Progressive Education and Robotics:

A Behavioural Evaluation of Learning with Robots and Simulators

by

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Abstract

This study was designed to determine if the use of virtual simulation software is beneficial to students while they learn to build and program robots. Twelve student participants ranging from Grades 9-12 were randomly placed within three treatment groups: One group was given access to LEGO *EV3* robots, one group was given individual access to a virtual simulator of the *EV3*, and one group was given simultaneous access to both the robots and the simulators.

To determine whether the treatment benefitted learning, a progressive view of assessment aligned with a sustainable approach to education was utilized. The assessment looked only at the learning behaviours of the participants, as opposed to the more traditional approach of testing for written outcomes, and determined if learning was *passive, active, constructive,* or *interactive* according the *ICAP* framework suggested by Chi & Wylie (2014).

The results showed that higher-level learning behaviours were demonstrated by the treatment group that had simultaneous access to the physical robots and the virtual simulators, indicating that the group learned more as well as demonstrated behaviours that fostered increased collaboration and leadership within a group.

Keywords: education, robotics, simulators, assessment, sustainability

Chapter 1: Introduction

Overview

After more than ten years of teaching science in Manitoba, I feel there are some shortcomings to science education that must be addressed. Assessment that is not reflective of learning is a significant issue, although this could be the symptom of an improper philosophical approach to what science actually is. Science is a process, not a collection of facts, and should be taught and assessed as so.

I am a teacher who strongly emphasizes relationships and activity in a classroom. I am also a graduate student who has studied sustainability education and is interested in reforming science education into a more holistic and constructive approach that could lead to a more sustainable society. I have come across an opportunity to incorporate these interests into a research study. This study has been facilitated by a partnership between the robotics industry and the University of Manitoba Faculty of Education. The Winnipeg-based robotics software company known as Cogmation Robotics Inc. expressed a desire for their software to be tested in an educational setting. The Canadian not-for-profit organization known as Mitacs agreed to split half the cost of the study with Cogmation to perform credible research on their product, including a stipend for a Masters student to perform the research. Fortuitously, I was awarded the grant to perform the study. If students were learning STEM skills in a robotics class, how might their assessment of learning align with the paradigm of science as a process? This chapter will introduce all parties involved with the project along with my personal experiences that helped contributed to the study design.

Cogmation and programming. Cogmation Robotics Inc. is a Winnipeg company that creates virtual robotics software. This means that they make a simulator that mirrors how a real robot is constructed, programmed, and functions. In partnership with LEGO and Microsoft, Cogmation created a virtual simulator for a *LEGO Mindstorms* (also known as an *EV3*) robot, a robot with various sensors (optical, infra-red, ultrasonic, touch, etc.) and motors. *EV3* robots were created for a person with no knowledge of text-based programming languages, such as Java or C++, to allow them to develop the logic necessary to get a robot to perform a task. This skill is known as programming *logic.* With Cogmation's software known as the *Virtual Robotics Toolkit* (*VRT*), an individual could build a robot virtually and practice using the programming logic to make the robot do things without having to pay more than $400 for an actual *EV3* robot. The Cogmation team sees their simulator as having value to the education community given that computer science, programming, and Science, Technology, Engineering, and Mathematics (STEM) projects are becoming more popular (EdSurge Research, 2018; Herold, 2016; Kajeet, 2017; Park, 2018). Teaching programming logic using robots has been used by many schools to implement or enhance STEM education (S1-4-9) (Manitoba Education, Citizenship and Youth, 2000). The public perception of computer science and computer programming has increased considerably in recent years, making it a desirable component to educational facilities (Touretzky, 2010). When teaching programming logic using robots, there are many options when purchasing materials that educators can consider with respect to the quality of the equipment and/or cost. Virtual robotics software could appear to be a viable option, with its relatively lower cost (when compared to a physical robot) and its ability to be easily downloaded and distributed.

Mitacs. A national, not-for-profit organization, Mitacs has designed and delivered research and training programs in Canada since 1999. They have worked with 60 universities, 4,000 companies, and both federal and provincial governments. The aim of Mitacs is to build partnerships that support industrial and social innovation in Canada with a focus on mathematical sciences and associated disciplines. In 2003, Mitacs established a research internship program designed to increase deployment of graduate students into the private sector known as the *Accelerate* program. This is the program that awarded me the grant to perform this particular research study (Mitacs, 2018).

My story. My name is Michael Zurba, and I am a Master of Education candidate at the University of Manitoba in the Department of Curriculum, Teaching, and Learning. I received a Bachelor of Science from the University of Manitoba in 2003, a Bachelor of Education in 2005 and have been teaching science and physics at Sanford Collegiate since 2008.

Programming robots is a unique and dynamic field in science, and I believe that a new outlook on assessment will address a gap in the research and will benefit the robotics industry along with other fields of science. The robots in this study will be the vehicle through which I can achieve my goal of rationalising and executing a more progressive approach to assessment in science education. I feel compelled to perform this study in this manner after discovering a lack of robust assessment in other robotics studies. In the following paragraphs, I connect my experiences in science education as a learner and as a teacher, then use those connections to justify the design of the study.

My Experiences

Throughout my career as an educator and a student, there have been notable experiences that have helped to develop my philosophy of teaching science. In short, I believe that teaching science as a collection of sedentary pieces of information is misleading and ineffective for students. For that reason, this study will not attempt to assess participant learning experiences as an assessment of programming facts about the robots they are working with. Science is a process that obtains evidence in support of hypotheses and theories (Tyson, 2016) – it is about action and activity. Why not consider assessing robotic programming in the same spirit? When programming a robot, any arrangement of block code is analogous to a scientific prediction, albeit not a cautionary null hypothesis, but the actions of the robot would be analogous to the experimental observations determining if the prediction was correct. In this spirit, the logical progression of cause and effect is maintained and cognitively strengthened.

Educating. One of the courses in my Master of Education program was focused on historical and contemporary approaches to curriculum. I was surprised that, as a science teacher, I never really considered the subjectivity of the selected outcomes of the senior years' science curricula, along with the particular foundations (Tyler, 1969) upon which it was built. Social constructivism maintains that learning, specifically the construction of understanding, is different for each individual and that the learning process is experienced in an infinite number of ways (Counts, 1938; Dewey, 1938; Vygotsky, 2012). Yet, the senior years science curricula are composed of *specific learning outcomes (SLOs)*; discrete, universal, one-size-fits-all checkpoints. I must acknowledge and give credit to Cluster 0 and the *general learning outcomes* (*GLOs*) that suggest scientific behaviours and attitudes (Manitoba Education, Citizenship and Youth, 2000), but the inclusion of the curricular *SLOs* and the traditionalist focus on them ought to be of concern. I found myself wondering how accurate an assessment of "learning" could actually be if it were simply an assessment of these constituent *SLOs* of a curriculum. These are disconcerting thoughts for a science teacher required to implement Manitoba science curricula, and I have carried these thoughts through to this study. All this considered, I cannot select subjective outcomes of robotic programming, assess participant retention of those outcomes, and then claim that they are a reflection the learning that may have taken place during the study.

Learning. I can recollect my own experiences with high school science curricula. My experience was with several Advanced Placement courses that emphasized written assessments. I was rewarded for repeating on written assessments what a teacher had lectured during class and received some university entrance scholarships. Did I learn something? I cannot say, as I have forgotten much of what I had learned in high school. Did my school experience mean more to me than someone who received lower grades on assessments? I again cannot say with any degree of certainty. I was able to memorize what teachers thought was important to know, and I performed the minimum amount work that was required to do so; perhaps too narrowly focused my own grades and competing with my classmates for those subjective results. In a Deweyan sense (Dewey, 1938), I did not experience much.

Sustainability education. Several years after I began my teaching career, I was accepted into and completed a Post Baccalaureate Diploma in Education (PBDE) at the University of Winnipeg. The focus was on education for sustainability. Reflecting on this opportunity and profound experience, I can linearly summarize my path to enlightenment: if the world contains a finite number of resources, and those resources are the foundation of our global economy, but at the same time our global economy demands infinite growth, then our Earth exists in paradox. The Earth's ecosystems cannot survive along this path, yet society ignorantly expects them to.

In 2018, Earth Overshoot Day was August 1st. This "marks the date when humanity's demand for ecological resources and services [biocapacity] in a given year exceeds what Earth can regenerate in a year" (Earth Overshoot Day, n.d.). Any consumption beyond that day results in ecological deficit. Furthermore, whether they realize it or not, the 7.6+ billion humans inhabiting Earth are part of this ecosystem. And further still, why is this realization absent from individual consciousness, or at best a fleeting part of it? Let me connect this to education. The

Social Reconstructionist ideology asserts that education is both a construction and a constructor of society (Gutek, 2006). If an education system focusses curricula on discreet subjective learning outcomes that have been selected by others, and if students are rewarded for focussing solely on those learning outcomes, then we may be creating students who are not able to see reality in a holistic sense. To clarify, if an individual only focuses on individual details, the sum of all parts that creates a larger picture may never come into focus. For example, students may learn important facets of ecology – food chains, products of photosynthesis, etc. – but may miss the "big picture" in an ecological sense that we are all connected to both the biotic and abiotic through our every action. Without a sense of ecological connectedness that can only be seen through a wide-angle lens, an individual may find themselves working with only small segments of knowledge and combining them with the competitive spirit instilled in them from other institutional influences. In the worst-case scenario, the result could be individuals with ambitions to use their knowledge of resources to out-earn their peers, regardless of how finite planetary resources are. I have often questioned if, as a teacher, I am just a cog in the neoliberal system that creates such students of consumption, slowly changing our Earth into an environment that is unsuitable for us humans? I remain firmly convinced that the education system does not *have* to be the way I have described, we do not *have* to teach our children to live life on Earth in this way, and we do not *have* to relegate ourselves to being competitive individual consumers that fit into an economic framework. Subtle changes in how we instruct and assess our students may be a step in the right direction. Robotics education has a place in education for a sustainable future, provided it is included for the right reasons. Educators must be leery of corporate sponsorship that brings funding to public education for robots or computer programming courses, as the end goal could be to increase the number of computer programmers and ultimately lower demand and wages for skilled professionals as such. However, if an educator can foster an ideal learning environment, then a robotics class can bring together groups of students to collaborate, be creative, and to solve problems while exercising logical thought processes. These skills and the connectivity they promote will certainly be essential to a sustainable future, as they will help students practice beyond mere consumption of information.

Research Interest

I am interested in observing how students engage in learning when introduced to new topics and challenges in science. I am *not* interested in testing if the participants in our robotics study have consumed more selected learning outcomes than others. This includes activity, creativity, and collaboration. The robotics software and the *EV3* robots will be the scientifically relevant vehicle I am using to make my observations. Generally speaking, I am interested in a holistic approach to teaching and assessment in science, a subject that has been traditionally focussed on specific learning outcomes.

Gap in the Research Literature

While researching other studies of how students learn to program robots, I noticed a lack of robust assessment. Data remained strictly quantitative, and assessments were based on pre-tests and post-test that could have been challenged on grounds of validity (Morrison & Morrison, 1995). Furthermore, as Manitoban science curricula specify *Cluster 0* behaviours, and United States educational institutions make a call for *Next Generation Science Standards* (NGSS Lead States, 2013) with a focus on creativity and critical thinking, the literature has yet to respond and report in a manner other than a quantitative analysis of test results.

Research Question

Cogmation Robotics Inc. has partnered with Mitacs to research the benefits of the *Virtual Robotics Toolkit* while learning how to program. Understandably, Cogmation is hoping for a positive correlation to learning so they can better promote their product. Through the Mitacs *Accelerate* Grant, I was fortuitously handed the research problem: "How does the *Virtual Robotics Toolkit* program help students learn to program robots?" I feel ethically obliged to answer that question within an educational framework that aligns with my philosophy of education: an anti-banking model (Freire, 1970) of teaching and learning that focusses on relationships, experiences, and actions.

Purpose and Objectives of the Research

The purpose of research was to determine if learning robotics is more effective with a physical robot, a virtual robotics simulator, or a combination of both. The sub-objectives related to this general objective included:

a) Compare participant learning behaviours between each treatment group;

b) Analyze the progression of participant learning behaviours within each treatment group;

c) Observe and analyze participant learning behaviours in a mixed-group setting when posed with group robotics challenges; and

d) Perform oral interviews of selected participants to suggest reasons for specific levels of engagement

Assumptions of the Study

The largest assumption of this study is that the participants' levels of engagement while learning are reflective of actual learning. The validity of this statement is almost entirely based on the *Interactive*, *Constructive*, *Active*, and *Passive* (*ICAP*) framework by Michelene Chi and

Ruth Wylie (2014), but has been reinforced with my 13 years of teaching experiences. The *ICAP* framework, more thoroughly described in Chapter 2, predicts that as students become more engaged with the learning materials, from *passive* to *active* to *constructive* to *interactive*, their learning will increase. Since learning is deeply personal and can occur in an infinite amount of ways with a corresponding infinite amount of specific learning outcomes, (Eisner, 1967) perhaps this could be the most valid form of learning assessment.

Definitions of Terms

Included here are terms that have not already been defined within the body of this thesis that would be relevant and helpful to any readers not familiar with the dialect of an educator.

- *Assessment:* A variety of methods or tools that educators use to measure and document student learning or skill acquisition.
- *Block code*: the programming language of the *EV3* that uses blocks of shapes and pictures arranged in a liner statement in place of a traditional coding language.
- *Evaluation*: A variety of methods or tools used to judge the quality of learning that has taken place.
- *General Learning Outcome (GLO)*: a selected activity, behaviour, or even a value determined to be important practice during the acquisition of *Specific Learning Outcome*.
- *Learning behaviours*: The actions and activities of a student displayed while in the learning environment.
- *Logic*: a cognitive framework that is based on cause and effect
- *Programming*: Commonly referred to as *coding*, it is the process of designing a sequence of instructions that will automate the performance of a task for solving a given problem.

In the context of this study it relates to the performance of a physical or virtual LEGO *EV3* robot.

- *Robotics*: Robotics deals with the construction, operation, and use of robots. In the context of this study this will include the software for control of the *EV3* operations as well as the physical engineering of the robot.
- *Specific Learning Outcome (SLO):* a selected piece of information that has been determined to be essential to learning. In other words, a particular learning achievement that is often evaluated at the end of a course or program.
- *STEM:* learning activities that include *science, technology, engineering,* and *mathematics.*
- *Virtual*: A computer simulation. In our context, a simulation of the construction, programming, and operation of a robot.

Organization of this Thesis

My hopes are that the reader has received a sufficient introduction to me, the additional players that were essential to the conception of this study, my educational philosophy, and the purpose of this study as I see it. A review of literature related to the study is presented in Chapter 2. The research methodology and method, fashioned to address the research questions with a modern and relevant approach, is described in Chapter 3. Chapter 4 will display the data in various graphical forms and provide a basic analysis alongside each chart. Chapter 5 will incorporate direct quotes from student interviews to provide suggestions and launch discussions to explain the results observed in Chapter 4.

