attendance being slightly higher could be linked to lower anxiety about completing assessments (Zeidner, 1998). Students in this class did not mention that they specifically did not attend school for issues related to the content; this idea has been discussed related to other courses with specific students. Students stress may have been reduced due to not having to study for or completing tests (Huberty, 2009), not having to worry about completing perfect versions of projects, having more extended periods for completion of projects, or having access to more consistent feedback. All of these aspects affected several students in the class and allowed them to succeed as their anxiety levels were lowered in this environment. Students expressed that they felt less anxiety while learning in the STEM PBL format compared to the other courses during the year. Student anxiety that was not impacted were aspects not related to content or schooling specifically. This warrants further research. Moving forward, STEM PBL could be a tool that helps students who suffer from test or assessment anxiety.

The context around high school students with SENs and how student anxiety is connected to PBL or STEM PBL has not been previously explored in the literature. Student’s perception of STEM PBL was also observed in students with SENs, with positive results directly linked to additional time for the student with ADHD and dyslexia. It allowed the student to take his time during the projects and also provided him with projects where he could work with technology and use a hands-on approach. The small number of students with additional SENs, not related to anxiety, provides a glimpse into one way this teaching method could benefit students with these SENs, but should not be used to dictate how other students may react. Students with SENs often need additional time to complete assessments which may take away learning time. Educators who teach students with SENs can use this method to give these students more time to learn and complete assessments, which was shown over the duration of the study. Incorportaing STEM PBL while teaching students with SENs can help address some of the accomodations they need and allow them to participate in class. Past research has shown the benefits for students with SEN learning in a STEM PBL envirnonment (Han, Capraro & Capraro, 2015). The findings from this study add to the literature and continue to show the benefits of teaching SEN students in a STEM PBL environment.

Students' perceptions of how they were graded also differed during the course when compared to other classes. Students understood that the method of grading was not as focused on the result; the rubrics allowed students to explore topics and work towards a successful project. Students were able to submit projects which may not have been entirely successful, but showed that they understood the concepts and that they worked towards completing them. The student's perspectives allowed them to see success in the journey of learning and the trial and error of completing projects. Incorporating STEM PBL could reduce potential gaps for disadvantaged students in science and math course enrollment, and positively impact these concerns explored in prior research (Glennie, Mason, & Dalton, 2016; Han, Capraro, & Capraro, 2015; Howard-Brown, & Martinez, 2012).

Teaching using PBL

Prior to starting the course, the teacher's understanding of PBL was minimal as he was focused on science and math as secondary school subjects. His assessment knowledge consisted of understanding some progressive assessment practices and those found in *"Growing Success"* (Ontario Ministry of Education, 2010) and the Ontario curriculum. He had not experienced integrating STEM subjects into his courses prior to the study; he also generally focused on the creation of products for assessment. He had a different relationship and confidence level in terms of teaching and assessing STEM content.

The teacher initially focused on assessment as it related to core concepts, thus ensuring that his assessments met the standards of the Ministry of Ontario. His understanding of assessments related to STEM PBL was not developed as he had not previously worked in this environment. The first significant step in terms of changing his understanding of assessment in STEM PBL was two-fold – to understand that the final product is not the only and final assessment, and the importance of the process whereby students are able to explore and explain the concepts. The final products created did have an essential role in the assessment process, but it was not the only assessment. He mentioned that this process aligned more with the Ontario mission statement as he was able to seamlessly integrate conversations, observations, and products into his lesson. The students were also able to recognize this and achieve grades without having a fully realized version of the project. The teacher was able to learn and incorporate new assessment techniques. This is important as many teachers may not feel comfortable trying a new teaching technique, but findings from this study reveal that teachers do not need experience teaching through this method to achieve success. This increases the potential for new and experienced teachers to incorporate practices associated with STEM PBL.

The second change was teacher self-efficacy or the teacher feeling successful in his teaching methods and assessment. He shifted from lacking confidence relating to assessing through this PBL, to being able to explain some of the difficulties he experienced and the benefits he witnessed as he was using PBL, to explaining that he intended to teach another science course through this method, and that he felt comfortable assessing students in this way. He mentioned that the amount of teacher preparation in a PBL environment occurs at a higher level before the course than during the course. Students had more opportunities to work with the teacher and feedback was more consistent as a result of effective preparation. He was able to interact more with the students while giving them time to be creative and come up with their own solutions to problems. This is important as the teacher's perceived success increases their self-confidence and efficacy, and helps them realize the benefits of using a STEM PBL teaching method.

The third aspect of the teacher's understanding of assessments was related to confidence with the material and its applications. The teacher was confident with the necessary level of information prior to the course but had not used a PBL learning format to assess students. Before the study, he was unsure if he would be able to assess student knowledge in the same way without a content-based test format. He also explained that he did not have experience creating the projects that students would be creating, and was unsure if the projects were possible for his students to complete within the required time limit. Throughout the study, he was more able to assess if his students were able to finish their work. He was initially concerned about incorporating all key objectives; but once he was teaching in a STEM PBL format he was able to adjust his way of thinking. This concern is shown to be incorrect in the literature (Mitchell, Foulger, Wetzel, & Rathkey, 2009), as well as highlighted in DeCoito and Myszkal's (2018) exploration of science instruction and teacher self-efficacy. The teacher in the study was able to show his ability to adapt to the new teaching and assessment method in a short amount of time. This means that other teachers could also incorporate this method into their classes. Teachers would need access to resources to facilitate their understand of STEM PBL generally, but they do not need to have experience in all of the STEM fields or STEM PBL to experience success.

Principals and schools may want to incorporate this teaching method more and this study has shown that previous experience is not nessasary (Capraro et al., 2103).

PBL and STEM skills

Students and the teacher demonstrated and explained that their STEM skills improved or stayed at the same level during the study. Changes were manifested in the students and the teacher through their knowledge and skills related to PBL. Before the study, they did not possess several skills related to PBL including understanding the process of engineering, coding, and specific scientific collection skills. Previous research has shown that students are able to learn a variety of new skills while learning in a STEM PBL learning environment (Capraro & Slough, 2013; Decoito, 2016). Students' soft skills were changed including the ability to communicate, think critically, be creative, work in teams, manage time effectively, demonstrate a strong work ethic, to name a few (Schulz, 2008). Many of the skills are related to aspects found within STEM fields (Capraro, Capraro & Morgan, 2013). The major soft skill changes demonstrated explicitly in this study were related to creativity, co-operation and leadership, and time management. Creativity is not as crucial in courses that focus on knowledge and application. Many traditional STEM courses typically focus on tests and assignments; this limits the amount of creativity students need to employ to succeed in these contexts. Real-world STEM fields often use creativity as a problem-solving mechanism. Many students in this class struggled with starting assignments that involved creativity and thinking. This was true in the first two assignments, especially during the first hour. Students were used to completing assignments that focused on content and regurgitation. Developing their ideas through expanding on content removed students from their comfort zones. Students struggled with developing their ideas and creating in the first two assignments, but became more comfortable as the course progressed. This facilitated the critical thinking skills and soft skills that students developed.

In the teacher interviews, he mentioned that some of the student’s assignments were extremely creative and that they used the content in different ways. Students were able to add their flair to their projects and make them ‘fun’, thus allowing them to express their creativity in ways that relate to the curriculum but also allowed them to go beyond. These are moments when students were most engaged and creative, and reveal how students improve aspects of their creativity and feel comfortable embedding this into their work. Previous research has explored how student creativity can be linked to STEM subjects (Oner, Nite, Capraro, & Capraro, 2016), as creativity is an important soft skill that is in demand, especially in STEM fields (Henriksen, 2014). Teachers who are able to incorporate student creativity into projects are preparing their students for a variety of different experiences in the future.

Co-operation and leadership skills are soft skills, which varied prior to the study. Students, like Vincent and Emily, did not want to interact with specific students for a variety of reasons. The other students generally explained that they preferred to work alone, but were willing to work in small groups. The teacher did not assign students to roles; he allowed the groups to develop naturally. Most students at the end of the course still preferred working independently. The students said that they felt more comfortable working alone, even though when given a chance to work independently for the final project, the students decided to work in two groups. This shows some disconnect between students answers and actions. Students knew that finishing the project independently would take more work and time compared to being part of a group. Aspects relating to co-operation and leadership have been explored (Capraro, Capraro, & Morgan, 2013) and students should improve these skills while learning in a PBL environment. STEM fields are increasingly needing people who have good co-operation and leadership skills (Brown, Brown, Reardon, & Merrill, 2011). Students learned the importance of working collaboratively even if it was less comfortable. Teachers who teach through a STEM PBL framework can provide students the opportunity to learn how to collaborate in meaningful ways.