Chapter 2: Literature Review

This chapter explores the relevant literature to the study and identifies the gap within the research that this study intended to fill. I have separated the review into two sections. The first examines research studies in the field of robotics education and allows me to respond to the various methods and results from each. These studies were helpful to frame this particular study, as they reported on participants who learned to program on a virtual platform. However, no reviewed literature used assessments as robust and relevant as this study intended to. The second review section compares and contrasts philosophies of student engagement and learning that validate the design of this study.

Robotics Education

If an educator subscribes to the ideas of developmental/learning theorists such as Vygotsky (2012), then the implications for technology to provide student engagement with a physical and social environment are widespread. As stated by early research on the burgeoning field of robotics, "The combination of careful analysis of cognitive processes and the techniques of computer simulation has led to important new insights into the nature of mental representations, problem solving processes, self-knowledge, and cognitive change" (Pea & Kurland, 1984, p. 140). Furthermore, in our age of information, the ability for people to deal effectively with computers becomes an essential skill for the future. Programming robots can be a workshop to hone those skills.

Questioning reliability of pre- and post-treatment test of student learning. A study reported in 2013 indicated a correlation between learning programming with the use of a virtual robotics platform resulting in an increased speed of learning (Liu, Newsom, Schunn, & Shoop, 2013). The study analyzed pre-test and post-test averages along with the average time taken by high school students to complete a programming course taught by an instructor. The independent variables were students who learned to program with a physical robot (made by *VEX*), and students who learned to program with virtual simulation software. Scores were also categorized by questions in the field of algorithmic thinking, general programming, robotic syntax, and a physical robot test. No details were given on what qualified a score to fit in a category, nor were the test questions provided. Reliability of each testing method was not provided. My argument for not performing an analysis of pre- and post-testing is that no written test could reliably reflect an individual learning experience. A series of written assessments could provide an indication that learning has occurred, but I suggest that observation of student behaviour is a more reliable method of determining student learning (Eisner, 1967; Morrison & Morrison, 1995; Chi & Wylie, 2014).

Questioning validity of pre- and post-treatment test of student learning. A recent study indicated that the use of virtual robotic software led to a deeper level understanding of programming logic (Berland & Wilensky, 2015). The research was performed on students in Grade 8 with a learning group that used physical robots (made by *VBOT*) and a learning group that used virtual robotic software. These two groups were compared for their effectiveness in generating student understandings of complex systems content (in this case, being able to use systems modeling to address science content) and computational content (in this case, being able to use computer programming to address science content). The groups were given a pre-treatment test and a post-treatment test questionnaire, although some of the questions were repeated on both tests. All questions were graded on a scale of 0–3 by two graders with a 100% interrater reliability: a score of 0 is an unanswered question; a score of 1 means “incorrect”; a score of 2 means “partially correct or shows some understanding”; and a score of 3 is “correct or shows full understanding." Although the study showed 100% interrater reliability, an argument could be made against the validity of a student seeing the same question on two different tests with a time period between. There is no certainty that the ability to answer a question correctly a second time came from a particular treatment, as it could have come from a multitude of sources. Furthermore, validity of any written assessment could be influenced by the writing abilities of the individual being tested. Evaluators are significantly influenced by the mechanical characteristics of students' writing rather than the content, even when using a rubric (Rezaei & Lovorn, 2010). This suggests that a study of learning should avoid a written assessment to indicate learning has taken place within a treatment.

Questioning benefits of virtual robotics simulators found in previous studies. A 2004 report looked at the costs of high-end robots and looked at the pros and cons of including virtual software in a technology classroom (Geissler, Knott, Vasquez, & Wright, 2004). One could argue that due to cost constraints (a high-end robot from Mitsubishi can cost $16,000), a physical robot to learn programming logic could be difficult to obtain for individuals. LEGO *EV3* robots cost over $400 CDN for a basic package. Comparatively, a single purchase of Cogmation's *Virtual Robotics Toolkit* is $50 for a perpetual license (Cogmation, 2018). For most students wishing to learn how to program, the lower cost and ability to remotely download a virtual robotic simulator *should* make it easier to access. However, if a young robotics enthusiast does obtain a physical robot, and virtual robotic programming simulators are easily accessible, how would simultaneous use of both enrich or weaken their learning experience? The 2004 report stated that the infusion of virtual robotics into a technology curriculum will increase the level of technology literacy in students and help prepare them for future careers in technology and engineering. Only hypothetical data were provided in the conclusion, warranting a further investigation of learning into the various learning environments.

Benefits of virtual simulators in industrial settings. Many other studies exist in the realm of industrial robotics applications, and they find similar benefit in virtual simulation software. Example benefits include an increase in speed of learning and overcoming of safety issues (Yap, Taha, Dawal, & Chang, 2014) or to provide a wider range of scenarios than is physically possible during training (Abreu, Romano-Barbosa, & Mendes-Lopes, 2013). The literature is rich in studies such as these, likely due to the economic value to a burgeoning industrial robotics industry. These scenarios are further removed from our public education setting, as the studied participants were required to find optimum programming for an assembly line that builds electronics casing or other industrial scenarios. The results may parallel the learning situation of this proposed study, as the authors found that the lack of downtime that the virtual software provided and the inability to damage equipment allowed for students to complete learning modules in a shorter period of time compared to students who were working with only physical robots. For example, if an actual *EV3* robot crashed in an obstacle course, the user would have to set up the scenario physically and electronically to try again. A student using a virtual simulator would need only to hit a reset button.

Assessment of Learning

Of all the studies that attempted to correlate virtual robotics software with learning, the majority utilized quantitative data based on pre-test and post-test scoring. Testing included student knowledge of core ideas and a variety of isolated facts. This could be because objective-based assessments are easier to evaluate (Eisner, 1967, p. 250). Objective-based learning (Tyler, 1969) appears to be a foundation that the Manitoba Senior 1 (Grade 9) Science curriculum was built upon (Manitoba Education, Citizenship and Youth, 2000). Other science courses, such as Senior 2 (Grade 10) Science, Chemistry 30S and 40s (Grade 11 and 12), Physics 30S and 40S (Grade 11 and 12), take a similar approach to specific learning outcomes (Manitoba Government, 2018). However, this study has laid its foundation on the works of Eisner, recognizing that "the dynamic and complex process of instruction yields outcomes far too numerous to be specified in behavioural and content terms in advance" (Eisner, 1967, p. 254). Eisner also suggests that instruction should result in products of learning that are also unpredictable. In consideration of Eisner's findings, I sought an evaluation framework of unspecific student behaviours as an assessment of their learning.

Next Generation Science Standards. The National Research Council (NRC) of the United States has suggested that outcome-based assessments are contrary to Next Generation Science Standards (NGSS). NGSS focuses less on core ideas and more on multi-disciplinary skills that set students up for life-long learning, collaboration, and problem solving to enable them to process hypotheses, studies, and developments in fields that may not exist currently. The NRC understands that:

> "…given the cornucopia of information available today virtually at a touch –people live, after all, in an information age– an important role of science education is not to teach "all the facts" but rather to prepare students with sufficient core knowledge so that they can later acquire additional information on their own. (NGSS Lead States, 2013, p. XV)

This study attempted to assess indicators of learning that were more in line with the direction of the NGSS, under the assumption that they will be more relevant to modern students, educators, and the corporations in relevant fields (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). Furthermore, attempts were made to avoid researching just the participants themselves or just the environment we put them in. The focus was on the essence of the relationship between the two as manifested by their learning behaviours (Eddles-Hirsch, 2015).

ICAP benchmarks and learning behaviours. The *Interactive*, *Constructive*, *Active*, and *Passive* (*ICAP*) framework described by Michelene Chi and Ruth Wylie (2014) predicts that students will become more engaged with learning materials and learning will increase as the students' progress from *passive* to *interactive*. Justification for the hierarchy of the *ICAP* framework is as follows: *Passively* learned material will only be retrieved when a very similar activity is presented to the learner. *Actively* learned material can be retrieved, as a new activity requires previously learned material to fill in gaps and assimilate into a new schema. *Constructive* learning not only retrieves previously learned information, but also revises it in the process to gain a better understanding. *Interactive* learning results as a consequence of reciprocally *constructing* knowledge with a peer. One can say that learners in this *interactive* mode have achieved the deepest level of understanding (Chi & Wylie, 2014; Canelas, Hill, & Novicki, 2017). For that reason, this study did not focus on the knowledge content of participants, as was previously assessed in other studies of programming logic with pre-testing and post-testing. This study focussed on the learning behaviours of the students to reflect engagement and higher-level learning in a constructivist sense. Qualitative data was collected according to specific *ICAP* framework benchmarks for learning engagement but the benchmarks were based on concepts with diverse meanings, intending to avoid a strictly quantitative analysis (Kincheloe, 2003, p. 188). See *Table 1* for an example of the *ICAP* learning behaviours that were analyzed in a robotics context.

Table 1
Example of ICAP framework benchmarks: modeled after the work of Chi & Wylie (2014) and reframed to fit the observations and analysis of an EV3 robotics environment

	PASSIVE *Receiving*	ACTIVE *Manipulating*	CONSTRUCTIVE *Generating*	INTERACTIVE *Dialoguing*
BUILDING a robot	Observing another individual who was engineering or constructing an *EV3*, either physically or virtually Watching an online video or tutorial that was sent by another individual	Finding pieces (or software) required for future construction of the *EV3*, either physically or virtually Seeking specific online tutorials for construction suggestions Uploading a pre-built virtual robot	The act of putting together portions of the *EV3*, either physically or virtually Drawing a diagram of a robot for future analysis Creating a flowchart for future reference	Discussing or debating with another individual over the planning or best method of constructing the *EV3*, either physically or virtually Asking comprehension questions of a peer
WRITING code	Observing another individual who was creating block code Watching an online video without doing anything else	Seeking specific online tutorials for block code functions Writing down block code suggestions from online tutorial in notebook	The act of creating or reorganizing the block code to be inputted to the *EV3* brick Recopying sections of block code into a notebook for future reference	Discussing or debating with another individual over the creation or reorganization of the block code Discussing similarities and differences

Lave and knowledge construction. From her studies of how individuals learn both in the mind and the lived-in world, Jean Lave (2009) has reasoned that written assessments are ineffective at determining knowledge. She expressed the four following points to encompass knowledge and learning in practice:

1. Knowledge always undergoes construction and transformation in use.
2. Learning is an integral aspect of activity in and with the world at all times. That learning occurs is not problematic.
3. What is learned is always complexly problematic.
4. Acquisition of knowledge is not a simple matter of taking in knowledge; rather, things assumed to be natural categories, such as “bodies of knowledge,” “learners,”

> and "cultural transmission," require reconceptualization as cultural, social products. (Lave, 2009, p. 232)

I must acknowledge that an assessment of learning behaviours is not a fool-proof approach. Undoubtedly, the participants will be constantly learning *something* while in the study, but what was learned at one time may be transformed in a future activity, possibly even unlearned at some point. This makes any research of which learning treatment resulted in the most learning to be exceedingly complex and problematic. To increase complexity further, the participants in the study are necessarily products of a social and cultural framework that could have an overriding influence on their behaviour, whether they are learning or not. The complexities involved in cultural transmission of behaviours would be utterly impossible to account for in an assessment of learning behaviours.

Activity vs. grades. Wolff-Michael Roth argues that most aspects of an educational institution are oriented toward grades, rather than a production of knowledge, as an individual's grades are what determine the degree that they will have access to other social activities and practices (Roth, 2016, p. 109). I attribute this to the competition of capitalism that has permeated all facets of our society, and my background in sustainability education pushes me to avoid this competition. Interestingly, Roth states that *activity* should be the fundamental category to measure within society (Roth, 2016, p. 110). Participants in this study would obviously have an unequal amount of experience in STEM fields such as robotics. Some participants may have an *EV3* robot at home and use it often, some participants may have an *EV3* robot at home that they hardly use. Some participants may never have previously connected two pieces of LEGO together. How could I be sure that something was learned during the study and not previous to it? Activity is a non-self-identifiable unit of difference and change that spans space and time.

One of the objectives of this study was to measure the engagement, as suggested by their behaviour, of the students while they were learning something new. In other words, this study was trying to assess activity with the intention of avoiding inaccurate data resulting from the inequity of participants' previous opportunities or experience in the field of robotics or computer programming.

The zone of proximal development and learning with peers. Engestrom's conceptualization of how people learn to do new things elaborates the idea that zones of proximal development are collective, rather than individual (Engestrom, 2000). The concept of a zone of proximal development was first introduced by Vygotsky in the 1970's as the distance between the actual developmental level and the level of potential development in collaboration with peers. I agree with Engstrom that learning occurs best in groups, and for that reason the study participants remained in group settings to maximize their learning potential and perhaps mirror a more realistic scenario of learning that will occur in future experiences with technology, as predicted by the *NGSS.* Recent study findings seem to corroborate the stated goals of the *NGSS*, and give a clear picture of what we should be looking for in students in any learning environment:

> Classroom structures promoting cooperative learning are associated with greater perceived development of concept mastery, generic skills such as the ability to work collaboratively in a team and demonstrate leadership in a problem-solving task, and transferable process skills such as the ability to work with complex ideas, recognize valid sources of data, and draw conclusions on the basis of evidence. (Canelas, Hill, & Novicki, 2017, p. 453)

According to Vygotsky, learners construct technical knowledge with others through social interaction. It is only through a social reference (even if others are not immediately present) that learners can experience and internalize new knowledge (Vygotsky, 1978). A significant part of the social learning environment comes from a learner's peers. This means that a learning environment would optimally remain a social setting to allow participants to more easily reason, understand, and remember experiences.

Concluding Remarks

The literature that has been reviewed in Chapter 2 led to the identification of a gap in the research of teaching robotics using virtual simulation software. There are minimal studies to correlate improved learning on a virtual platform in a school setting, and there are none that reported results that would be considered valid through the lenses of social reconstructionism and education as a personal experience. The goal of this study was to avoid individual, outcomes-based assessment of learning, and there is significant literature to support such a stance.

My personal stance is that a transformation of science education is necessary at this time. Consider a comment from George Counts:

> Here is a society which a mastery over the forces of nature, surpassing the wildest dreams of antiquity, is accompanied by extreme material insecurity; in which dire poverty walks hand in hand with the most extravagant living that the world has ever known;
>
> (Counts, Dare progressive education be progressive?, 1932)

This comment could have been written today about many societies all around the world, indicating a lack of progress on these social issues since 1932. The result is a social erosion and a corresponding erosion of our ecosystems, also becoming apparent all around the world.

Chapter 3 will describe the methodology of this study, filling the gap identified in research and aligning with my personal approach to education that I have attempted to validate through the reviewed literature.

Chapter 3: Research Methodology

Introduction

This chapter describes the methodology and methods of the research study. Participants were placed in three separate learning environments and assessed as they learned how to build and program robots. The specifics of the learning environments, as well as how the students were recruited, observed, and assessed were a consequence of the research reviewed in the previous chapter. The intention was to enable students to learn how to program robots in various environments while allowing them to construct their own experiences with others. The assessment of learning was centered on student engagement.

Theoretical Framework

Reiterated here are the theoretical framework reviewed in Chapter 2 that influenced the research methods under the umbrella of social constructivism (Vygotsky, 1978). Although outcomes-based assessments may be easier to evaluate (Eisner, 1967), I chose to evaluate learning behaviours as a more accurate reflection of a learning experience (Chi & Wylie, 2014; Canelas, Hill, & Novicki, 2017). A written assessment can be ineffective at determining content knowledge and performance (Morrison & Morrison, 1995; Lave, 2009; Rezaei & Lovorn, 2010). Granted, some studies have shown in undergraduate students that multiple true-false questions are a good indicator of complexity of thinking as opposed to multiple choice questions (Brassil & Couch, 2019). However, a study involving university students may not be an accurate reflection of the diversity in language backround and cognitive abilities that are present in a public secondary school. Two-tiered tests (with written and graphical responses in a witten assessement) have also shown to be a good measure how students' ideas have changed by comparing pre- and post-instructional answers (Sampson, 2006). However, in this study the participants did not receive explicit instructions or lessons to learn. The possibilites for what an individual could have learned throughout a study session would be infinite, therefore pre-making an asssessment to determine what was learned in that session would be impossible. Hence, this study analyzes student behaviours while learning; as the learning behaviours and activities should be considered a fundamental marker of learning itself (Roth, 2016). Furthermore, literature suggests that zones of proximal development are collective (Engestrom, 2000). In other words, the act of learning requires a social framework of previous understanding in which to insert a new construction of knowledge (Vygotsky, 1978). In fact, collaboration (and creative thinking) as opposed to rote memorization of concepts, have been deemed most essential in modern fields of science (NGSS Lead States, 2013). My research method was based on these frameworks in an attempt to generate the most accurate reflection of student learning.

Research Method

The study was designed as a mixed-methods case study (Creswell, 2015). It was an exploratory case study, as I sought to explore the cause and effect relationships of student engagement in a bounded population of students attending a particular high school. The priority was quantitative; to establish a possible cause and effect between *independent* and *dependent* variables. In this case, the independent variables were the treatments that three different learning groups received, and the dependent variable was a measure of student engagement. The participants were randomly assigned a treatment group to equate any variables that they may bring to the group. As the participants brought in their signed consent/assent forms, I staggered their placement into groups 1, 2, and 3. In other words, each working group had an equal chance of acquiring an individual with previous skills that translate well to programming logic, or any other such advantages. Likewise, each group had an equal chance of acquiring a participant who naturally has difficulties with linear or logical thinking.

Since there was no pre-testing or post-testing in this research study, there were no control covariates. The data were first collected qualitatively, but the results were then quantified for ease of analysis. I then compared the progression of learning behaviours of different groups quantitatively to provide data to industry partners in a language that is more accessible to individuals not in the field of education.

The results were analyzed using *descriptive statistics* (Creswell, 2015, p. 180). I performed an analysis on each learning group for *ungrouped frequency* (Ayiro, 2012, p. 263) to indicate how often each learning behaviour occurred (see section on *Student Engagement* for more details of learning behaviour criterion and hierarchy). The leaning behaviours, gathered from students' written responses in notebooks over nine days, were analyzed for growth and decline and percent composition. The participant behaviours were also observed and recorded by researchers during the three days of group competitions. Finally, a purposeful sample of participants was selected after the learning and competition periods for one-on-one interviews. The participants interviewed displayed the most *interactive* learning behaviours from each treatment group. As well, an individual participant who showed the most growth from *passive* learning behaviours to *interactive* learning behaviours over the nine days of observation was also interviewed.

The results were quantified into a binary representation of either showing evidence of a learning behaviour or not. To summarize, these values were used to identify participants becoming more, or perhaps less, engaged as they learned by displaying the learning behaviours outlined in the *ICAP* framework: *passive, active, constructive,* and *interactive* (Chi & Wylie, 2014). Participant engagement was seen as the most accurate reflection of the amount of learning experienced by the participant.

Research Position and Assumptions

As an educator, I assumed that the students who were exposed to both the virtual software and the actual *EV3* robot simultaneously would show greater engagement. I assumed this would come from the wider variety of options that students could develop, share and implement within the learning. I predicted that the students who were only exposed to the virtual software would have more opportunities to explore the robots, as they could run simulations on their own time outside of the study. I was interested to see if, in fact, the students would take the opportunity to run more simulations when they were not at all required to do so.

Even though I predicted greater engagement from students who were working with the robots and software simultaneously, I made every attempt possible to provide the students in all three learning groups with the exact same baseline knowledge from which they would move forward from and construct their learning experiences.

Participant Recruitment

Approval for this study was granted by University of Manitoba Education/Nursing Research Ethics Board (ENREB) on January 16, 2019 (See *Appendix* A) under a slightly different project title. There was not enough time left in the first semester to complete the study so the project was postponed until the beginning of the second semester. Participants were recruited from a rural school in Southwestern Manitoba. Written consent was provided by the superintendent of the School Division and the principal of the school before any steps were taken toward participant recruitment (see *Appendix B*). Announcements were made and posters (see *Appendix C*) were placed in the school to inform students who were interested in robotics to come to an information meeting over a particular lunch hour. For the students who attended, a script was read (see *Appendix D*) explaining who was eligible for the study and its overall purpose. As a teacher in the study school, only students who were not enrolled in the courses I was teaching for the duration of the study were eligible to participate. Twelve students who were first to provide written consent from parents/guardians (see *Appendix E*), irrespective of gender or grade, participated in this study. Participation was strictly voluntary and did not take place during regular class times. To increase validity, the participants were systematically assigned to one of three learning groups by the order in which they provided parental consent. The first student who provided consent/assent documents was assigned to Group A, the second was assigned to Group B, the third to Group C, the fourth to Group A, and so on. During the 6 initial learning days, Group A was given access to physical robots only, Group B access to virtual robotics software only, and Group C access to physical robots and virtual robotics software simultaneously. The chosen facility is a Grade 9-12 school that in 2017 identified as 17% Aboriginal, 83% non-Aboriginal. Moreover, 61% of these students plan to attend university, 17% plan to attend college, and 7% plan to enter a trade. Every student in the school had been provided with a personal laptop through a divisional grant. I am currently employed at the school teaching Grade 9 Science, Grade 10 Science, and Grade 12 Physics.

Data Collection

Each of the three groups were given six lunch periods of collaborative learning within their two weeks of assigned group treatment. The materials were introduced to the participants during their week of learning only at the fundamental level, i.e. students will be shown how to connect their computers to the physical robot and students will be shown how to download the relevant virtual software to their personal laptops (see *Appendix F).*

The students were provided with a colour-coded notebook to record whatever they wished during the learning process. They had previously been informed that their proficiency in programming would be observed during a robot-building competition with the students in other groups. I expected that this would encourage the students to record as much detail as possible in their notebooks to help them remember what they learned and performed well. A template of suggestions on what to record in their notebooks (see *Appendix G*) was provided to each student but was intentionally left open-ended to encourage a better record of the participants' experiences. The participants only answered the questions that they felt were applicable to that day's experience. Following the *ICAP* Framework, the notebook questions intended to provide indication of the learning behaviour categories; question 3 & 4 *passive* learning, questions 5 & 6 *active* learning, questions 7 & 8 *constructive* learning, and questions 9 & 10 *interactive* learning. At the end of the study, the notebooks were analyzed for evidence of *interactive, constructive, active*, or *passive* learning behaviours using the *Notebook Analysis Coding Framework* (see *Appendix H*) according to aforementioned criteria and correlated by a second examiner (my advisor, Dr. Hechter) to improve reliability. If the examiners determined that the answer or answers were valid for each group of questions, then the participant was recorded as showing that type of learning behaviour. The results were tallied, then calculated as an average student score for every day for each group. Basic quantitative analysis showed which tendencies belonged to which groups, and if the groups progressed to higher lever learning behaviours. These levels of engagement were taken as indication of the degree of learning that the participants and groups experienced.

During week 5 of the study, the twelve students from all three groups were systematically mixed into two groups of 6 students each to perform various challenges with the two physical robots that were provided for the study. Day 1 began with the Groups 1 and 2 being assigned by the chronological order in which the participants were accepted into the study. The groups were systematically recombined each following day. On Day 2, participants 2, 4, and 6 on each team were traded. On Day 3, participants 2, 4, and 6 from team 1 were traded with participants 1, 2, and 3 of team 2. During the three days of competition, the two groups were given a programming challenge that was kept secret until the day of the challenge. Each challenge was given a primary and secondary goal:

Day 1 Challenge:

- Create a robot that moves to follow a black line track
- Have the brick light change display colours with every lap

Day 2 Challenge:

- Create a robot that moves constantly on the floor but does not bump into anything
- Have the robot make a sound when it approaches an object

Day 3 Challenge:

- Have your robot drive when activated by the touch sensor (like an “on” button)
- Allow your robot to navigate corners by following a human

Participants were instructed to keep their notebooks with them at all times to facilitate anonymous observations and recording by colour. Dr. Hechter observed one group while I observed the other, and we each completed the *Observational Analysis Coding Framework* (see *Appendix H*). Furthermore, Dr. Hechter was unaware of which colour notebook belonged to which treatment group to increase validity of the results. The group activity was observed and analyzed for discrete *ICAP* learning behaviours. The learning behaviours from the observations were tallied, then calculated, then combined to show the overall behaviour tendencies of each learning group.

Following the final day of group challenges, the participants were invited to a free pizza lunch to celebrate the completion of the research and were given an exit slip (see *Appendix I*) informing them of the general learning behaviours the study was looking for in their notebooks and in their group activities. These details were not divulged to them at the beginning of the study to keep their behaviours more organic.

After the quantitative results were analyzed, interviews were conducted with the participants who displayed the highest level of learning behaviour from each group, and with an individual who showed the greatest growth toward *interactive* learning behaviours. The individuals were selected by Dr. Hechter from the anonymous data, as he was not present when the students were recording in their notebooks and did not know the twelve participants by sight or name. This was decided to increase the level of anonymity and validity of the interview participant selection process. To ensure anonymity was maintained in the notebooks, the participants selected a numerical or symbolic pseudonym to identify their notebook. Dr. Hechter kept an identification key that allowed a student to be identified after the quantitative data had been analyzed. The lack of personal identification within the notebook eliminated any opportunity for bias in the analysis of the notebook data. After the notebook analysis had been completed, Dr. Hechter informed me of the students from each learning behaviour category that I could approach for an interview. The purpose of these interviews was to corroborate the quantitative data with each participant's verbal responses and to suggest reasons for their observed learning behaviours (see *Appendix J*). The interviews were audio recorded and transcribed by an online transcription website (rev.com) to eliminate any possibility or perception of bias. The website ensures confidentiality and data encryption (see https://www.rev.com/security), although no names of any participants were spoken during the interviews.

De-limitations of the Study

As previously mentioned, I did not test for any specific learning outcomes. The literature review has provided support in suggesting that student acquisition of specific learning outcomes is not necessarily reflective of student learning. I chose to allow only twelve participants because the number divisible by both two and three – two for the number of robots that I purchased and three for the number of treatment groups. This left the groups large enough to be collaborative but small enough to be effectively observed by two individuals. A treatment group of four allows a small ratio of students per robot (2:1) for initial learning. It also allowed for a larger collaborative group ratio during the final week (6:1) while still being small enough that one individual can observe one group effectively. I recruited participants based on expressed personal interest, as a purely random sample of students at the high school would result in portions of each group not wanting to learn to program at all. The study was open to all students from Grade 9 to Grade 12 for the benefit of the study and the school. Ideally, the older students would provide leadership and focus for a more cohesive learning environment. As the robots will be staying in in the school following the study, ideally the younger students would be available for more years to teach more of their peers how to program to sustain interest in the devices. The learning period was intentionally short, only six lunch hours, to keep the content as fresh possible in the minds for the first learning groups during the final week of collaborative work. The *EV3* group and the *VRT* group performed their six learning days simultaneously, but then had to wait two weeks while the combined *EV3/VRT* group performed their six learning periods. Any longer of a wait could have been detrimental to the first two groups. Furthermore, this study was designed to test for engagement during an initial learning period, not longevity of engagement.

Limitations of the Study

A necessary, but unfortunate limitation of the study was the small sample size. Any larger, and I believe that the data could not be accurately collected by two individuals. This could have been remedied with more resources and co-researchers, a repetition of the study in a future school year, or a repetition of the study in another school altogether. The exploratory learning periods were shortened for reasons listed above, however with more robots and researchers the initial learning periods could have been run simultaneously to remove the possibility of a participant forgetting material during periods of inactivity. A limitation that affected the reliability of the results was that my advisor and I were required to simultaneously observe two different groups for learning behaviours during the final competition week of the study. That meant that observational data could not be corroborated or checked like the notebook analysis. This could have been remedied with an ENREB approval of videotaping, however videotaping in a school setting is not always welcomed by administrators or the community, and I wished to avoid any feelings of disinclination. From my experience with modern teenagers of a digital age, I observe different behaviours while being video recorded. This could be a consequence of ubiquitous Instagram, “selfies”, or Snapchat documentation of their everyday activities, but a digital façade is a large part of young lives. They all have been taught that their lives carry a digital footprint, and it is ingrained in them. They are reflexively not comfortable with the possibility of recording a response that could make them seem unintelligent. I am not certain they would have been able to ignore that reflex during the study, even if I assured them that it was confidential and that the records will be destroyed. In my opinion, the likely increase of observational accuracy from having video-recorded activities available for multiple reviewers, would have been negated by the possible inorganic responses elicited in the students who were aware that they were being video-recorded

Chapter 4: Data and Analysis

This chapter will present the data that was collected from the participant notebooks during the six learning days of each treatment group and the three competition days, as well as the observations that were taken during the three competition days. Before the results were charted, the interrater reliability was analyzed to ensure the notebook data was reliably recorded. The data was charted and analyzed as learning behaviour comparisons between treatment groups. Then, each group's learning behaviours were internally compared for growth or decline between the initial six learning days and the three group competition days at the end of the study. Finally, the observational data of learning behaviours were charted to determine if there were any dominant trends stemming from a particular treatment group during the three days of mixed-group competition.

Interrater Reliability

The disparities were recorded in reference to the notebook coding analysis (*See Appendix B*) of Michael Zurba (MZ), the learning or competition day (L or C), and the question number (Q) that was not matched by Richard Hechter. See *Table 2* for matched questions and an explanation of each disparity. Matching 779 of 792 possible scores places the interrater reliability at 98.4%.