Time management was a consistent issue for all students in this class, and the teacher mentioned that this occurred throughout the year and during the student's education. The teacher explored this in his interview and indicated that students needed extended time to develop this skill. Many students did not finish the projects and assignments within the time given, especially assignments where they were allowed to work independently. Previous research has shown students should increase their time management skills while learning in a STEM PBL environment (Capraro, Capraro & Morgan, 2013). All of the previous skills (creativity, collaboration, leadership, time management) are important soft skills and students who possess these will be successful in their future work environments (Kyllonen, 2013; Schulz, 2008). Educational leaders should pursue teaching strategies that facilitate both student knowledge and the development of soft skills. Findings of this study demonstrate that students with SENs can develop soft skills within a STEM PBL learning environment, as highlighted in previous research (Capraro, Capraro & Morgan, 2013).

There were several science skills students may not have known previously, but were able to demonstrate after the study, including data collection, differentiating between qualitative and quantitative types of data, measuring using scientific tools, and ensuring accuracy and validity. These skills were under-developed before the course, despite the fact that students should have learnt these skills in other Grade 11 biology courses. Student improvement in these skills is likely related to the skills required in the STEM PBL teaching method. The teacher did assess these skills in the projects, and the assessment completed demonstrated student improvement related to these skills. The increase in STEM skills while learning in a STEM PBL environment has been shown repeatedly in the literature (Capraro, Capraro & Morgan, 2013; DeCoito, 2016; Han, Capraro & Capraro, 2015). Limited research has explored how each of the STEM disciplines may been impacted by an integrated approach to STEM PBL.

The students demonstrated improvement in skills that they were familiar with, such as search engine research and Microsoft Office. The students had opportunities to use these tools during their projects; students did not have all the skills needed to successfully create professional looking products, create graphs, or use a variety of software programs with which they were unfamiliar. Some students mentioned that they learned technological skills, but most did not mention them in their interviews. The teacher also improved his technology skills; he had no knowledge of coding prior to the study and was able to successfully teach and help students (also with no prior knowledge of the software) to complete a game focused on course content. T-STEM findings indicate the most significant increase was in student technology use. He also explained that he felt more comfortable using this technology in a later course, as opportunities to develop 21st-century skills was evident in the study.

Students did not always understand what was meant by engineering skills and needed an explanation to understand the variety of skills encompassed in this topic. Many thought engineering was higher level skills like creating real working products and using robotics. This may have reduced the student’s awareness of their perceptions of their engineering skills, and whether they were using engineering in the class. The teacher explained how students could incorporate these ideas into multiple projects, which students demonstrated. The artifacts illustrate that students were able to use engineering testing and refining processes to create projects successfully. One student mentioned that her lung project were perfect at the end, and there were no hardships, yet she was one of the students who actually had a difficult time developing a prototype and working on the structure. Her group had to recreate her lung project several times before creating a model that functioned the way they intended. Students used the same skills involved in testing their prototypes when creating their Scratch program, and some students created devices to help them successfully collect data. The skills developed were not directly related to the curriculum, and these changes may not have occurred outside the STEM PBL teaching context.

Several students in this class had math anxiety or disliked math; one did not enjoy collecting data as it involved numbers. Students were able to show their ability to use a variety of math skills they already knew, but some students needed to have basic concepts explained (e.g., how to calculate an average). The projects did not include higher level math concepts as student's math skills were not being evaluated, and may have caused the students with math anxiety unnecessary hardship. The teacher and students did not show significant improvement in their math skills.

Overall, some STEM skills did show improvement, but not all of them. Many of these skills were observed by the researcher and the teacher, but students did not always internalize these skills. Students improved their perception of both hard and soft STEM skills, as reflected in the literature (Capraro, Capraro & Morgan, 2013; DeCoito, 2016). This research has shown the potential to develop students' STEM skills while teaching science. Not all of the skills that were learned or practiced were directly related to the content explored. Students were able to learn and explore STEM skills that could benefit them in the future (Council of Canadian Academics, 2015), without sacrificing content knowledge required for the course. Educational professionals may look for a teaching strategy that engages students, teaches key concepts, soft and hard skills, and is successful with students with SENs. STEM PBL has been shown to address all of these metrics, and demonstrating success with a teacher without previous experience with this pedagogy. Further research should explore these claims in different contexts, and with larger sample populations.

Consideration, Further Research and Conclusion.

This research has demonstrated some of the changes which can occur when teachers and students work in a STEM PBL environment. The current research has gaps related to the intersectional situations regarding STEM PBL and involving students with SENs in an Ontarian or Canadian context. This study explored a few different ways STEM PBL can impact students and teachers. Because this study is the first of its kind relating to the metrics, a descriptive case study was completed to provide in-depth evidence. This also means that the data cannot be directly extrapolated to other circumstances. The study has shown that STEM PBL increases SEN students'perceptions of STEM subjects, their interest and success.

This study presents data demonstrating STEM PBL has the potential to benefit students with high anxiety or certain SENs. This study gives a depth of information as to how the teacher and students develop over a short period of time, but additional studies can be completed to expand this gap in the research. This study sheds additional light on how STEM PBL positively impacts student learning, and the importance of increasing the implementation of this method in schools with students with SENs and anxiety.

Considerations.

The research was completed in a specific environment, as mentioned above. The major factors to be considered are that the school is private, the small class size, a single class studied, one teacher, and a semester time of one month. The format in which students are taught is an essential consideration as it allows for a focused, almost captive audience. During the enactment of STEM PBL, it is important to take into consideration the needs of students to ensure successful implementation.

Only some students choose and have the funds to attend this specific school. The school ensures accommodations for students from FNMI backgrounds and students from low-income families. The parents of these children are either in an economic situation that indirectly supports funding the cost of their child's education or have personal funding to support their child. Indigenous students' governmental education funds are allocated to this private school. The school is also willing to negotiate to ensure students who need the smaller class sizes can attend. Teachers who intend to implement this type of eduction need to take into consideration the number of students in the class, access to resources, and that students' educational needs are incorporated. During the early stages of implementation, some of the students and the teacher had difficulty adjusting to the new context. This was alleviated as help was accessible during the study.

There was only one teacher involved and observing his development over the duration of the study provides a sole perspective of teaching STEM PBL. The teacher had access to all resources required and the ability to talk to experts in this field. The information collected pertaining to his personal growth may enable further research into understanding the importance and types of resources, and their impact on the integration of STEM PBL in a given context. He expressed that it would have been more difficult without the support, in terms of resources such as lesson plans, projects, books and articles explaining methodology, and access to experts in the field that were provided by the researcher in this study. Ensuring that teachers and students have access to potentially important resources was previously explored (Capraro, Capraro & Morgan, 2013), and is reiterated in my study. Without the additional support provided by the researcher, both the teacher and students may not have experienced the same amount of success. The implications of this study highlight the need to develop strategies for facilitating the growth of teachers and students when using a STEM PBL teaching method. In moving forward with implementation, principals and teachers should ensure that they have access to adequate resources to facilitate success.

The students in this study have more access to the teacher as there are fewer students per class. Within this classroom, more students have SENs than in a typical classroom. This alters the dynamic of the classroom and how the teacher uses their time. This was also the only class studied, and no comparative element involved in this study; however, there was a series of interviews to assess progress, a test/re-test rather than case/control. This study has shown STEM PBL is successful in a small class size environment. Student success has been previously explored involving class size (Smith & Glass, 1980), and when accompanied by PBL students with anxiety (Kearney & Diliberto, 2013). These ideas are mimicked in my study, and provides the characteristics of a successful situation involving the implementation of STEM PBL.

Further research.

The study is novel and the first of its kind for many reasons, as previously discussed. There were several high-level characteristics which focused on special situations and groups of students, and extrapolating to larger populations would increase the external validity. For further research, first, recreate this study with similar parameters, but in a broader context. Further research can increase the body of knowledge related to STEM PBL and students with SENs through increasing the size of the study, including more students with different SENs, including more educational context, and expanding on the types of questions explored. In this study the sample size was small, with six students and one teacher. To increase external validity, future studies should focus on increasing the number of students, teachers and classes. This could include students from a variety of different contexts, such as rural and urban students, increasing the types of schools with a focus on students with SENs, including public and private schools, and students from different socio-economic backgrounds.

Secondly, this study explored how students responded to this teaching method in biology. Designing a longitudinal study over several years to follow a cohort of students could more accurately reflect the potential impact of this approach over a longer duration of time.

Thirdly, this study was broad in terms of the types of data collected and the range of questions explored. This type of study was purposefully completed due to the paucity of research available, and this could identify areas of promise for more focused research. Further studies could focus on one aspect of the research and collect similar data from additional sources. Data triangulation was achieved in the study, however, having a specific focus may be beneficial when researching a larger population.

Finally, the research was conducted in the province of Ontario. The resources created and used may not be suitable for use in different provinces or environments. When comparing provinces and countries, the metrics and cultures associated with learning and assessment are widely (or vastly) different and may affect how students relate to the STEM PBL framework, and their perceptions, assessments and skills.

Conclusion.

Globally, there is limited research on the effects, and potential benefits STEM PBL may have on learning outcomes and engagement when considering students with SENs. This study aimed to explain the importance and the effect of STEM PBL on students with SENs, as PBL has not been studied with this population in a Canadian context. This research study involved the implementation of STEM PBL in a small private school. Data were collected from the teacher and students before, during and after the implementation process and analyzed to address specific research questions.

Within this study, current research and literature around STEM education, PBL, students with SENs, and the interactions between them were explored. Given the gaps in the literature around STEM PBL and students with SENs, the importance of this research has been highlighted. In designing the research, a descriptive case study was selected, and the methods of data collection were discussed. The resources, the literature informing their development, and the reason for developing them were rationalized.

The research concluded that students with SENs preferred learning through a STEM PBL format compared to other teaching methods they experienced. Students increased some of their perceptions of STEM fields during the study; these were linked to prior experiences and integration of the subjects. The teacher changed his perception of assessments and how students learned in a STEM PBL context. He preferred teaching students through this approach and saw the potential benefits for students. Students and the teacher developed some new STEM-related skills which they may not have learned without immersing themselves in a STEM PBL context. This research is essential as a starting point for exploring how STEM PBL affect teaching practices, and SENs student's engagement and motivation, conceptual understanding, and skills development.

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APPENDICES

Appendix A: Lesson Assessments and learning objectives

Appendix A lists the specific objectives and assessment varieties for each lesson and activity within the course. It breaks down the assessments into each of the significant categories listed in the Ontario curriculum.

This appendix was used during the course as a recording resource for the teacher.

The first column shown which specific lesson each activity and assessment relates to. The second column lists the specific activity. The third lists the specific objectives relating to each of the activities within the course. These objectives are taken from the Ontario Curriculum Document University Level Biology Course Code SBI3U. The fourth lists the assessment types being used in each of the lesson when analyzed through a variety of different criteria. Below is a description of the types of assessments used and their purpose. The remainder of the columns are for the teachers use and location for assessment results.

<u>Descriptions of assessments</u>

1. (FOR/AS/OF) The nature of assessment.
    a. This involves the nature of the assessment of the activity. This determines the purpose behind the assessment that occurs during the activity.
        i. Assessment for learning. (FOR) This involves assessment to inform the teachers practices regarding the information that the teacher is teaching
        ii. Assessment as learning. (AS) This involves assessment to facilitate the learning process in students. Teacher look to see how students are learning through the activity and make assessments based on their knowledge acquisition.
        iii. Assessment of learning. (OF) This is what is traditionally considered assessment and involves products which students create to assess their understanding and skills of a topic. There is usually no further assessment after this stage.

2. (IP,C,PR,AI) Four broad areas of scientific inquiry.
    a. “Students learn to apply scientific investigation skills in four broad areas: initiating and planning; performing and recording; analyzing and interpreting; and communicating.

i. Initiating and planning (IP) skills include formulating questions or hypotheses or making predictions about ideas, issues, problems, or the relationships between observable variables, and planning investigations to answer those questions or test those hypotheses.
ii. Performing and recording (PR) skills include conducting research by gathering, organizing, and recording information, and safely conducting inquiries to make observations and to collect, organize, and record data.
iii. Analyzing and interpreting (AI) skills include evaluating the adequacy of the data from inquiries or the information from research sources and analyzing the data or information in order to draw and justify conclusions.
iv. Communication (C) skills include using appropriate linguistic, numeric, symbolic, and graphic modes of representation, and a variety of forms, to communicate ideas, procedures, and results." (Ontario curriculum, 2008)

3. (C,O,P) Methods of Assessment
   a. There are different methods which can be used to obtain assessments. "Assessment is the process of gathering information from a variety of sources (including assignments, day-to-day observations, conversations or conferences, demonstrations, projects, performances, and tests) that accurately reflects how well a student is achieving the curriculum expectations in a course." (Ontario curriculum, 2008)
      i. Conversation (C). This can include conferences, notes, journals, forums, student feedback and much more. These involve the verbal and written communications between students, teacher and peers.
      ii. Observation (O). This can include records, vocabulary checks, listening, speaking, group work, processfolios questions to name a few. These involve the teacher observing the student's ability to understand and work through problems.
      iii. Products (P). This can include assignments, tests, projects, graphs checklists, and variety of other sources. These involve the final product after learning has finished. There is often not further assessment after this.

4. (KU, TI, C, A) Categories of knowledge and skill.
   a. "The categories, defined by clear criteria, represent four broad areas of knowledge and skills within which the subject expectations for any given course are organized. The four categories should be considered as interrelated, reflecting the wholeness and interconnectedness of learning
      i. Knowledge and Understanding. (KU) Subject-specific content acquired in each course (knowledge), and the comprehension of its meaning and significance (understanding).
      ii. Thinking and Investigation. (TI) The use of critical and creative thinking skills and inquiry, research, and problem-solving skills and/or processes.
      iii. Communication. (C) The conveying of meaning through various forms.
      iv. Application. (A) The use of knowledge and skills to make connections within and between various" (Ontario curriculum, 2008)

Appendix B: Assessments of the Projects

This Section includes the rubrics used to analyze the of the projects. This analysis tests if, and how the projects fall within a STEM PBL framework. The analysis is adopted and adapted from Appendix B, Appendix S, Appendix U, and Appendix X from the Capraro, Capraro & Morgan Book (2013). This book explains the importance of using these resources when creating successful STEM PBL, especially as a new teacher.

Referenced Appendices

<u>*Appendix B from Capraro, Capraro & Morgan Book: Formatting Adapted)*</u>

	Unacceptable	Acceptable	Exemplary (*In addition to acceptable)*
Authenticity	❒ Project has little or no connection with the outside world or other curricular areas ❒ Questions have little or no meaning to the students ❒ Task has a single correct answer	❒ Project simulates the "real world". Working world adults are likely to tackle the task ❒ Question has meaning to the students and provides a clear "need to know" ❒ Project has several possible correct solutions	❒ Entities or persons outside of the school will or could use the product of student work ❒ Students will present and defend their solution to a real and appropriate audience
Academic Rigor	❒ Project is not based on content standards ❒ Project demands little specific knowledge of central concepts	❒ Project is derived from specific learning goals in content area standards ❒ Project demands specific knowledge of central concepts ❒ Student develop & demonstrate life skills (e.g. collaboration; presentation; writing)	❒ There is a well-defined, clear driving question that is derived from national, state or district content standards ❒ Project demands breadth and depth of central concepts. ❒ There is an expectation for supporting evidence, viewpoints, cause and effect, precise language, and persistence)
Applied Learning	❒ Recent knowledge not in solution ❒ Students work primarily alone ❒ Social interaction is not required ❒ Learning occurs out of context or at home	❒ New knowledge applied in solution ❒ Students work in groups where content is discussed and debated in project context ❒ Students use self-management skills informally	❒ Knowledge applied to a realistic and complex problem ❒ High-performance work organization skills (e.g., teamwork, communicate ideas, collect, organize and analyze information) ❒ Formally use self-management skills (e.g., develop a work plan, prioritize work, meet deadlines, allocate resources)
Active Exploration	❒ Little independent research is required. ❒ Majority of information gathered from textbooks or encyclopedia-like materials provided by the teacher	❒ Students conduct own, independent research ❒ Students gather information from authentic sources ❒ Students use raw data provided by the teacher	❒ Includes field-based or experimental research (e.g., interview experts, survey groups of people, work site exploration) ❒ Students gather information from a variety of sources through a variety of methods (interviewing and observing, gathering and reviewing information, collecting data, model-building)
Adult Connections	❒ Students have no contacts with adults other than the teacher(s)	❒ Students have limited contacts with outside adults (e.g., guest speakers, parents) ❒ Teacher uses role playing or other staff members to simulate "expert" contact	❒ Students have multiple contacts with outside adults who have expertise and experience that can ask questions, provide feedback, and offer advise ❒ Outside adults provide students with a sense of the real-world standards for this type of work
Assessment Practices	❒ Students are not provided with clear explanation of the assessment process or and expectations ❒ Assessment of project is summarized into a single final grade	❒ Clear explanation of assessment and expectations ❒ Structured journals or logs used to track progress ❒ Assessments are varied: include content & life skills ❒ Final product is an exhibition or presentation demonstrating student knowledge	❒ Students help in establishing assessment criteria ❒ Students have many opportunities for feedback on their progress from teachers, mentors, and peers
Use of Technology	❒ Students are not required to use technology or technology use is superficial	❒ Technology is used to conduct research, report information, or to calculate results where appropriate	❒ Create interactive media, conduct experiments, manipulate data, or communicate with adult experts