Table 2: *Notebook analysis comparison and disparities with interrater reliability*

Participant	Matched	Of	Disparity	Explanation
Green 1	72	72		
Green 2	64	64		
Green 3	56	56		
Green 4	72	72		
Yellow 1	63	64	MZ-L5-Q7	scored: uncertainty with meaning of "nothing yet"
Yellow 2	70	72	MZ-L2-Q8	scored: "not really" indicates partial comparison
			MZ-L5-Q5	scored: RH did not recognize arrow as a repeated response
Yellow 3	69	72	MZ-L1-Q6	no score: just stated "all of it", but did not sketch
			MZ-L6-Q7	scored: "nope" indicated a visual was in mind, but refused to sketch
			MZ-L6-Q8	scored: "nowhere" indicating there was a visual but could not link it to a particular place
Yellow 4	45	48	MZ-L4-Q8	no score: "I haven't" indicated they could not connect to previous knowledge
			MZ-L5-Q8	no score: "Nowhere" did not score
			MZ-C1-Q10	no score: "I kinda stood back and watched" RH thought it was a conscious decision after seeing group dynamic
Pink 1	62	64	MZ-L4-Q7	no score "I didn't" indicated the robot did nothing
			MZ-C3-Q7	scored: "Push button, robot drives" RH did not recognize as a list of steps
Pink 2	72	72		
Pink 3	64	64		
Pink 4	70	72	MZ-L2-Q6	no score: "more on block" no sketch lacks confirmation of visual, no score
			MZ-L3-Q6	no score: "I'm still learning how the EV3 brick works" no sketch lacks confirmation of visual, no score
Total	**779**	**792**		

The interrater reliability of 98.4% indicates an instrument that is of an acceptable degree of reliability. The disparities that were recorded can be thematically categorized as negative responses. This was not predicted beforehand, but when a participant recorded “nowhere” or “I haven’t” or other such negatives, the response *may* not have meant the same as a response that was intentionally left blank by the student. This was a subjective call by the researcher. Excessive subjectivity does not lend itself to reliable results, but fortunately these cases did not happen frequently enough for me to question the reliability of the instrument.

Learning Behaviours by Day

The following analysis was obtained from participant notebooks by isolating the question groups that indicated *passive, active, constructive,* or *interactive* learning behaviours. The students were asked to answer questions from a template in an anonymous notebook (*see Appendix G*). According to the *ICAP* framework (Chi & Wylie, 2014) valid responses to Questions 3 and 4 indicate *passive* learning:

3. What did you learn about today from reading online tutorials?
4. What did you learn about today from watching online videos?

Valid responses to Questions 5 and 6 indicate *active* learning:

5. Of everything you learned today, what would you most like to remember?
6. Sketch a diagram of a part of the robot that you would like to learn more about.

Valid responses to questions 7 and 8 indicate *constructive* learning:

7. Make a chart (or just list the steps) of how you got the robot to perform something today.
8. Where have you seen something similar to what you did with the robot today?

And valid responses to Questions 9 and 10 indicates *interactive* learning:

9. Describe a conversation with a group member that you feel was important to programming.
10. Describe how you worked together with a group member today to accomplish a task.

The data was considered binary and scored if the analysis review of both my advisor and I determined that the responses to both questions were valid. The maximum score was 2 if both questions were answered and the minimum score was 0. The scoring was combined with the entire learning group and averaged to help determine trends that may have developed as a result of the treatment group learning environment. The results were displayed across all learning and competition days. The three colours of bars represent the performance of the group average score on each question set from each of the learning groups – the group who only had access to a physical *EV3* robot (blue), the group who only had access to the *VRT* simulation software (orange), and the group that had simultaneous access to both the *EV3* robot and the *VRT* simulation software (gray). The notebooks were analyzed for all 6 learning days as well as the 3 group competition days. Both my advisor and I analyzed the data sets to determine if the participant recorded a valid answer to the question and showed an interrater reliability of 98.4%.

As previously mentioned, the listed order of these learning behaviours represents a hierarchy, with *passive* learning being the lowest functional level of learning and *interactive* being the highest representation of individual learning. There is a notable distinction between the behaviours of the groups during the learning days (Learn 1-6) compared to the competition days (Comp 1-3). Throughout the nine days of the study, the *EV3* group members had a total of 4 absences, the *VRT* group had a total of 4 absences, and the combined *EV3/VRT* group had a total of 2 absences. During competition Day 3, one *EV3* group member arrived 18 minutes late along with one VRT group member (they were in a yearbook committee meeting), and one *EV3/VRT* group member arrived 10 minutes late from an appointment. The competition challenges lasted exactly 30 minutes.

Passive learning behaviours.

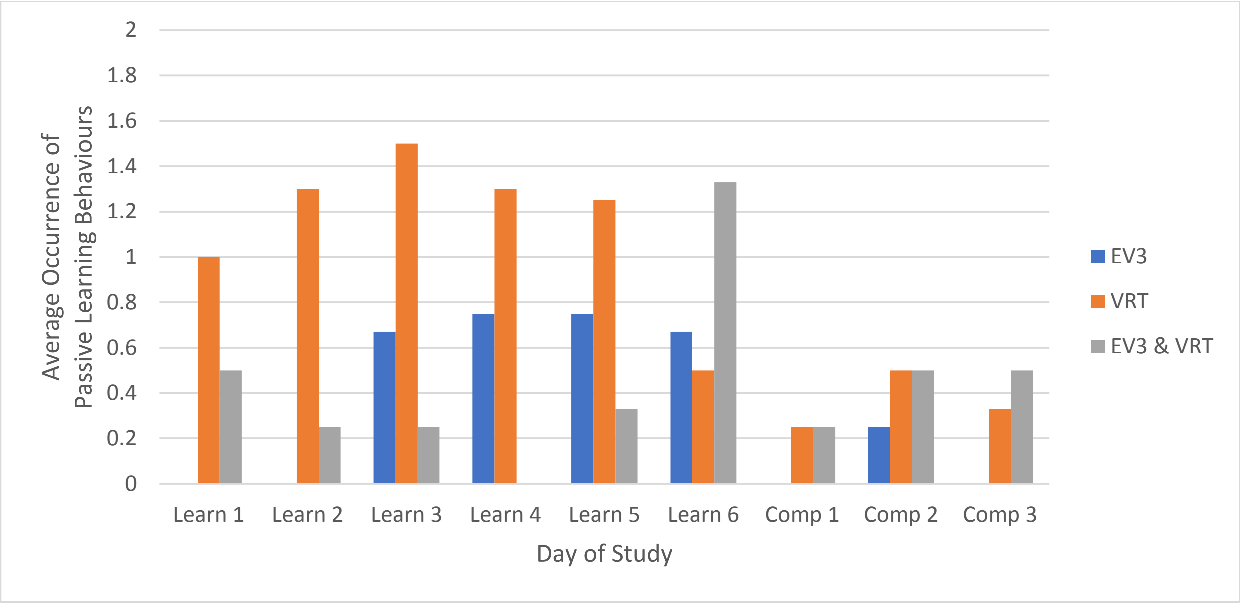

Figure 1: Passive learning behaviours, daily average of learning group (analyzed from notebook questions 3 & 4)

In *Figure 1*, the data shows that the group that learned only with the *VRT* showed indication of higher levels of *passive* learning while learning to program, but their passiveness dropped to levels more consistent with the other groups during the competition days. The *VRT* group had the most amount of *passive* behaviour 5 of the 6 learning days. The *EV3* group both began and ended the study with the least amount of *passive* learning, and showed the least total amount of *passive* behaviour. All three groups showed a considerable decline in *passive* learning for the 3 competition days. Peak *passive* days were different for all three groups. Day 6 showed uncharacteristically high *passive* behaviours for the combined *EV3/VRT* group. This may have been the result of some *EV3/VRT* participants having previous commitments and being unable to spend the lunch hour with the rest of their group.

Active learning behaviours.

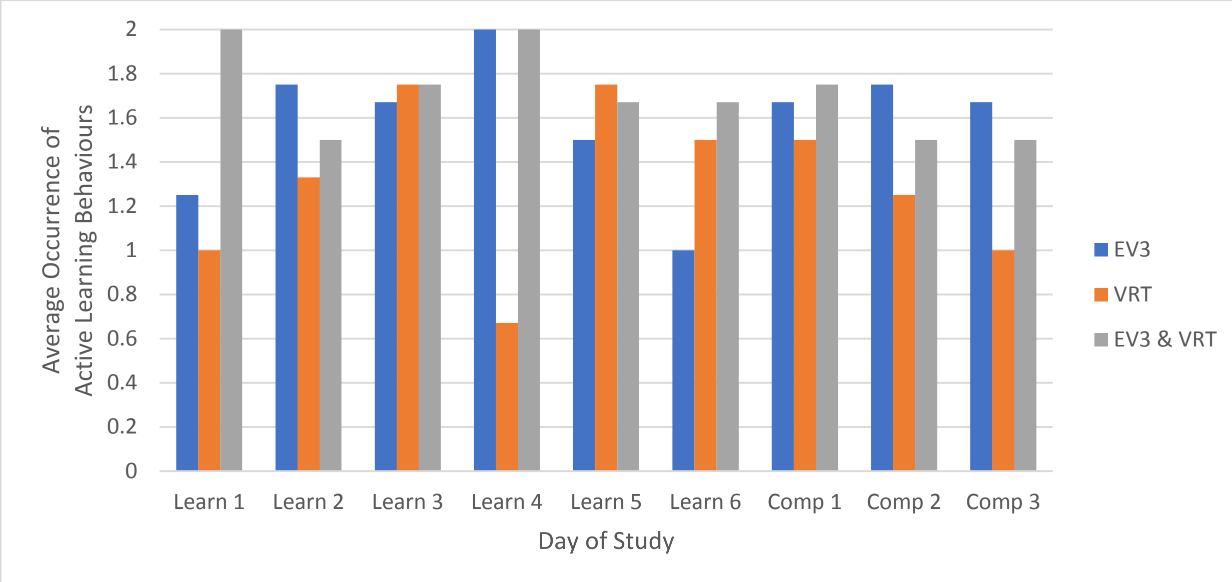

Figure 2: Active learning behaviours, daily average of learning group (analyzed from notebook questions 5 & 6)

In *Figure 2*, the data shows that *active* behaviours were much more common than *passive* for all three groups. After having increased for the first three learning days, the *VRT* group showed a sharp decrease in active behaviours on learning Day 4. The *EV3* group showed a decline in *active* behaviours on the sixth learning day. The combined *EV3/VRT* group showed the most consistency at high levels, and scored the maximum amount of average *active* behaviours twice.

Constructive learning behaviours.

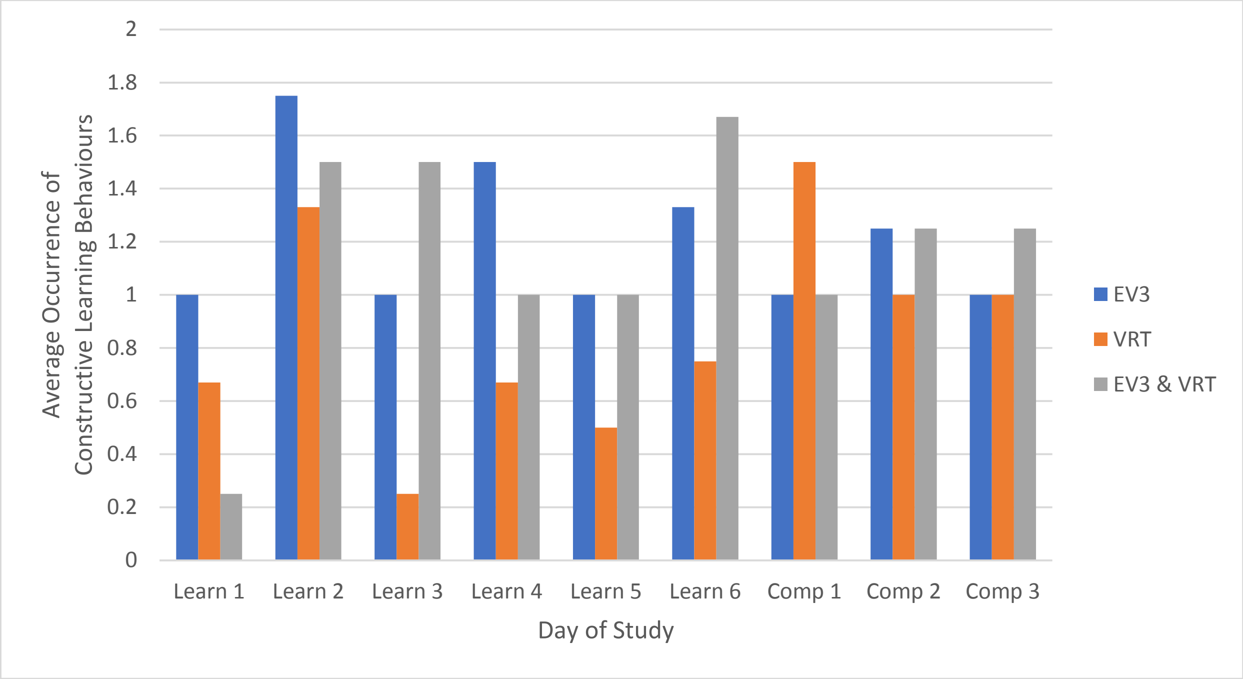

Figure 3: Constructive learning behaviours, daily average of learning group (analyzed from notebook questions 7 & 8)

In *Figure 3*, the data showed that the *EV3* group was in a higher constructive form of learning during the first two days of learning compared to the other groups. The *VRT* group was less inclined to construct new knowledge during the learning days, showing the least amount of *constructive* learning during Days 3, 4, 5, and 6 as well as competition Day 2. The *EV3* and combined *EV3/VRT* scored the same values on 3 of the 9 days, but never scored the same as the *VRT* group, save for the last competition day. The *VRT* group was the only group to show a noticeable increase in *constructive* behaviour during the 3 competition days. The *EV3/VRT* scored considerably lower *constructive* behaviour on the first day compared to the other two groups.

Interactive learning behaviours.

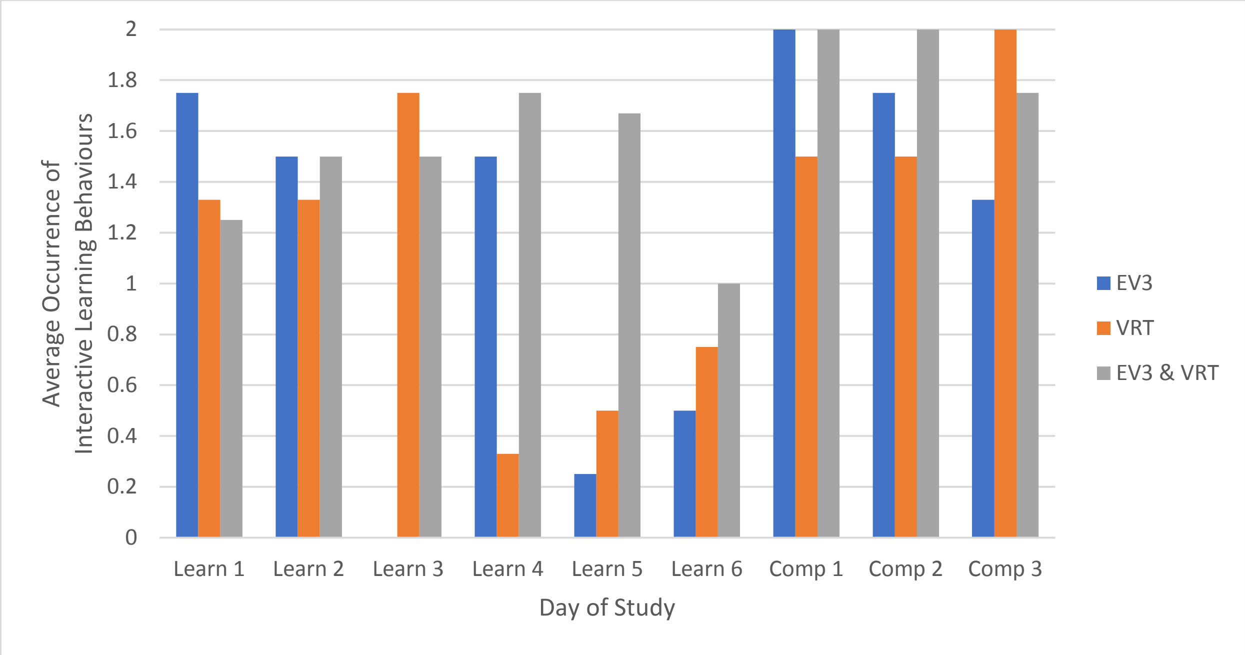

Figure 4: Interactive learning behaviours, daily average of learning group (analyzed from notebook questions 9 & 10)

The data in *Figure 4* showed that all three groups ended with higher levels of interaction during the group competition days compared to the learning days. There was a noticeable decrease in *interactive* behaviors for the *VRT* group during learning Days 4, 5, and 6. There was a noticeable decrease for the *EV3* group during Days 5 and 6. The *VRT* group members were all present during the days of decrease. Some *EV3* group members had schedule conflicts during Days 5 and 6 and were unable to spend the lunch hour with the rest of their group. The *EV3* group steadily decreased their *interactive* behaviour throughout the 3 competition days. The combined *EV3/VRT* group showed the most total *interactive* behaviours over all 9 days.

Learning Behaviour Composition by Group

The following data is a breakdown of the *ICAP* learning behaviours recorded by the students in their notebooks. The data was calculated as a percentage of the total responses given within each learning group during the six initial learning days and the three group competition days.

***EV3*-only group.**

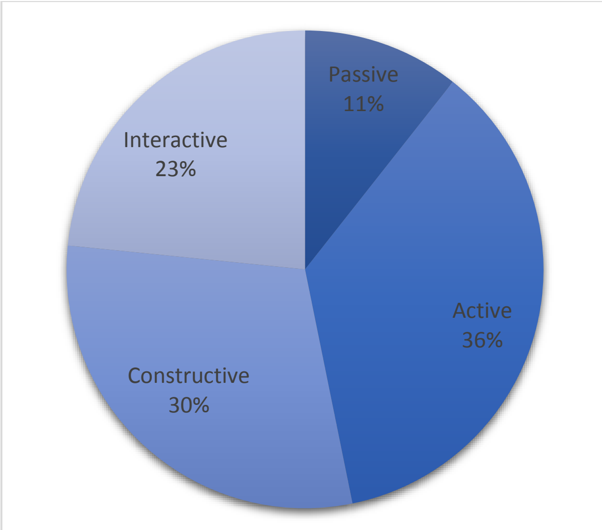

Figure 5: EV3 group learning behaviours as recorded in notebooks during initial learning periods.

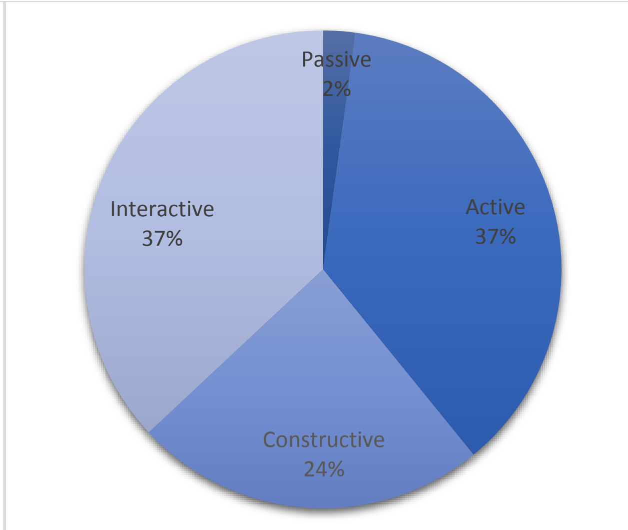

Figure 6: EV3 group learning behaviours as recorded in notebooks during competition.

When comparing the six initial learning days to the three group competition days, the data shows a 9% decrease in *passive* learning behaviours, a 1% decrease in *active* learning behaviours, a 6% decrease in *constructive* learning behaviours, and a 14% increase in *interactive* learning behaviours.

While all groups were permitted to learn more about robotics outside of the scheduled learning and competition days, the *EV3* robots themselves were not allowed to leave the study site. However, there are many online communities, forums, and informational sites (such as YouTube) that provide many avenues for continued learning. The *EV3*-only group logged a combined **120 minutes** of extra learning that was entirely due to their own interest and volition.

VRT-only group.

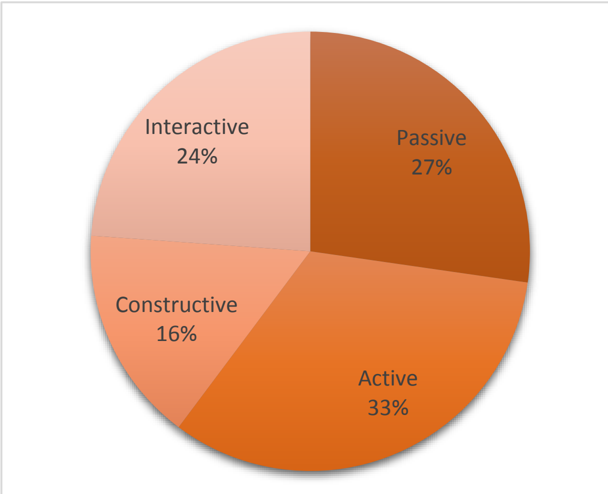

Figure 7: VRT group learning behaviours as recorded in notebooks during initial learning periods.

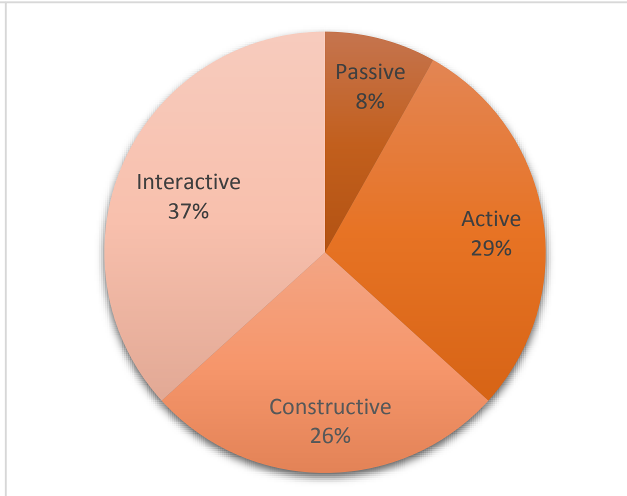

Figure 8: VRT group learning behaviours as recorded in notebooks during competition.

When comparing the six initial learning days to the three group competition days, the data shows a 19% decrease in *passive* learning behaviours, a 4% decrease in *active* learning behaviours, a 10% increase in *constructive* learning behaviours, and a 13% increase in *interactive* learning behaviours.

While all groups were permitted to learn more about robotics outside of the scheduled learning and competition days, the *EV3* robots themselves were not allowed to leave the study site. However, the *VRT*-only group kept the software on their own personal laptops and, therefore, were able to create a very similar learning environment to what they were exposed to during the scheduled learning days. The *VRT*-only group logged a combined **600 minutes** of extra learning that was entirely due to their own interest and volition.

Combined EV3/VRT group.

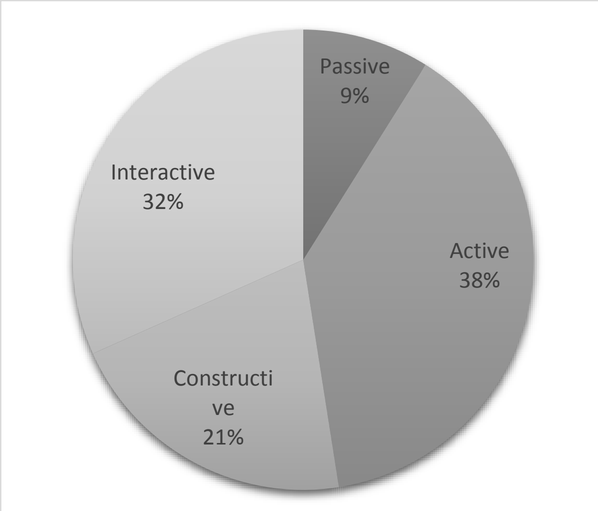

Figure 9: EV3/VRT group learning behaviours as recorded in notebooks during initial learning periods.

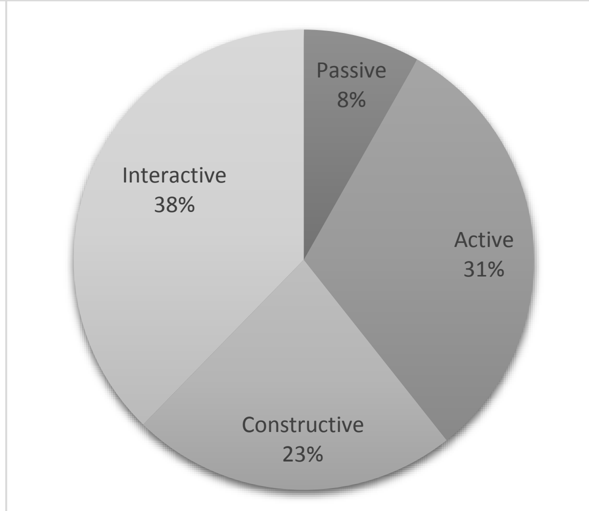

Figure 10: EV3/VRT group learning behaviours as recorded in notebooks during competition.

When comparing the six initial learning days to the three group competition days, the data shows a 1% decrease in *passive* learning behaviours, a 7% decrease in *active* learning behaviours, a 2% increase in *constructive* learning behaviours, and a 6% increase in *interactive* learning behaviours.

While all groups were permitted to learn more about robotics outside of the scheduled learning and competition days, the *EV3* robots themselves were not allowed to leave the study site. However, the combined *EV3/VRT* group kept the software on their own personal laptops and could therefore continue to run simulations to further their learning. The combined *EV3/VRT* group logged a combined **233 minutes** of extra learning that was entirely due to their own interest and volition.

Group Observations during Competition

Each discrete behaviour event was observed and recorded by my advisor and me. For example, if a group member was passively watching other members perform a task, then those individuals moved on to a new task, the passive individual would have been recorded as two discrete *passive* learning behaviour events. If an individual assembled an intelligent brick support, and then a motor tread, two discrete *constructive* behaviour events would have been recorded. If group members were discussing coding, each function that was discussed would have been scored as a discrete *interactive* learning behaviour event. My advisor and I randomly chose a single group to observe exclusively each day, but as the group members were reshuffled each day, we never observed the same mix of participants twice. The group scores were combined to help smooth any observer subjectivity on behaviour events that may have permeated a single group result.

Over the three days of competition, the learning groups showed some notable trends (*see Figures 11, 12, & 13)*. The *EV3*-only group showed a consistent spread of *passive, active, constructive,* and *interactive* behaviour; not much growth or transition between learning behaviours and no particular behaviour that showed dominance. The *VRT*-only group showed *constructive* learning as a dominant behaviour, although on day two of competition seemed to transition more toward *interaction.* The combined *EV3/VRT* group showed the least amount of passive learning behaviours and consistently showed *interactive* as a dominant learning behaviour. The combined *EV3/VRT* group appears to have more discrete learning behaviours recorded than the other groups – considerably more than the *EV3*-only group. For this to be recorded, they must have performed more activities than the other groups in the allotted 30 minutes. For example, a *passive* behaviour could go on for several seconds, even minutes.

Whereas two participants could interact and debate multiple topics in a relatively short period of time. I have left the data from each competition day separate to reflect the consistency of the findings.

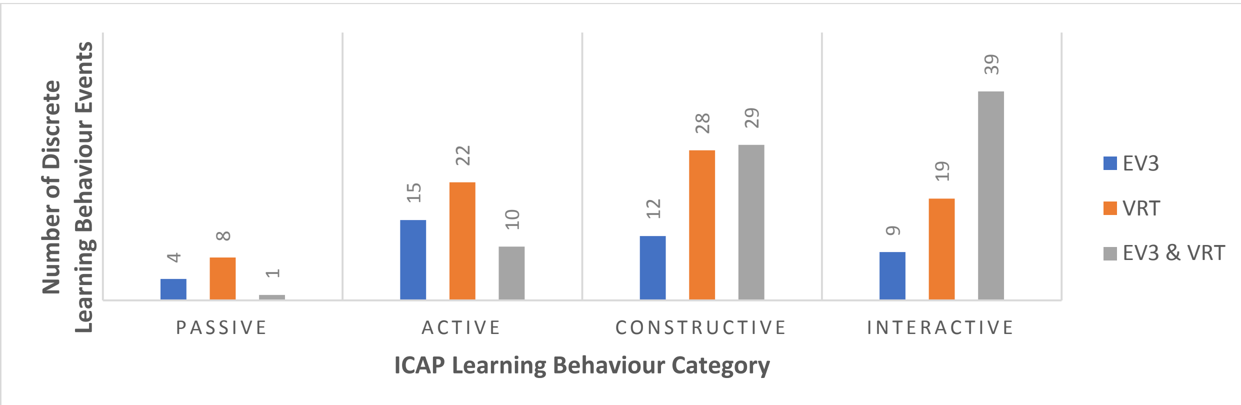

Figure 11: Competition Day 1 observations, *ICAP* learning behaviour events, Groups 1 and 2 combined.

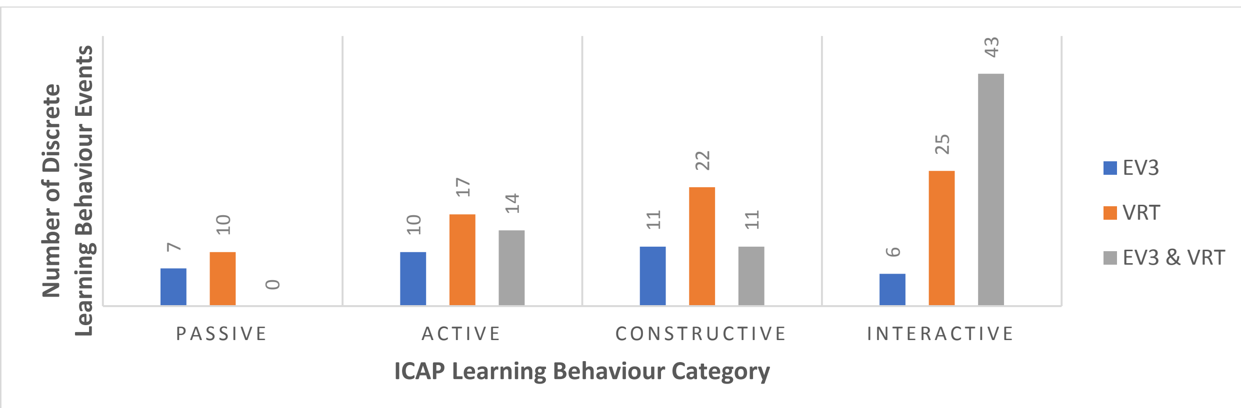

Figure 12: Competition Day 2 observations, *ICAP* learning behaviour events, Groups 1 and 2 combined.