Appendix S from Capraro, Capraro & Morgan Book: Formatting Adapted

TEACHER PEER EVALUATION OF STEM PBL PROJECT: PROJECT CRITERIA
The project is focused on questions that engage students in the central concepts and principles of a discipline.

EVIDENCE Check all that Apply
❒ Project is centered on curriculum and aligned with national, state, or district standards.
❒ Project demands depth and breadth of understanding of central concepts and “Big Ideas”.
❒ Project is organized around an open-ended driving question, problem, or question that inspires higher-level thinking.

The project involves students in investigation of authentic issues.
❒ The driving question or problem has meaning to students and may be generated by them.
❒ The questions or problems are like those faced by people in the world outside of school.
❒ Students are required to do extensive exploration and research, including field-based activities.
❒ Students are required to have contact with adults outside of the classroom teacher or have the opportunity to work with adults in the community or online.
❒ Students are encouraged to direct their own inquiry process and investigate their own questions.

The project incorporates the use of authentic tools, including technology.
❒ Students develop and use habits of mind (e.g. concern for evidence, viewpoint, cause and effect; precision; persistence).
❒ Project work provides opportunities to develop workplace competencies (e.g. work in teams, use technology appropriately, communicate ideas, collect, organize and analyze information).
❒ Students work in groups and use formal self-management skills (e.g. develop a work plan, prioritize pieces of work, set deadlines).
❒ Students and teachers are involved in a wide range of communication patterns, roles, and activities.
❒ Technology is used to extend and enrich learning. Students have opportunities to use computers and other technologies as tools for creating, analyzing, and presenting new knowledge.

The project requires products that solve problems, explain dilemmas, or present information
❒ Knowledge and skills are applied to solving a complex problem. ❒ Information comes from a variety of sources, many of which are discovered by the student (e.g. readings, interviews, observations, libraries, websites, etc.).
❒ Final product(s) and performances show that all students have the opportunity to understand the subject matter in depth, acquire new skills, and demonstrate their knowledge.

The project requires products that solve problems, explain dilemmas, or present information
❒ Knowledge and skills are applied to solving a complex problem. ❒ Information comes from a variety of sources, many of which are discovered by the student (e.g. readings, interviews, observations, libraries, websites, etc.).
❒ Final product(s) and performances show that all students have the opportunity to understand the subject matter in depth, acquire new skills, and demonstrate their knowledge.

The project uses performance-based assessments that describe high expectations and rigorous challenges
❒ Criteria and standards by which student work will be judged are clearly explained to students, who may also help establish the criteria.
❒ Students are taught how to self-assess and are required to use structured methods such as journals, conferences, rubrics, reviews of progress, etc.
❒ Students receive timely feedback on their work in progress. ❒ Products and performances are closely aligned to standards and are rich and varied enough to make credible judgments about their learning.
❒ Students complete a culminating exhibition, presentation, or product that demonstrates their knowledge and skills.
❒ Student work is reviewed by a “real” audience. ❒ Students understand what is required of them, and are given exemplars (models of high quality work) and tools (rubrics, checklists) for monitoring their own performance.
❒ The project helps all students develop and apply skills in writing, reading, or mathematics.

Appendix U from Capraro, Capraro & Morgan Book: Adopted

CRITERIA	UNSATISFACTORY	PROFICIENT	ADVANCED in Addition to Proficient
Goals	❒ Goals of the project do not seem to be tied to any specific content area standards or are not rigorous enough to challenge the students ❒ Goals of the project seem to address only the lowest levels of critical thinking	❒ The goals of the project are tied to specific content area standards and 21st Century Skills ❒ Goals are rigorous enough to challenge all students. ❒ Goals of the project require the students to use high-order critical thinking skills.	❒ Goals of the project are clearly defined and successfully integrate content standards from multiple subject areas
Engagement	❒ Engagement seems unlikely to engage the student's curiosity. ❒ Precipitating event fails to create a realistic role or project for the students ❒ Task seems unclear but leads to a content based "need to knows" or next steps. ❒ Engagement fails to establish a timeline	❒ Engagement seems likely to engage the student's curiosity in a realistic scenario ❒ Engagement establishes a clear role and tasks. ❒ Engagement leads to a list of content-based "need to knows" and next steps ❒ Engagement establishes a clear timeline and assessment criteria	❒ Engagement engages the students in a real world problem that they can help solve ❒ Entry document creates a thorough list of relevant, content specific "need to knows" ❒ Project is launched with the help of outside person or entity
Planning	❒ The project plan may be a good idea, but little thought has been put into how to implement the idea in the classroom ❒ No thought has been put into the resources and materials required for this project	❒ The project plan has a general outline including the various phases and student activities ❒ Some thought has been put into resources and materials that are required for this project ❒ The project has a list of student products	❒ The plan includes a . . . ❒ Detailed description of various phases with progress checks and benchmarks ❒ Complete list of resources and materials ❒ Well thought out plan for implementation ❒ Description of student products and how they will be evaluated against the project goals
Scaffolding	The project lacks activities to help students ❒ Work as an effective team on a long term project ❒ Reflect on their "need to knows" and to develop next steps ❒ Understand the content and make use of the resources available (including any remediation that might be necessary)	The project has appropriate activities to help students ❒ Work as an effective team on a long-term project (time management, collaboration, etc) ❒ Reflect on their "need to knows" and to develop next steps ❒ Understand the content and make use of the resources available (including any necessary remediation that might be needed)	The project has differentiated activities for individual students and groups ❒ Work as an effective team on a long term project ❒ Reflect on their "need to knows" and to develop next steps ❒ Understand the content and use resources available (including any remediation necessary)
Assessment	❒ Rubrics are not developed, do not seem tied to the goals of the project, or are unusable by students ❒ Evaluation does not include use of schoolwide rubrics	❒ Rubric are designed to clearly lay out final product expectations as defined by project goals ❒ Evaluation includes the use of school-wide rubrics ❒ Rubrics are easy for students to use in self- and peer-assessment activities.	❒ Several rubrics are used to evaluate multiple individual and group products based on the stated content and goals of the project. ❒ Assessment includes input from outside sources
End Product	❒ End product does not demonstrate understanding and application of content standards ❒ End product is not authentic ❒ End product is not age level appropriate	❒ End product clearly demonstrates understanding and application of content standards ❒ End product is authentic and reflects real world work ❒ End product is tailored to student skill level	❒ End product contains multiple opportunities to demonstrate learning (multiple products) ❒ End product could be used externally ❒ End product incorporates a variety of media