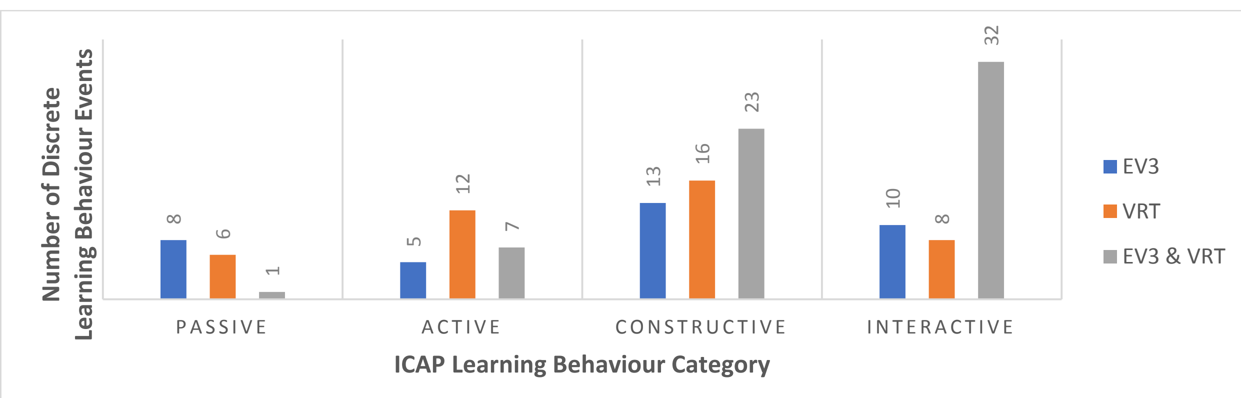

Figure 13: Competition Day 3 observations, *ICAP* learning behaviour events, Groups 1 and 2 combined.

Chapter 5: Discussion

Analysis Refocus

The original plan for data analysis included a ranking system for each learning behaviour. The following is an excerpt from my original thesis proposal:

> I will assign a hierarchal value to each learning behaviour (*passive, active, constructive,* and *interactive* from 1 to 4) and then use *measures of central tendency* (mean, median, and mode) to graphically display and show growth or decline in each learning group. To clarify, *mean* representing the average score on learning behaviour, *median* being the middle score of each learning behaviour, and *mode* being the score that appears most frequently (Creswell, 2015).
>
> With the results being quantified, I can utilize an analysis of *variance* to describe the dispersion of scores around the mean. To clarify, *variance* is calculated by finding the difference between the mean and the raw score for each individual, squaring this value for each individual, summing the squared scores for all individuals, and dividing by the total number of individuals. This will indicate the amount of variability and how dispersed the learning behaviours are within each treatment group (Creswell, 2015, p. 183). To take the analysis further, I would like to analyze the *standard deviation* (the square root of the variance) in order to calculate the *z-score* (the score subtract the mean divided by the standard deviation) and give an indication of positive or negative growth within each treatment group. To summarize, these values would represent students becoming more engaged as they learn, or perhaps less engaged.

The issue that became clear while the study was underway was that of the numerical quantities (from 1 to 4) that were assigned to each learning behaviour. For example, is *active* learning (scored as 2) exactly twice as good as *passive* learning (scored as 1)? Mathematically it would be represented so. Although a hierarchy in learning behaviours was certainly suggested in the *ICAP* framework (Chi & Wylie, 2014), a quantitative representation of the hierarchy would be misleading. While observing the students in their environments, it became clear that a simple binary (yes or no) representation of each learning behaviour would tell a much clearer story. The frequency of each learning behaviour could be analyzed for growth from multiple perspectives and be more reflective of each learning experience. I was certain that a focus on quantitative statistical analysis (as I had previously proposed) would hide the real story of each learning group, especially if its foundation was on a quantitative misrepresentation of data. Furthermore, as I have discussed in Chapter 2, learning is more qualitative in nature. While I originally thought that the industry partners would appreciate and be more inclined to utilize quantitative results, I became certain that a focus on numbers would lack a valid reflection of learning.

Participant Interviews and Suggestions from the Data

The interviewees were selected from the anonymous responses in their daily learning journals. Participants who were identified as showing the most *interactive* learning behaviours were selected from each treatment group (*EV3*-only, *VRT*-only, and combined *EV3/VRT*) for an approximately ten-minute interview (see *Appendix J* for interview script). The most *interactive* participant was selected under the assumption that they learned the most out of their group, as suggested by the *ICAP* framework (Chi & Wylie, 2014). One more individual was selected for interview who showed the largest growth from *passive* to *interactive* behaviours. These interviews were conducted to help corroborate data and glean larger themes of causation. All interviews were recorded and then transcribed by a third-party. I will use excerpts from each interview as launching pads for discussion and suggestions as to why the learning behaviours progressed, plateaued, or declined as they did.

***EV3*-only learning environment.** This group began at the highest percent *constructive* learning behaviours (30%, see *figure 5*). When asked about the dynamics of the learning group, the participant stated, "Well, sometimes creating different things and putting different parts that were not entirely in the instructions, kind of to see what worked." The participant also indicated that it was only in the second day of learning that everything seemed to "click", earlier than some of the other interviewed participants. This indicates that the participant's experience could have been more tangible. When asked a question of what they thought they could have learned more about in this study, the participant responded, "Probably more about just different methods of putting it together. We had our one way that we did it, but probably if we could do it again, just different ways of doing it." This indicates a dominant tactile concept of the robots, as opposed to a virtual understanding of the programming code. The participant most remembered the physical constructing of the robots, and wanted to learn more about the physical constructing of the robots. When asked if the learning days prepared the participant for the team competition days, the participant responded, "Yeah. For sure. It really helped out. Just getting that many hours of working, we got familiar with how we could build it up pretty quickly." Again, no mention of programming software or code. I suggest that access to a physical robot allowed the participants to physically understand the physical construction of the robots rather quickly. The interviewee indicated it was around day two of learning where things started to "click". However, the progression to higher level learning behaviours may have also been limited by primarily concrete understanding of the robots.

Throughout the team competition days, the *EV3*-only group did not show a dominant learning behaviour (see *Figures 11, 12, 13*). The frequency of each learning behaviour remained fairly consistent across all four learning behaviours, whereas a more desirable trend would be to have more higher-lever learning behaviours (*constructive* and *interactive*) compared to lower-level learning behaviours (*passive* and *active*). The *EV3* group members may have remained passive as other team members displayed their expertise in the programming of the robots. There may have been an unfair advantage to the other team members as they learned the programming aspect, as they were able to bring their primary source of learning code home with them. This was suggested as the *EV3*-only group showed the least amount of learning minutes outside of the regularly scheduled learning periods (120 minutes, versus 600 *VRT*-only group and 233 minutes *EV3/VRT* group).

To summarize, the *EV3*-only group may have caught on quickly, but may not have been able to progress to the abstract understanding of coding in the relatively short time period provided to them. I suggest that a *learning plateau*, or an even spread of passive to interactive behaviours, would not be indicative of the most effective learning environment and one that an educator should work to avoid if possible.

***VRT*-only learning environment.** The *VRT*-only group began learning with the highest percentage of *passive* learning behaviours (27%, see *Figure 7*). This is should not be surprising. When asked about the number of online videos or tutorials watched, a participant responded "That's just what we did. We just sat there watching them, because we didn't really know what we were doing until we watched them." The *VRT*-only group also began with the lowest percentage of *constructive* learning behaviours (16%, see *Figure 7*). In response to an interview question regarding building robots in the team competitions, a participant responded:

> Because I imported the whole robot itself, already built, so I didn't even virtually build it. So when they were building it, I honestly couldn't help them at all, because I've never used LEGO before either, so I had no idea."

Observations of the *VRT*-only group during the team competition showed *constructive* learning as a dominant behaviour, but this does not necessarily relate to the construction of a robot. This could be attributed to a participant constructing new knowledge from previous knowledge, for example, applying what one knows about programming infrared sensors to programming touch sensors. The participant who showed the most *interactive* behaviour in the *VRT*-only group stated:

> If it would've just been the [VRT-only] people, but we still had to build stuff, then I don't think we would have been able to, unless someone was really good building LEGO or something. But yeah, since we were mixed, it really helped.

Statements such as these, along with the group learning behaviour data, suggest that it was difficult for participants to gain a concrete knowledge of the robots themselves. This could be limiting on an individual level, but perhaps encouraging of higher-level learning behaviours (*constructive and interactive*) when in diverse groups (see *Figures 11, 12, 13*). The steep drop of *passive* learning (27% to 8%, see *Figures 7, 8*) and the increase of *interactive* learning (24% to 37%, see *Figures 7, 8*) indicates what I suggest is a relatively steep *learning curve*. I suggest this is due to the lack of a concrete grasp of the structure of a robot in the beginning learning stages followed by, once it all "clicked" a rapid growth through abstract programming as the participants were already familiar with the abstract world of the simulator. This is further suggested by the participant, who was part of the *VRT*-only group, who showed the most growth through the notebook responses. The participant stated:

> The simulator takes a while to learn. It takes a lot of time to get as good as you might get building them, and using them, and programming them in a virtual space; compared to the physical space. Because the physical space is just more intuitive.

When asked to comment on the difference between the learning days and the team competition days, the participant said:

> The programming [learning days] often just made you sit on your computer and try to figure it out for yourself, because it was kind of unsocial. All of a sudden I had, instead of being me left to do something, other people pitch in and I was like ‘oh yeah’. There were other people helping and they had their own ideas too, as opposed to just me left by myself.

This does suggest a combined environment that would foster a rapid growth into higher-level learning behaviours.

The *VRT*-only group had the largest amount of outside learning time (600 minutes). A participant from that group stated, “It seems to learn it, just like any other kind of digital software would, there’s a bit of a learning curve; and that learning curve wasn’t exactly able to fit in the amount of time we had.” This indicates that the participant (the one who showed the most growth throughout was a member of this learning group) struggled to understand the *VRT*, and that the participant felt the six lunch hours were an insufficient amount of time to become proficient. Although it must be recognized that the *VRT* certainly allowed the participant to spend as much time as they felt necessary on their home laptop.

There was a notable drop in *constructive* learning on learning Day 3 as well as a drop in *active* and *interactive* learning on Day 4. This could be explained as group interaction may have been generated in the beginning through a lack of understanding what was going on and feelings of being overwhelmed. These feelings were expressed to me by some group members after the first learning days. Perhaps they would also be inclined to discuss these feeling with other group members and actively seek more answers. Once things “clicked” and a general understanding of the *VRT* was achieved, perhaps the participants “got down to business” learning, but were doing so in a solitary manner on their laptops. Once more was learned to the level of a general proficiency, or simply more confidence was built, the participants may have felt more comfortable sharing and interacting with group members again.

To summarize, the *VRT*-only group had difficulty grasping the concepts of robotics in the beginning stages, but had the largest growth to higher-level leaning behaviours compared to the other groups. I suggest this is due to the abstract nature of a virtual simulator. Once a concrete understanding was reached however, the relative familiarity of the simulator unlocked a faster pace and a higher ceiling to learning as users practice programming skills in a greater variety of virtual settings.

Combined *EV3/VRT* learning environment. The most remarkable data was observed during the team competition days. The combined *EV3/VRT* learning group showed both the fewest *passive* learning behaviours along with the most *interactive* learning behaviours (see *Figures 11, 12, 13*). The student from the combined *EV3/VRT* learning group who was most *interactive*, showed all the signs of a learner who was fully engaged. The participant described the learning environment as follows:

> Very friendly. We had lots of things to talk about and go over with because we had the robots, of course, to build. We also had multiple programs we could go over. So if we ever got bored of something or interested in something else we could always move on to a different thing we can work on.

With multiple areas of the brain being engaged, notably concrete and abstract simultaneously, the participants would likely get a more fulfilling educational experience. Perhaps this is why the participant was the only interviewee who described the learning as “enjoyable”.

The combined *EV3/VRT* participant also showed signs of a greater understanding of the learning process itself, more so than the other interviewed participants. When asked for thoughts regarding a learning environment that did not include a traditional instructor, the participant stated:

> We were left with all the tools, but we didn't have somebody explain to us how to do stuff. We had to figure it out on our own. It was really interesting and kind of unique because you're not usually taught like that. Especially when you work with a peer to do something and then when you finally accomplish it, then you're like, we did it, and it all worked out in the end.

This suggests a confidence that was fostered and allowed the combined *EV3/VRT* learning group to show more leadership qualities in the team competitions. By far, the combined *EV3/VRT* learning group was more inclined to take charge, delegate, and even predict upcoming challenges during the group competitions. This was observed by both my advisor and I throughout all three days of group competition. They were more interactive during the learning days, and this evolved into more interaction during the competition days (see *Figures 9, 10*). I suggest that the confidence arose from the metacognition that was displayed by the interviewed group member, and that it may have resulted from a learning environment with a wider variety of engagement points. The participants were able to actively choose what they wanted to engage in, so they became more aware of what they were choosing to engage in.

To summarize, the combined *EV3/VRT* learning group had more cognitive areas (abstract and concrete, virtual and physical) in which to engage while learning, making them more aware of the learning process itself. I suggest this environment could only be recreated with minimal instructive teaching and maximal discovery learning with peers, allowing the areas of engagement to be actively chosen by the learners. I further suggest that metacognition results in a confidence that helps develop individuals into team leaders and create an environment that is dominated by higher-level learning behaviours.

Report for Cogmation Robotics Inc.

I intend to provide a report to the company that includes the data and charts provided in Chapter 4 and discussed in Chapter 5. I will allow them to use or disseminate the findings as they see fit. I will summarize that, although it is not a requirement that individuals using the *Virtual Robotics Toolkit* have access to a LEGO *EV3* robot physically, the data strongly suggests that it would be beneficial to the learners. Physically constructing an *EV3* robot while using the *VRT* allows students to gain an understanding of the robots and their abilities that is more concrete, serving as a foundation that allows the *VRT* to take student skills and understanding to higher levels than would be available to an individual with only access to an *EV3* robot. Access to both an *EV3* and the *VRT* simultaneously allows a student of robotics more freedom to learn and engage according to their interests and curiosity. This may create a metacognition that accelerates learning, creativity, and develops leadership skills in a group setting. All of these qualities are agreed upon as skills required by the next generation of learners and employees. I believe that Cogmation and their industry partners will be interested in what was written in the *Participant Interviews and Suggestions from the Data* section of this chapter.

Implications for Learners & Learning

Learners ought to become more aware of what they are learning and how they learn. Learners should seek out learning environments where one can make choices that guide the learning process, in this case exploring the engineering or construction of a robot or the programming commands that will make the robot function. This will inherently make a learner less *passive*. In my experience, there is a faction of high-achieving secondary students that prefer a *passive* learning environment where a teacher will simply tell them what they need to memorize for their high marks. Learners need to experience freedom within exploratory learning to feel the differences in learning that result, and a robotics course with similar components as this study could push them out of their *passive* comfort zone.

Implications for School Administrators

I was not a robotics expert before this study began and admittedly, I still am not. The participants in this study undoubtedly have a higher skill set with building and programming *EV3* robots than me, as I did not take part in the social learning hours that they did. Even so, there is no question that all twelve participants in this study learned how to program. All I needed to understand was how they behaved and interacted while they learned and worked, and I could recognize a spectrum of progress. Administrators should recognize that they do not need a robotics expert on staff to initiate a robotics class. Furthermore, administrators should find ways to offer unique classes that could foster student learning on higher levels than a traditional classroom setting and build skills (creativity, social productivity, logic, agency, etc.) that will be critically relevant to students in the near future.

Implications for Industry

The Ed-Tech industry is a rapidly growing sector of education even while being restrained by various factors. For example, a traditional approach to education would resist technology-based education. Prohibitive costs, a lack of resources, and a lack of specialty teachers would also limit growth of technology-based education. This study could be used by the industry to help educators and administrators see value in Ed-Tech but also reverse the misconception that you need trained roboticists to facilitate a robotics course. Increased use of digital robots could help democratize the use of robots in education, enabling more students to participate and benefit even if the institutions they attend are constrained financially. This study should increase demand for programming companies to increase the diversity of virtual simulators designed and developed for the classroom, whether in robotics or other scenarios not-yet imagined. Furthermore, it seems that virtual simulators, if placed correctly into a learning environment, can help produce students that interact, collaborate, and lead. All of these qualities are highly sought by the tech industry for future employees that need to fill positions that have not even been conceived yet.

Implications for Teachers & Teaching

This study certainly suggests a learning benefit to students who learn robotics in an environment that contains both physical robots and virtual simulation software. They appear more engaged and develop self-determination that could translate into leadership qualities in a group setting. In this study, the ratio of students to robots was 2:1 while learning to build and program, although there was no suggestion of an optimal ratio. Each student did receive an individual copy of the *Virtual Robotics Toolkit*. I believe this to be an important aspect to the learning environment, as it allowed students to learn on their own time whenever they were so inclined. The ability to satisfy curiosity would logically increase self-determination. Perhaps even a higher ratio of students per physical robot alongside a personal copy of the *VRT* would begin to lower classroom costs and still maintain the positive learning environment seen in this study.

Assessment of learning behaviours, as opposed to specific learning outcomes from a selected curriculum, should play a larger role than it currently performs in classrooms. I will reiterate – if learning can take place in an infinite amount of ways, equal to the infinite levels of diversity that we see in our classrooms, then an assessment of learning must remain dynamic or it risks becoming irrelevant. A teacher's approach to assessment of learning ought to be as diverse and unique as her/his students, and I believe assessment of learning behaviours allows room for such individualism. Although this assessment of *passive*, *active*, *constructive,* and *interactive* learning behaviours took place in a robotics study, the framework could easily extend into other fields. As previously discussed, an activity-based assessment could also play a role in the transformation of education into the reflection of a more sustainable society.

In Conclusion

This study determined that the use of virtual simulation software is beneficial to students while they learn to build and program robots, provided that they have access to a physical robot simultaneously. This conclusion was drawn from an analysis of learning behaviours from three sources: student learning journals, researcher observations, and participant interviews. The data was compared to groups of students who, in a two-week learning period, were given access to just physical robots, just a virtual simulator, and a physical robot in conjunction with a virtual simulator. The group of students who had access to a simulator and a physical robot simultaneously showed more higher-level learning behaviours, particularly *interaction* with peers, indicating a higher level of engagement and advanced learning. In a collaborative setting faced with a robotics engineering and programming challenges, the participants from that group also showed increased leadership qualities.

This study also intended to showcase the benefits of a more progressive approach to assessment via learning behaviours, rather than specific learning outcomes, that align with the skills deemed more useful to the learners, citizens, and employees of the sustainable society we have yet to realize. I believe this study was successful in showing that assessments of learning could be valid, reliable, and meaningful without focussing on specific content knowledge. Our education system is in need of transformation with the same urgency that our society needs to transform on the brink of ecological disaster. After all, an education system and society are a reflection of each other. For 12 years we reinforce in our students that it is what they know, not how they act, that counts in our society. Should knowledge be power, or should it sow compassion? We must open up our classrooms to allow for the curiosity, collaboration, and creativity that will be necessary to alter our current trajectory. We must take the focus off subject content to allow the students to focus on each other, for this is the training that our students require. I am not suggesting that changing how we assess science, or any other subject for that matter, will change the world …but it may be one of the first steps if we plan to take a long walk together.

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Appendices

Appendix A: ENREB Certification

UNIVERSITY OF MANITOBA | Research Ethics and Compliance

Human Ethics
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PROTOCOL APPROVAL

TO: **Michael Zurba** **(Advisor Richard Hechter)**
Principal Investigator

FROM: **Zana Lutfiyya, Chair**
Education/Nursing Research Ethics Board (ENREB) [redacted]

Re: **Protocol #E2018:034 (HS21661)**
Teaching Robotics Programming in Conjunction with Virtual Simulation Software: An Evaluation of Learning Behaviors in Secondary Students

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Effective: January 16, 2019 **Expiry:** January 16, 2020

Education/Nursing Research Ethics Board (ENREB) has reviewed and approved the above research. ENREB is constituted and operates in accordance with the current *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans.*

This approval is subject to the following conditions:

1. Approval is granted for the research and purposes described in the application only.
2. Any modification to the research or research materials must be submitted to ENREB for approval before implementation.
3. Any deviations to the research or adverse events must be submitted to ENREB as soon as possible.
4. This approval is valid for one year only and a Renewal Request must be submitted and approved by the above expiry date.
5. A Study Closure form must be submitted to ENREB when the research is complete or terminated.
6. The University of Manitoba may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans*.

Funded Protocols:
- **Please mail/e-mail a copy of this Approval, identifying the related UM Project Number, to the Research Grants Officer in ORS.**

Research Ethics and Compliance is a part of the Office of the Vice-President (Research and International)
umanitoba.ca/research

Appendix B: Administrator Consent Form

UNIVERSITY OF MANITOBA | Faculty of Education
Department of Curriculum, Teaching and Learning

230 Education Building
University of Manitoba
Winnipeg, Manitoba
Canada R3T 2N2
Telephone (204) 474-9014
Fax (204) 474-7550

ADMINISTRATIVE INFORMATION AND CONSENT FORM

Title of Study: Teaching programming using robots: an evaluation of the learning benefits of virtual simulation software

Principal Investigator
Michael Zurba, Teacher at [redacted] Collegiate
MEd Candidate, University of Manitoba Department of Curriculum, Teaching and Learning
Email: [redacted]

[redacted]

M.Ed. Program Advisor Contact Information
Dr. Richard Hechter
Department of Curriculum, Teaching and Learning
University of Manitoba

227 B Education Building
71 Curry Place
Winnipeg, MB, R3T 2N2
Tel: (204) 474-9054
Email: richard.hechter@umanitoba.ca

Sponsor
Cogmation Robotics Inc. (a simulation software company based in Winnipeg) and Mitacs (a not-for-profit organization that builds partnerships between governments, companies, and universities in Canada to support industrial and social innovation)

With your permission, students in your school will be asked to participate in a research study. Please go through this consent form and initial the bottom of each page, indicating it has been read and understood. This consent form may contain words that you do not understand. Please ask me or Dr. Hechter to explain any words or information that you do not clearly understand. The study and its data are intended to be used for my Master of Education thesis. I will be acting as the principal investigator and Dr. Hechter will be overseeing all procedures and data collection as the thesis advisor.

Purpose of Study

Studies have indicated that teaching robotic programming using computer programs may increase the speed of learning and deeper-level understanding. I intend to study how students learn when provided with just physical robots, just virtual robotics software, and using both together. This study will also attempt to evaluate the types learning that are considered more modern by Next Generation Science Standards (NGSS), under the assumption that they will be more relevant to modern students, educators, and the corporations in relevant fields. While the students are learning to program in different groups and scenarios, I will be looking for indications of deeper-level learning behaviours, as I believe this will be a better reflection of genuine learning. I will not be giving tests for the content itself.

Study Procedures

A total of 12 students, those who are first to provide written consent from parents/guardians, will participate in this study. Student participants will be "randomized" into one of 3 study groups described below. "Randomized" means that you are put into a group by chance, like flipping a coin. Students will have an equal chance of being placed in any group. Participants will be recruited on a volunteer basis following parental consent from the group of students who are not currently being taught by Mr. Zurba nor will be throughout the duration of the study. The participants will be randomly assigned to three different learning groups: A (access to physical robots only), B (access to virtual robotics software only), and C (access to physical robots and virtual robotics software simultaneously). Since each learning group will be allotted to an entire week, consideration may be given if participants would prefer placement in a particular week due to scheduling conflicts**. Participation in this study will be for 9 lunch hours throughout the months of February and March (3 lunch hours per week).**

If students interested in taking part in this study, they will undergo the following procedures:
Materials will be introduced to the participants during their week of learning only at the fundamental level, i.e. students will be shown how to connect their computers to the physical robot and students will be shown how to download the relevant virtual software to their personal laptops. The students will be provided with a colour-coded notebook to record whatever they wish during the learning process, previously being informed that their proficiency in coding will be ranked during a robot programming challenge at a later date against the students in other groups. A template of suggestions on what to record in their notebooks will be provided to each student.

During the fifth week of the study, the students from all groups will be mixed into two groups to perform various challenges with the two physical robots that were provided for the study. Again, this will take place over 3 lunch hours. The group activity will be observed by Mr. Zurba and Dr. Hechter and analyzed for indicators of learning behaviours, with the colour coded notebooks being used to help identify which students came from which groups as they display learning behaviours.

Following the learning sessions and group activities, two students from each learning behaviour category will be randomly selected for follow-up interviews that will last no longer than 30 minutes. The interviews will take place in Room 15 at [redacted] Collegiate over a lunch hour that is convenient for the participant. The interviews will be audio recorded and transcribed by Mr. Zurba, but the participant's names will not be identified to help ensure anonymity.

The researcher may decide to take you off this study if a lack of lunch hour attendance limits your ability to learn the basics of programming. You can stop participating at any time by contacting me or Dr. Hechter using the contact information listed above. However, if you decide to stop participating in the study, I encourage you to first talk to me. If you decide not to continue your participation all data collected from you will be destroyed and not included in the study.

Risks and Benefits

There is minimal risk associated to participation in this research. For example, there is the possibility that students may be identified by researchers or students as taking part in the study. All efforts will be made to protect anonymity in the results and dissemination. There is immediate benefit to the participants in this study: to potentially learn how to program robots, to gain a trial access to Cogmation Robotics' *Virtual Robotics Toolkit* software, and to become "Robot Leaders" at [redacted] Collegiate to pass on what they have learned to their peers and teach others how to operate the robots.

Costs

Materials and procedures performed as part of this study are provided at no cost to you. [redacted] Collegiate will keep the robots at the conclusion of the study.

Payment for participation

The students will receive no payment or reimbursement for any expenses related to taking part in this study.

Confidentiality

Information gathered in this research study may be published in research journals or presented in public forums, however names and other identifying information will not be used or revealed. Despite efforts to keep your child's personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law.

All notebook journals students will be using will be left anonymous before handed back to me for analysis.

All data and documents (such as consent forms) related to this research will be securely stored in locked cabinets in Room 15 at [redacted] Collegiate and only Mr. Zurba will have access to these records. If any of your research records need to be copied to Dr. Hechter, your name and identifying information will be removed. No information revealing any personal information such as your name, address or telephone number will leave [redacted] Collegiate. All written and digital data will be destroyed and deleted on January 1st, 2020.

Results from the study will be reported to Mitacs, Cogmation Robotics, and may also be disseminated the through conference presentations and research articles. You may indicate that you would like to receive a copy of the materials produced for dissemination of this research by signing the appropriate field below.

Voluntary Participation/Withdrawal from the Study

Participation for students in the study will be for a total of 9 lunch hours in the months of February or March. Students may be randomly selected and asked to participate in an additional interview after initial data analysis has been completed. This will take no longer than 30 minutes and can take place at a time that is convenient to the student. Students may withdraw from the study at any time. A student's decision not to participate or to withdraw from the study will not affect their education or performance evaluation at [redacted] Collegiate. If a student is absent for 3 or more of the 6 initial learning periods, they will be notified personally that they will be removed from the study and the data collected to the point of withdrawal will be destroyed.

Questions

You are free to ask any questions that you may have about the treatment and rights of the research participants. If any questions come up during or after the study, contact Mr. Zurba and/or the study staff at the contact information stated on the first page of this document. For questions about your rights as a research participant, you may contact:

The University of Manitoba
Education Nursing Research Ethics Board (ENREB) Office
humanethics@umanitoba.ca
(204)474-7122

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.

I would like to receive:

☐ copies of dissemination materials ☐ a summary report of this research

Please, send me these by:

☐ Email at: ____

☐ Regular mail at the following address:

____

____

____

Statement of Consent

I have read this consent form. I have had the opportunity to discuss this research study with Mr. Zurba and/or Dr. Hechter. I have had my questions answered by them in language I understand. The risks and benefits have been explained to me. I believe that I have not been unduly influenced to participate in the research study by any statements or implied statements. Any relationship (such as employer, supervisor or family member) I may have with the study team has not affected my decision to participate. I understand that I will be given a copy of this consent form after signing it. I understand that my participation in this study is voluntary and that I may choose to withdraw my students at any time. I freely agree to participate in this research study.

I, the undersigned, have fully understood the relevant details of this research study and support the research that is being performed at [redacted] Collegiate.

Printed Name: __________________________________

Administrative Role: ____________________________

Signature: ____________________________ Date ___________________
(day/month/year)

A copy of this consent form will be given to you to keep for your records and reference.

Appendix C: Recruitment Poster & PA Announcement Script

© Disney

ROBOTS ARE COMING TO [redacted] COLLEGIATE!

If you are interested in learning how to program a robot, you are invited to take part in a study on how students learn with robots.

The study will be performed by Mr. Zurba and Dr. Richard Hechter from the University of Manitoba. It will take place over 9 lunch hours throughout February and March of 2019.

You must attend a meeting in Mr. Zurba's room at the beginning of **lunch** on ____________________ to receive information and parent/guardian consent forms.

Mitacs COGMATION ROBOTICS UNIVERSITY OF MANITOBA

Appendix D: Recruitment Script for Students

Thank you for taking time out of your lunch hour to attend this information session. Please make sure you sign the attendance sheet that is being passed around. As you may have heard, robots are coming to [redacted] Collegiate and you have the opportunity to learn how to program them, and, to take part in a study on which ways students can best learn how to program. This study has been approved by the University of Manitoba Education and Nursing Research Ethics Board, also known as ENREB. It will be performed by me and Dr. Richard Hechter from the University of Manitoba and the research data will be used to help me complete my Master of Education Thesis. It will be sponsored by Cogmation Robotics (a simulation software company based in Winnipeg) and Mitacs (a not-for-profit organization that builds partnerships between governments, companies, and universities in Canada to support industrial and social innovation). The data collected is intended to be used for my MEd thesis.