<u>Appendix X from Capraro, Capraro & Morgan Book: Adapted</u>

Yes	No	PBL Heading			
		Project Title:			
		Teacher Names:			
		Grade Level:			
		PBL Dates:			
		Teacher			
		Objectives: *Selected from Ontario Curriculum*	*Does this section Include...*	*Yes*	*No*
			Rigor		
			Interdisciplinary Link		
		7) Connections: *How does this PBL connect to other units in your subject?*			
		8) Introduction: *An introductory paragraph to PBL written for the students*	*Does this section include...*	*Yes*	*No*
			Relevance		
		9) Well-defined Outcome:	Rigor		
		10) Materials Used:			
		11) Engagement	*Does your plan address..*	*Yes*	*No*
			Problem Identification		
			Ideation		
		Grouping *Large* *Small*	*Questioning* *(Indicate the number)* Open-ended … Probing … Guiding …		
		12) Exploration: *Explain the conditions of the free exploration and the real PBL experience; talk about the constraints, limitations, and introduce the formative assessment rubric.*	*Does your pan address…*	*Yes*	*No*
			1. Problem Identification		
			2. Research		
			3. Ideation		
			4. Analysis of Ideas		
			5. Testing and Refinement		
			6. Communication and Metacognition		
		13) Explanation: *Explain the*	*Does your plan address*	*Yes*	*No*
			1. Problem Identification		
			2. Research		
			3. Ideation		
			4. Analysis of Ideas		
			5. Testing and Refinement		
			6. Communication and Metacognition		
		14) Extension: *How can you extend this PBL for the students who are more able and/or for those who have finished before the others?*			
		15) Evaluation: *Includes the formative and summative rubric; as well as Good Questions*			
		16) References (websites); Guest Speaker information; Ordering information			

Appendix Ci: Student Interview Guide

In-Depth Interview Guide: Utilizing the Three Interview Series

Interview One: Focused Life History

Why are you attending the REDACTED INFORMATION instead of a different public school?

(A review of the participant's life history and how they ended up at this private school.

Objective: To discover as much as possible about the context of the participant's life; specifically relating to their perspectives of STEM. This includes experiences with families, friends, etc.)

Why did you choose to take science/math classes this year?

Further Questions/Explorations:

What was that like for you?

How did that affect... ?

What/who shaped... ?

How do you think that contributed to... ?

How was that significant in your development as (e.g. a teacher of reading)... ?

How would you describe... ?

Interview Two: The Details of Experience

What is it like to study science in a project-based learning format?

What did you think about your Biology class this term so far? You can talk about the assessments, teaching strategies, projects, perceptions, or anything else in the classroom.

Further Questions/Explorations:

Have you incorporated technology, engineering or math into any of your projects?

Explain the goals that you have while in school, specifically in this biology class.

Explain how you worked with your classmates?

Did you learn any skills or anything that you are proud about?

Did you make anything significant or important to you?

Interview Three: Reflection on the Meaning

Given what you previously said about your class and the REDACTED INFORMATION, how do you understand science, technology, engineering and mathematics differently after the projects.

Further Questions/Explorations:

Does making projects in class make you more or less comfortable than completing an exam?

Do you feel more or less successful while learning through PBL?

Which method do you prefer learning through?

Did PBL impact any anxieties you have about school or science?

Did you feel connected to any of the content which you learned about during the course?

Do you have any other questions or comments?

Appendix Cii: Teacher Interview Guide

In-Depth Interview Guide: Utilizing the Three Interview Series

Interview One: Focused Life History

Why did you decide to become a teacher?

What are your teaching certifications?

How long have you been teaching?

Explain your experiences at each teaching opportunity.

Why did you choose to teach at the school you are specifically at?

What is your experience with different teaching strategies?

What is your experience with STEM PBL?

(A review of the participant's life history and how they ended up teaching. Objective: To discover as much as possible about the context of the participant educational life; specifically relating to their perspectives of STEM. This includes experiences with families, friends, etc.

Why did you choose to work in the fields of STEM subjects?

Further Questions/Explorations:

What was that like for you?

How did that affect... ?

What/who shaped... ?

How do you think that contributed to... ?

How was that significant in your development as (e.g. a teacher)... ?

How would you describe... ?

Interview Two: The Details of Experience

What is it like to teach science in a project-based learning format?

Further Questions/Explorations:

What did you think about your Biology class this term so far?

You can talk about the assessments, teaching strategies, projects, perceptions, or anything else in the classroom.

How are the students reacting to this method of teaching?

Have you seen technology, engineering or math incorporated into any of the students projects?

Explain the goals that you think the students have regarding this class?

Explain how students worked in this environment? (Did they work more or less collaboratively, calmer, grade differences etc.)

Have you seen students learn any new skills and feel excited about this.

Do you think any of your students will be able to take these skills and expand on them.

Interview Three: Reflection on the Meaning

Given what you previously said about your experiences teaching and the student experiences, do you think their understanding of science, technology, engineering and mathematics has changed. If so how?

Further Questions/Explorations:

Do you think making projects in class makes the students more or less comfortable than completing an exam?

Do you feel more or less successful while learning through PBL?

Do you feel the students are more or less successful learning through PBL?

Which method do you prefer teaching through?

Did STEM PBL impact any anxieties students in your class had? Please be specific.

Did STEM PBL change how students with learning disabilities interacted with the curriculum?

Were there certain students who were more successful in this environment compared to their peers? Why do you think so.

What was the biggest predictor of success using this type of teaching method.

Do you have any other questions or comments?

Appendix D - Rubrics Used for STEM PBL Assessment

There were four different Units and the Rubric for Unit 1 was included.

Engineering Organ Systems

Rubrics to be used for evaluation of the Process and knowledge during project.

Building A Structure : Organ Technology Research Team Process and Knowledge

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Teacher Name: REDACTED INFORMATION

Student Name: ____

CATEGORY	**Exemplary**	**Proficient**	**Novice**	**Emerging**
Assessment of process	/30			
Group Identification	2 Points Students successfully created standards for their groups which they will be working in and all agreed upon them.		1 Point Students successfully created some standards for their groups which they will be working which some agreed upon	
Ideas of Prototypes	4 Points Students created multiple ideas for possible prototypes collaboratively. They chose the best prototype based on the function and cost. These were all checked by the instructor.	3 Points Students created multiple ideas for possible prototypes collaboratively. These were all checked by the instructor.	2 Points Students created an ideas for possible prototypes collaboratively. This was checked by the instructor.	1 Point Students started building their projects without ideas about their projects.

Budgeting	4 Points Students created a budget for each of their prototypes and a fully costed plan for their presentation. This was correctly calculated and thought out.	3 Points Students created a fully costed plan for their presentation. This was correctly calculated.	2 Points Students included some costs into their projects for the presentation	1 Point Students did not create a budget.
Initial Creation of Prototype	12 Points Students will collaboratively create their chosen prototype. Prototypes are based off context knowledge and include key concepts and vocabulary. Groups also thought about possible improvements or adaptations.	9 Points Students will collaboratively create their chosen prototype. Prototypes included context knowledge and include key concepts and vocabulary.	6 Points Students created a chosen prototype.	3 Point Students did not create a prototype.
Re-imagination of Prototype	8 Points Students created new versions of their initial prototype. This was because they came up with a more functional cheaper or generally successful alternative. This could also include adaptations for drug companies.	6 Points Students created a new version of their initial prototype. This was because they came up with a more functional cheaper or generally successful alternative. This could also include adaptations for drug companies.	4 Points Students created new versions of their initial prototype. There was no improvement or reason for doing so.	2 Point Students did not create any improvements on their initial prototype.
Assessment of Knowledge during project	/ 16			

Scientific Knowledge	8 Points Explanations by all group members indicate a clear and accurate understanding of scientific principles underlying the construction and modifications. They include all key terms and the diseases explored.	6 Points Explanations by all group members indicate a relatively accurate understanding of scientific principles underlying the construction and modifications. They include key terms and the diseases explored.	4 Points Explanations by most group members indicate relatively accurate understanding of scientific principles underlying the construction and modifications. They include some key terms and the diseases are not explored.	2 Point Explanations by several members of the group do not illustrate much understanding of scientific principles underlying the construction and modifications. They include few key terms and the diseases are not explored.
Information Gathering	4 Points Accurate information taken from several sources in a systematic manner.	3 Points Accurate information taken from a couple of sources in a systematic manner.	2 Points Accurate information taken from a couple of sources but not systematically.	1 Point Information taken from only one source and/or information not accurate.
Journal/Log - Content	4 Points Journal provides a complete record of planning, construction, testing, modifications, reasons for modifications, and some reflection about the strategies used and the results.	3 Points Journal provides a complete record of planning, construction, testing, modifications, and reasons for modifications.	2 Points Journal provides quite a bit of detail about planning, construction, testing, modifications, and reasons for modifications.	1 Point Journal provides very little detail about several aspects of the planning, construction, and testing process.
Non-Teacher Evaluations	/4			
Peer and Self Evaluation	4 Points Evaluations were honest, positive and showed personal drive, collaboration and innovation.	3 Points Evaluations were generally positive and showed personal drive, collaboration and innovation.	2 Points Evaluations were present and students showed that they were able to self-evaluate successfully	1 Point Evaluations were not present.

Appendix E – Letters of Information and Consent and Debriefing Documents

There are eight subsections relating to consent. Some of the letters were reformatted for this inclusion.

E-i.	Letter of Information
E-ii.	Letter of Information and Consent – Parent
E-iii	Letter of Information and Consent – Teacher
E-iv	Letter of Information and Assent – Student
E-v	Debriefing Letter
E-vi	Oral Recruitment Script
E-vii	Teacher Recruitment Script
E-viii	School Recruitment Script

Western Education

Appendix E-i: Letter of Information

Study Title: Exploring Project-Based Learning in STEM with Exceptional Students

Name of Principal Investigator: Dr. Isha DeCoito, Western University Email: REDACTED INFORMATION
Co-Investigator: Miss Kayla Lambie, Western University Telephone: REDACTED INFORMATION

1. Why are you here?
You are here because you are a student in the Biology (SBI3U) course. We would like to inform you about a research study that will explore science, technology, engineering and math (STEM) Project-Based Learning (PBL) and will take place in your biology course. We are providing information that will help you determine if you want to participate in the study.

2. Why are they doing this study?
We would like you to learn new skills while taking your biology course.

3. What will happen to you?
Kayla Lambie will ask you to complete surveys (12 minutes), interviews (maximum 30 mins), and participate in the activities of the class.

4. Will there be any tests?
There will be no tests or marks for this study. You will be marked on the information you learn during the course not the projects.

5. Will the study help you?
The study may help you learn skills like engineering, coding, water testing and publication techniques.

6. Do you have to be in the study?
You do not have to be in the study. If you do not want to be in the study, tell Dr. DeCoito or your parents. Even if you say yes, you can change your mind later on.

7. What if you have any questions?
You can ask questions at any time, now or later. You can also talk to teachers, Dr. DeCoito or Kayla Lambie.

This letter is yours to keep for future reference.

Appendix E-ii: Letter of Information and Consent – Parents

Study Title: Exploring Project-Based Learning in STEM with Exceptional Students

Name of Principal Investigator:
Dr. Isha DeCoito
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

Co-Investigator:
Miss Kayla Lambie
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

1. Invitation to Participate
Your child is being invited to participate in a research study about the impacts of science, technology, engineering and mathematics (STEM) project-based learning (PBL). Your child is being invited because they are enrolled in Biology (SBI3U), and they are in a school with students requiring personalized education.

2. Why is this study being done?
This study will examine the experiences of students doing self and co-operatively guided projects while integrating science, technology, mathematics and engineering. There is currently a lack of research related to this approach to teaching, especially for students with exceptionalities.

3. How long will you be in this study?
Your child will be in the study for 22 days of school, during the Biology course.

4. What are the study procedures?
If you agree for your child to participate, he/she will be asked to complete a pre-survey (5-10 minutes), participate in a STEM PBL framework assessment and teaching, complete three interviews (5-10 minutes), and complete a post-survey (2 minutes). Each interview will be conducted by Kayla Lambie. The interviews will be done during class time when the students are working independently on an activity. Students who do not consent to be audiotaped can continue to participate. Kayla Lambie will be taking notes during the interview. All surveys, activities and interviews will occur in the classroom or school. Students who are not participating in the study will be provided with activities to be completed in the library. Kayla Lambie will be in the classroom everyday making observations of the children where consent is obtained to participate in the study. The study will not be evaluating students. Your child's grades will be based on their knowledge and understanding of classroom work, not on their ability to complete the project involved in the study.

5. What are the risks and harms of participating in this study?
Given that the classroom teacher is professionally trained to address anxiety in students and that your child has already worked with them, normal risks associated with teaching and learning will be present.

6. What are the benefits of participating in this study?
The possible benefits to your child include learning of skills and content which they would not normally learn within a traditionally taught biology class. These skills include building and engineering, understanding Indigenous ways of knowing, learning the basics of coding, and understanding how to test water supply at their home. This study will explore how your child learns in a STEM PBL environment and if this teaching method is beneficial to their learning. The results of this research will be used to help inform further research and curricular development regarding STEM PBL methods.

7. Can participants choose to leave the study?
Your child's participation in this study is voluntary. The participants can withdraw their consent at any time from participating in the study. This will include data included in the analysis phase of the study. You child may refuse to participate or withdraw from the study at any time without any risk to their grades or relationship with their teacher.

8. How will participants' information be kept confidential?
All data collected will remain confidential and accessible only to the investigators of this study. Digital files will be password protected and securely transmitted. Your child will choose their own username for the website and will not be asked to disclose any identifying data such as DOB, address, or student ID. Your child's initials will be used to identify participating students for data collection and reward purposes, but the data will be de-identified prior to analysis and dissemination. Any information collected as a part of this study will be reported in aggregate; school, teacher, or your child will not be identified. The researcher will keep any personal information about you and your child in a secure and confidential location for a minimum of 7 years. Representatives of The University of Western Ontario Non-Medical Research Ethics Board may require access to study-related records to monitor the conduct of the research. While we do our best to protect your information there is no guarantee that we will be able to do so. If data is collected during the project which may be required to report, by law we have a duty to report.

9. Are participants compensated to be in this study?
Your child will receive weekly lunches bought for the class. These lunches will be chosen by the students and the teacher each week. Your child will also be given a $10.00 visa gift card.

10. What are the rights of participants?
Your child's participation in this study is voluntary. He/she may decide not to participate. If you consent for your child to participate, he/she has the right to withdraw from the study at any time. If you choose for your child not to participate, or if your child chooses to withdraw from the study at any point, it will have no effect on their grades or relationship with their teacher. You do not waive any legal right by signing this consent form.

11. Whom do participants contact for questions?
If you have questions about this research study please contact Kayla Lambie (Student Researcher), at REDACTED INFORMATION or by phone at REDACTED INFORMATION.
If you have any questions about the research study, you may contact the thesis supervisor, Dr. Isha DeCoito at REDACTED INFORMATION or by phone REDACTED INFORMATION.
If you have any questions concerning your rights as a research subject or questions about the conduct of the study, you may contact the University of Western Office of Human Research Ethics at REDACTED INFORMATION.

Letter of Consent- Parent

Study Title: Exploring Project-Based Learning in STEM with Exceptional Students

Name of Principal Investigator:
Dr. Isha DeCoito
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

Co-Investigator:
Miss Kayla Lambie
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

I have read the Letter of Information and all questions have been answered to my satisfaction.

I agree for my child to be audio recorded in this research	☐ **YES** ☐ **NO**
I consent to the use of unidentified quotes obtained during the study in the dissemination of this research	☐ **YES** ☐ **NO**
I agree for my child to participate in surveys.	☐ **YES** ☐ **NO**
I agree for my child to participate in interviews.	☐ **YES** ☐ **NO**

Parent Name (please print): ______________________________

Parent Signature: ______________________________

Date: ______________________________

My signature means that I have explained the study to the participant named above. I have answered all questions.

Person Obtaining Consent: ______________________________

Date: ______________________________

Appendix E-iii: Letter of Information and Assent – Student

Study Title: Exploring Project-Based Learning in STEM with Exceptional Students

Name of Principal Investigator: Dr. Isha DeCoito, Western University Email REDACTED INFORMATION
Co-Investigator: Miss Kayla Lambie, Western University, Telephone: REDACTED INFORMATION

1. Invitation to Participate
You are being invited to participate in this research study about the impacts of Science, technology, engineering and mathematics (STEM) project-based learning (PBL) because you are enrolled in Biology (SBI3U), and in a school with students requiring personalized education.

2. Why is this study being done?
This study will examine the experiences of students doing self and co-operatively guided projects while integrating science, technology, mathematics and engineering. There is currently a lack of research related to this approach to teaching, especially for students with exceptionalities.

3. How long will you be in this study?
You will be in the study for 22 days of school, during the Biology course.

4. What are the study procedures?
If you agree to participate, you will be asked to complete a pre-survey (5-10 minutes), participate in a STEM PBL framework assessment and teaching, complete three interviews (5-10 minutes), and complete a post-survey (2 minutes). Each interview will be conducted by Kayla Lambie. The interviews will be done during class time when the students have independent study. Students who do not consent to be audiotaped can continue to participate. Kayla Lambie will be taking notes during the interview.

All surveys, activities and interviews will occur in the classroom or school. Students who are not participating in the study will be provided with activities to be completed in the library. Kayla Lambie will be in the classroom daily to make observations of the children who are participating in the study. The study will not be evaluating students. Your grades will be based on your knowledge and understanding of classroom work, not on your ability to complete the project involved in the study.

5. What are the risks and harms of participating in this study?
Given that your teacher is professionally trained to address anxiety and teach this course there will be no additional risks associated.

6. What are the benefits of participating in this study?
The possible benefits to you include learning of skills and content which you would not normally learn within a traditionally taught biology class. These skills include building and engineering, understanding Indigenous ways of knowing, learning the basics of coding, and understanding how to test water supply at their home. This study will explore how you learn in a STEM PBL environment and if this teaching method is beneficial to your learning.

7. Can participants choose to leave the study?

Your participation in this study is voluntary. The participants can withdraw their consent at any time from participating in the study. This will include data included in the analysis phase of the study. You may refuse to participate or withdraw from the study at any time without any risk to your grades or relationship with your teacher.

8. How will participants' information be kept confidential?
All data collected will remain confidential and accessible only to the investigators of this study. Digital files will be password protected and securely transmitted. You will choose your own username for the website and will not be asked to disclose any identifying data such as DOB, address, or student ID. Your initials will be used to identify participating students for data collection and reward purposes, but the data will be de-identified prior to analysis and dissemination. Any information collected as a part of this study will be reported in aggregate; school, teacher, and student. The researcher will keep any personal information about you in a secure and confidential location for a minimum of 7 years. Representatives of The University of Western Ontario Non-Medical Research Ethics Board may require access to study-related records to monitor the conduct of the research. While we do our best to protect your information there is no guarantee that we will be able to do so. If data is collected during the project which may be required to report, by law we have a duty to report.

9. Are participants compensated to be in this study?
You will receive weekly lunches bought for the class. These will be chosen by students and the teacher each week. You will also be given a $10.00 visa gift card at the completion of the study, even if you withdraw.

10. What are the rights of participants?
Your participation in this study is voluntary. You may decide not to participate. If you consent you have the right to withdraw from the study at any time. If you choose not to participate, or if you choose to withdraw from the study at any point, it will have no effect on your grades or relationship with your teacher. You do not waive any legal right by signing this consent form.

11. Whom do participants contact for questions?
If you have questions about this research study please contact Kayla Lambie (Student Researcher), at REDACTED INFORMATION or by phone at REDACTED INFORMATION.

If you have any questions about the research study, you may contact the thesis supervisor, Dr. Isha DeCoito at REDACTED INFORMATION or by phone at REDACTED INFORMATION.

If you have any questions concerning your rights as a research subject or questions about the conduct of the study, you may contact the University of Western Office of Human Research Ethics at REDACTED INFORMATION.

This letter is yours to keep for future referencs

Letter of Assent – Student

Study Title: Exploring Project-Based Learning in STEM with Exceptional Students

Name of Principal Investigator:
Dr. Isha DeCoito
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

Co-Investigator:
Miss Kayla Lambie
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

I have read the Letter of Information and all questions have been answered to my satisfaction.

I agree for my child to be audio recorded in this research ☐ **YES** ☐ **NO**

I consent to the use of unidentified quotes obtained during the study in the dissemination of this research ☐ **YES** ☐ **NO**

I agree for my child to participate in surveys. ☐ **YES** ☐ **NO**

I agree for my child to participate in interviews. ☐ **YES** ☐ **NO**

Parent Name (please print): ____

Parent Signature: ____

Date: ____

My signature means that I have explained the study to the participant named above. I have answered all questions.

Person Obtaining Consent: ____

Date: ____

Appendix E-iv: Letter of Information and Consent – Teacher

Study Title: Exploring Project-Based Learning in STEM with Exceptional Students

Name of Principal Investigator:
Dr. Isha DeCoito
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

Co-Investigator:
Miss Kayla Lambie
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

1. Invitation to Participate
You are being invited to participate in this research study about the impacts of science, technology, engineering and mathematics (STEM) project-based learning (PBL) on student understanding of science. You are being invited because you expressed interest, you teach the Biology course (SBI3U) with students requiring personalized education, including a variety of exceptional students.

2. Why is this study being done?
This study will examine the experiences of students doing self and co-operatively guided projects while integrating science, technology, mathematics and engineering. There is currently a lack of research related to this approach to teaching, especially for students with exceptionalities.

3. How long will you be in this study?
You will be in the study for 22 days of school, during the Biology course.

4. What are the study procedures?
If you agree to participate, you and the students in your Biology course who provide consent, will be asked to complete a pre-survey (5-10 minutes), participate in a STEM PBL framework of assessment and teaching, complete three interviews (5-10 minutes), and complete a post-survey (2 minutes). The time commitment for this project will encompass the length of the teaching time for the Biology Unit and 2 hours of preparation time before to help create the curriculum that will be used for the class. All surveys, activities and interviews will occur in the classroom or school. Students who are not participating in the study will be provided with activities to be completed in the library. Kayla Lambie will be in the classroom daily to make observations of the children who are participating in the study. The students will be taken out of the class during class time for the interviews. This should be done during a time of independent study.

5. What are the risks and harms of participating in this study?

Given that you are professionally trained to address anxiety in students and that you have already worked with these students, there are no additional risks beyond normal risks associated with teaching and learning in this context.

6. What are the benefits of participating in this study?
The possible benefits to you may involve modeling of pedagogy that promotes student learning of skills and content which they would normally not learn within a traditionally taught biology class. These skills include building and engineering, understanding Indigenous ways of knowing, learning basics of coding, and understanding how to test your water supply at your home.
The results of this research will be extremely beneficial in informing your curricular development in STEM PBL methods.

7. Can participants choose to leave the study?
Participation in this study is voluntary. The participants can withdraw their consent at any time from participating in the study. This will include data included in the analysis phase of the study. You may refuse to participate or withdraw from the study at any time with no effect on your future involvement with research initiatives.

8. How will participants' information be kept confidential?
All data collected will remain confidential and accessible only to the investigators of this study. Digital files will be password protected and securely transmitted. As a participating teacher, you will not be required to disclose your name or any other personal identifying information, except for the purpose of granting consent. All data will be de-identified prior to analysis and dissemination. Any information collected as a part of this study will be reported in aggregate; school, teacher, or individual students will not be identified. The researcher will keep any personal information about you in a secure and confidential location for a minimum of 7 years. Representatives of The University of Western Ontario Non-Medical Research Ethics Board may require access to study-related records to monitor the conduct of the research. While we do our best to protect your information there is no guarantee that we will be able to do so. If data is collected during the project which may be required to report, by law we have a duty to report.

9. Are participants compensated to be in this study?
You and your students will receive weekly lunches bought for the class. These lunches will be selected by your and your students each week. You and your students will also be given a $10.00 visa gift card.

10. What are the rights of participants?
Your participation in this study is voluntary. You may decide not to participate. If you consent to participate, you have the right to withdraw from the study at any time. If you choose not to participate, or if you choose to withdraw from the study at any point, your decision will have no effect on participation in future studies. You do not waive any legal right by signing this consent form.

11. Whom do participants contact for questions?
If you have questions about this research study please contact Kayla Lambie (Student Researcher), at REDACTED INFORMATION or by phone at REDACTED INFORMATION.

If you have any questions about the research study, you may contact the thesis supervisor, Dr. Isha DeCoito at REDACTED INFORMATION or by phone at REDACTED INFORMATION.

If you have any questions concerning your rights as a research subject or questions about the conduct of the study, you may contact the University of Western Office of Human Research Ethics at REDACTED INFORMATION

Letter of Consent- Teacher

Study Title: Exploring Project-Based Learning in STEM with Exceptional Students

Name of Principal Investigator:
Dr. Isha DeCoito
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

Co-Investigator:
Miss Kayla Lambie
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

I have read the Letter of Information, have had the nature of the study explained to me, and all questions have been answered to my satisfaction. I agree to participate by signing below.

My signature means that I have explained the study to the participant named above. I have answered all questions." above the signature of the person obtaining consent.

Teacher's Name (please print): ______________________________

Teacher's Signature: ______________________________

____

Date: ______________________________

________ ______________________

My signature means that I have explained the study to the participant named above. I have answered all questions.

Person Obtaining Informed Consent (please print): ____________________

Signature: ____________________

Date: ____________________

Western Education

Appendix E-v: Debriefing Form for Participation in the STEM PBL Research Study

University of Western Ontario

Thank you for your participation in our study! Your participation is greatly appreciated.

Purpose of the Study:

We previously informed you that the purpose of the study was to understand how students and teachers respond to a STEM PBL teaching and learning format. The goal of our research was to understand the important factors relating to students with exceptionalities and their learning of a STEM subject through a STEM PBL format.

Confidentiality:

You may decide that you do not want your data used in this research. If you would like your data removed from the study and permanently deleted please contact Dr. Isha Decoito or Kayla Lambie. Contact information will be written below.

If you agree to participate in the study and then later decides to withdraw your data, you will still receive compensation. you will still receive your $10 gift card to a store of your choice for your participation. If you choose to not participate in the study you will not be able to receive the 10$ gift card. You will also have the ability to participate in the free lunches if you choose to participate in the study or not.

Final Report:

If you would like to receive a copy of the final report of this study (or a summary of the findings) when it is completed, please feel free to contact us.

Useful Contact Information:

If you have any questions or concerns regarding this study, its purpose or procedures, or if you have a research-related problem, please feel free to contact the researchers.

Name of Principal Investigator:
Dr. Isha DeCoito
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

Co-Investigator:
Miss Kayla Lambie
Western University
Telephone: REDACTED INFORMATION
Email: REDACTED INFORMATION

If you have any questions concerning your rights as a research subject, you may contact the University of Western Office of Human Research Ethics at REDACTED INFORMATION

If you feel upset after having completed the study or find that some questions or aspects of the study triggered distress, talking with a qualified clinician may help. If you feel you would like assistance please contact one of the following.

Kids Help Phone Counsellor

Toll Free - 1-800- 688- 6868

Website - https://kidshelpphone.ca/

London Mental Health Crisis Service

Local number - (519) 433-2023

Toll Free - 1-866-933-2023

Website- http://reachout247.ca/

London Psychological Services

Local number - (226) 234-0713

Website - https://www.londonps.ca/contact-agnes-wainman-psychologist-counsellor-london-ontario

Further Reading(s):

If you would like to learn more about STEM PBL please see the following references:

References : These were excluded from the appendicies.

*****Please keep a copy of this form for your future reference. Once again, thank you for your participation in this study!*****

Western Education

Appendix E-vi: Recruitment Script

You are invited to participate in a study because you are a student in the Biology (SBI3U) course. We would like to inform you about a research study that will explore science, technology, engineering and math (STEM) Project-Based Learning (PBL) and will take place in your biology course. We are providing information that will help you determine if you want to participate in the study.

Kayla Lambie will ask you to complete surveys (5-10 minutes), interviews (maximum 5-10 mins), and participate in the activities of the class.

There will be no tests or marks for participating in the study. You will be marked on the information you learn during the course not the completion of the projects.

The study may help you learn skills like engineering, coding, water testing and publication techniques.

You do not have to be in the study. If you do not want to be in the study, tell Dr. DeCoito or your parents. Even if you say yes, you can change your mind later on.

You can ask questions at any time, now or later. You can also talk to teachers, Dr. DeCoito or Kayla Lambie.

Appendix E-vii: Script for Teacher Recruitment

Hello, I am a researcher from Western University is looking to complete a study in your classroom. This study will involve an integrated approach to teaching science, technology, engineering and mathematics (STEM) Project-Based Learning (PBL) which is being done under the supervision of Dr. Isha Decoito. The researcher is Kayla Lambie.

I am currently recruiting participants who are teaching biology in this school and who would like to participate in this study. Briefly, the study involves you and your students doing 2 surveys and completing 3 interviews and being observed throughout the course.

The Biology course will last 22 days of teaching time which is a normal school term. The surveys will last 5-10 minutes and the interviews will last 5-10 minutes each. The initial survey will be done before the start of the course and the final survey will be done after the course is completed. The first interview will be conducted before the start of the course. The second interview will be done while the course is happening approximately half way into the study. The final interview will be conducted after the course material has been finished. The total time commitment for the study will be within class time and should not interfere with your learning goals.

Thank you for considering participation in this study.

Kayla Lambie: REDACTED INFORMATION

Appendix E-viii: Script for School Recruitment

A researcher from Western University is looking to complete a study in your school. This study will involve an integrated approach to teaching science, technology, engineering and mathematics (STEM) project-based learning (PBL) which is being done under the supervision of Dr. Isha Decoito. The researcher is Kayla Lambie.

She is currently recruiting participants who are teaching biology and studying biology in this school and who would like to participate in this study. Briefly, the study involves students and teachers doing 2 surveys and completing 3 interviews and students being observed throughout the course.

The Biology course will last 22 days of teaching time which is a normal school term. The surveys will last 5-10 minutes and the interviews will last 5-10 minutes each. The initial survey will be done before the start of the course and the final survey will be done after the course is completed. The first interview will be conducted before the start of the course. The second interview will be done while the course is happening approximately half way into the study. The final interview will be conducted after the course material has been finished. The total time commitment for the study will be within class time and should not interfere with teaching and learning goals.

Thank you for considering participation in this study.

Kayla Lambie: REDACTED INFORMATION

Ethical Approval

Date: 17 April 2019 **To:** Dr. Isha DeCoito **Project ID:** 112808

Study Title: Exploring Project-Based Learning in STEM with Exceptional Students

Short Title: STEM

PBL Descriptive

Case Study

Application Type:

NMREB Initial

Application **Review**

Type: Delegated

Full Board

Reporting

Date: May 3 2019

Date Approval Issued: 17/Apr/2019

REB Approval Expiry Date: 17/Apr/2020

Dear Dr. Isha DeCoito

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the WREM application form for the above mentioned study, as of the date noted above. NMREB approval for this study remains valid until the expiry date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

This research study is to be conducted by the investigator noted above. All other required institutional approvals must also be obtained prior to the conduct of the study.

Documents Approved:

Document Name	Document Type	Document Date	Document Version
Debriefing Form April 16	Debriefing document	16/Apr/2019	2
Interview Structure and Questions. Nov21	Interview Guide	21/Nov/2018	2
LOI- Assent Letter. April 5th	Written Consent/Assent	05/Apr/2019	3
LOIC Parent. April 4	Written Consent/Assent	04/Apr/2019	3
LOIC.Teacher. April 5th	Written Consent/Assent	05/Apr/2019	3
Observation Template	Interview Guide	26/Mar/2019	1
Recruitment Script.Nov21	Oral Script	21/Nov/2018	2
School Recruitment Script.March25	Oral Script	25/Mar/2019	1
Student-Attitudes-toward-STEM.Nov21	Paper Survey	21/Nov/2018	1
Teacher Interview Guide. March 25th	Interview Guide	25/Mar/2019	1
Teacher Recruitment Script Researcher.March25	Oral Script	25/Mar/2019	1
T-STEMSurvey.Nov21	Paper Survey	21/Nov/2018	2

No deviations from, or changes to the protocol should be initiated without prior written approval from the NMREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Please do not hesitate to contact

us if you have any questions.

Sincerely,

Kelly Patterson, Research Ethics Officer on behalf of Dr. Randal Graham, NMREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations.

Curriculum Vitae

June 2019

NAME: LAMBIE, KAYLA

RANK: Student Researcher

FULL-TIME: Yes

DEGREES:

Designation	Institution	Department	Year
M.A	Western University	Education	2019
B.Ed	York University	Education	2015
B.Sc	York University	Health Science	2015

PROFESSIONAL DEVELOPMENT:

2018	Introduction to programming, Cousera
2018	Robert Macmillan Conference, Presenter
2017	e-learning module creation, Openlearning
2017	Curriculum leader group, Enfield Grammar School
2017	Classroom Strategies Inquiry-based Learning, EdX
2016	lesson study, Chace Community School
2016	plickers education workshop, UK
2015	Smarter Science Workshop, York University
2015	SMARTBoard Workshop, York University
2015	Aboriginal World Views and Education, Coursera

EMPLOYMENT HISTORY:

Dates	Rank/Position	Department	Institution
2016-2017	Teacher	Science	Enfield Grammar School
2015-2016	Teacher	Science	Enfield Chase Community School
2012-2014	Student Teacher	Science	Westview Secondary, North Albion