For starters, I will explain who is eligible to take part in the study. It is open to any students who are not currently taking Science 10F or Science 20F this semester. For ethical reasons, I cannot teach you at the same time as I am researching you. If this means that you are disqualified from the study and you really wanted to learn how to program robots, then all you need to do is wait until the study is finished and a student who had participated will be able to show you how the robots work. You must also have a functional laptop to bring each day (the one given to you by the division will be fine).

Studies have indicated a positive correlation between teaching robotic programming using a virtual platform with speed of learning and deeper level understanding. We will study how students learn to program when provided with just physical robots, just virtual robotics software, and then both in conjunction with each other. If you choose to be a part of this study, we will randomly place you in one of those three groups, see how you learn, and then put you in a competition with students from the other groups. The study will take place in February and March. Your laptop must be working and you will have to bring it (or any other PC laptop) for each lunch hour session. You will be asked to spend 45 minutes of your lunch hour for three consecutive days in one of three randomly assigned weeks in April. After that you will be asked to return to face robotics competitions in the 5th week of the study for another three consecutive lunch hours. That is nine lunch hours in total.

Following the learning sessions and group activities, two students from each treatment group will be randomly selected for follow-up interviews that will last no longer than 30 minutes. You do not have to take part in the interview if you do not wish to do so. The interviews will take place over a lunch hour that is convenient for the participant. The interviews will be audio recorded and transcribed by Mr. Zurba, but the participant's names will not be identified to help ensure confidentiality.
This study will also attempt to assess indicators of learning that are more in line with modern students, educators, and the corporations in relevant fields. Therefore, this study will focus more on your learning behaviors as a reflection of how you learned, as opposed to testing for the content itself. In other words, no tests to write!

If you would still like to be a part of this study, you must take home a consent form for your parents to sign and return by _________________. You cannot be a part of the study without it.
Keep in mind that, even if you decide to be a part of the study in the beginning, continued participation is strictly voluntary, and you can choose to remove yourself from the study. If a student is absent for 3 or more of the 6 initial learning periods, they will be notified personally that they have been removed from the study.

Are there any questions that any of you may have? Thank you for your interest, I look forward to working and learning with you.

Appendix E: Parental Consent / Participant Assent Form

UNIVERSITY OF MANITOBA | Faculty of Education
Department of Curriculum, Teaching and Learning

230 Education Building
University of Manitoba
Winnipeg, Manitoba
Canada R3T 2N2
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Fax (204) 474-7550

RESEARCH PARTICIPANT INFORMATION,
PARENT/GUARDIAN CONSENT & PARTICIPANT ASSENT FORM

Title of Study: Teaching programming using robots: an evaluation of the learning benefits of virtual simulation software

Principal Investigator
Michael Zurba, Teacher at [redacted] Collegiate
MEd Candidate, University of Manitoba Department of Curriculum, Teaching and Learning
Email: [redacted]

[redacted]

M.Ed. Program Advisor Contact Information:
Dr. Richard Hechter
Department of Curriculum, Teaching and Learning
University of Manitoba

Address: 227 B Education Building
71 Curry Place
Winnipeg, MB, R3T 2N2
Tel. (204) 474-9054
Email: richard.hechter@umanitoba.ca

Sponsors
Cogmation Robotics Inc. (a simulation software company based in Winnipeg) and Mitacs (a not-for-profit organization that builds partnerships between governments, companies, and universities in Canada to support industrial and social innovation)

You and your child are being asked to participate in a research study. Please go through this consent form together and initial the bottom of each page, indicating it has been read and understood. Please take your time to review this consent form and discuss any questions you may have with me or my thesis advisor Dr. Hechter. You may take your time to make your decision about participating in this study and you may discuss it with your friends, family or (if applicable) your doctor before you make your decision. This consent form may contain words that you do not understand. Please ask me or Dr. Hechter to explain any words or information that you do not clearly understand. The study and its data are intended to be used for my Master of Education thesis. I will be acting as the principal investigator and Dr. Hechter will be overseeing all procedures and data collection as the thesis advisor.

This project has been approved by Mr. Brad Curtis (RRVSD Superintendent) and Ms. Jaynie Burnell (Principal at [redacted] Collegiate) as well as the Education/Nursing Research Ethics Board (ENREB) at the University of Manitoba.

Purpose of Study

Studies have indicated that teaching robotic programming using computer programs may increase the speed of learning and deeper-level understanding. I intend to study how students learn when provided with just physical robots, just virtual robotics software, and using both together. This study will also attempt to evaluate the types learning that are considered more modern by Next Generation Science Standards (NGSS), under the assumption that they will be more relevant to modern students, educators, and the corporations in relevant fields. While the students are learning to program in different groups and scenarios, I will be looking for indications of deeper-level learning behaviours, as I believe this will be a better reflection of genuine learning. I will not be giving tests for the content itself.

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A total of 12 students, those who are first to provide written consent from parents/guardians, will participate in this study. Student participants will be “randomized” into one of 3 study groups described below. “Randomized” means that you are put into a group by chance, like flipping a coin. Students will have an equal chance of being placed in any group. Participants will be recruited on a volunteer basis following parental consent from any students who are not currently being taught by Mr. Zurba nor will be throughout the duration of the study. The participants will be randomly assigned to three different learning groups: A (access to physical robots only), B (access to virtual robotics software only), and C (access to physical robots and virtual robotics software simultaneously). Since each learning group will be allotted to an entire week, consideration may be given if participants would prefer placement in a particular week due to scheduling conflicts. **Participation in this study will be for 9 lunch hours throughout the months of February and March (3 lunch hours per week).**

If your child is interested in taking part in this study, s/he will undergo the following procedures:

Materials will be introduced to the participants during their week of learning only at the fundamental level, i.e. students will be shown how to connect their computers to the physical robot and students will be shown how to download the relevant virtual software to their personal laptops. The students will be provided with a colour-coded notebook to record whatever they wish during the learning process, previously being informed that their proficiency in coding will be ranked during a robot programming challenge at a later date against the students in other groups. A template of suggestions on what to record in their notebooks will be provided to each student.

During the fifth week of the study, the students from all groups will be mixed into two groups to perform various challenges with the two physical robots that were provided for the study. Again, this will take place over 3 lunch hours. The group activity will be observed by Mr. Zurba and Dr. Hechter and analyzed for indicators of learning behaviours, with the colour coded notebooks being used to help identify which students came from which groups as they display learning behaviours.

Following the learning sessions and group activities, two students from each learning behaviour category will be randomly selected for follow-up interviews that will last no longer than 30 minutes. The interviews will take place in Room 15 at [redacted] Collegiate over a lunch hour that is convenient for the participant. The interviews will be audio recorded and transcribed by Mr. Zurba, but the participant's names will not be identified to help ensure anonymity.

The researcher may decide to take you off this study if a lack of lunch hour attendance limits your ability to learn the basics of programming. You can stop participating at any time by contacting me or Dr. Hechter using the contact information listed above. However, if you decide to stop participating in the study, I encourage you to first talk to me. If you decide not to continue your participation all data collected from you will be destroyed and not included in the study.

Risks and Discomforts

There is minimal risk associated to participation in this research. For example, there is the possibility that your child may be identified by researchers or students as taking part in the study, but all efforts will be made to protect student anonymity in the results and their dissemination. Students who volunteer are not being taught by Mr. Zurba, and they are volunteering to spend their own free time at lunch to be participants in the study. Students will be asked to manipulate a robot on the floor of the classroom throughout the lunch hour, so general mobility will be required.

Benefits

There are immediate benefits to the participants in this study: to potentially learn how to program robots, to gain a trial access to Cogmation Robotics' *Virtual Robotics Toolkit* software, and to become "Robot Leaders" at [redacted] Collegiate to pass on what they have learned to their peers and teach others how to operate the robots.

Costs

Materials and procedures performed as part of this study are provided at no cost to you. [redacted] Collegiate will keep the robots at the conclusion of the study.

Payment for participation

You will not receive payment nor reimbursement for taking part in this study.

Confidentiality

Information gathered in this research study may be published in research journals or presented in public forums, however names and other identifying information will not be used or revealed. Despite efforts to keep your child's personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law.

All notebook journals students will be using will be left anonymous before handed back to me for analysis.

All data and documents (such as consent forms) related to this research will be securely stored in locked cabinets in Room 15 at [redacted] Collegiate and only Mr. Zurba will have access to these records. If any of your research records need to be copied to Dr. Hechter, your name and identifying information will be removed. No information revealing any personal information such as your name, address or telephone number will leave [redacted] Collegiate. All written and digital data will be destroyed and deleted on January 1st, 2020.

Results from the study will be reported to Mitacs, Cogmation Robotics, and may also be disseminated the through conference presentations and research articles. You may indicate that you would like to receive a copy of the materials produced for dissemination of this research by signing the appropriate field below.

Voluntary Participation/Withdrawal from the Study

Participation for students in the study will be for a total of 9 lunch hours in the months of February or March. Students may be randomly selected and asked to participate in an additional interview after initial data analysis has been completed. This will take no longer than 30 minutes and can take place at a time that is convenient to the student. Students may withdraw from the study at any time. A student's decision not to participate or to withdraw from the study will not affect their education or performance evaluation at [redacted] Collegiate. If a student is absent for 3 or more of the 6 initial learning periods, they will be notified personally that they will be removed from the study and the data collected to the point of withdrawal will be destroyed.

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Questions

You are free to ask any questions that you may have about your treatment and your rights as a research participant. If any questions come up during or after the study or if you have a research-related injury, contact Mr. Zurba and/or the study staff listed on the first page of this document.

For questions about your rights as a research participant, you may contact:
The University of Manitoba
Education Nursing Research Ethics Board (ENREB) Office
humanethics@umanitoba.ca
(204)474-7122

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.

I would like to receive:

☐ copies of dissemination materials ☐ a summary report of this research

Please, send me these by:

☐ Email at: ____

☐ Regular mail at the following address:

____

____

Statement of Consent

I have read this consent form. I have had the opportunity to discuss this research study with Mr. Zurba and/or Dr. Hechter. I have had my questions answered by them in language I understand. The risks and benefits have been explained to me. I believe that I have not been unduly influenced to participate in the research study by any statements or implied statements. Any relationship (such as employer, supervisor or family member) I may have with the study team has not affected my decision to participate. I understand that I will be given a copy of this consent form after signing it. I understand that my participation in this study is voluntary and that I may choose to withdraw my child at any time. I freely agree to participate in this research study.

I understand that information regarding my personal identity will be kept confidential, but that confidentiality is not guaranteed. I authorize the inspection of any of my records that relate to this study by The University of Manitoba Research Ethics Board for quality assurance purposes. By signing this consent form, I have not waived any of the legal rights that I have as a participant in a research study.

Student participant printed name: ___________________________

Student participant signature ________________________ Date ______________
(day/month/year)

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe that the participant has understood and has knowingly given their consent.

Parent/legal guardian printed name: _____________________

Parent/legal guardian signature ______________________ Date ______________
(day/month/year)

A copy of this consent form will be given to you to keep for your records and reference.

Appendix F: Participant Learning Group Start-up Information

Group 1: Mindstorms EV3

Use the following programs and tutorials to help you learn to program your robots

1. Use the instruction booklet provided
    - Begin with the TRACK3R robot

2. LEGO Mindstorms EV3 software
    - You require EV3 programming software for advanced operation of your robot. Download at: www.virtualroboticstoolkit.com/download_links
    - Click on the link for EV3 software download for Windows and follow the instructions
    - Under the "quick start" tab, begin with the TRACK3R robot
    - Eventually, you can check out the "more robots" tab and build whatever looks interesting to you.

3. Internet Resources
    - Some programming lessons can be found at http://ev3lessons.com/
    - Try the "beginner lessons" to start

Group 2: Virtual Robotics Toolkit

Use the following EV3 simulation software to help you learn to program EV3 robots, without actually handling a robot (yet).

1. Virtual Robotics Toolkit (VRT) by Cogmation Robotics Inc.
    - Download the VRT from www.virtualroboticstoolkit.com/download_links
      Enter product key: [redacted]
    - Follow the link to the VRT YouTube Channel on the main screen to learn how to get started as quickly as possible
2. LEGO Digital Designer
    - This program is required to build advanced robots and in order to be used in the VRT
    - Download at: www.virtualroboticstoolkit.com/download_links
    - Click on the link for LEGO Digital Designer software and follow the instructions for a Windows download.
    - Click on the Mindstorms tab and build. This will allow you to use all the bricks, motors, and sensors available within a regular Mindstorms EV3 package.
    - You can also download pre-built designs to use and/or modify to save some time.
3. Internet Resources
    - Some programming lessons can be found at http://ev3lessons.com/
    - Try the "beginner lessons" to start

Group 3: Mindstorms EV3 and Virtual Robotics Toolkit

Use the following programs and tutorials to help you learn to program your robots

1. Use the instruction booklet provided with the EV3

- Begin with the TRACK3R robot

2. LEGO Mindstorms EV3 software

- You require EV3 programming software for advanced operation of your robot. Download at: https://www.lego.com/en-us/mindstorms/downloads/download-software
- Click on the link for EV3 software download for Windows and follow the instructions
- Under the "quick start" tab, begin with the TRACK3R robot
- Eventually, you can check out the "more robots" tab and build whatever looks interesting to you.

4. Virtual Robotics Toolkit (VRT) by Cogmation Robotics Inc.

- Download the VRT from www.virtualroboticstoolkit.com/download_links
  Enter product key: [redacted]-[redacted]-[redacted]-[redacted]
- Follow the link to the VRT YouTube Channel on the main screen to learn how to get started as quickly as possible

5. LEGO Digital Designer

- This program is required to build advanced robots and in order to be used in the VRT
- Download at: www.virtualroboticstoolkit.com/download_links
- Click on the link for LEGO Digital Designer software and follow the instructions for a Windows download.
- Click on the Mindstorms tab and build. This will allow you to use all the bricks, motors, and sensors available within a regular Mindstorms EV3 package.
- You can also download pre-built designs to use and/or modify to save some time.

6. Internet Resources

- Some programming lessons can be found at http://ev3lessons.com/
- Try the "beginner lessons" to start

Appendix G: Participant Journal Question Framework

Journal Template (answer all that apply)

1. **TITLE:** *Robotics Programming Journal day #* **DATE:** *day/month/year*

2. Since your last journal entry, estimate the amount of time spent outside of the scheduled lunch hour on any robotics material.

3. What did you learn about today from reading online tutorials?

4. What did you learn about today from watching online videos?

5. Of everything you learned today, what would you most like to remember?

6. Sketch a diagram of a part of the robot that you would like to learn more about.

7. Make a chart of (or just list the steps) of how you got the robot to perform something today.

8. Where have you seen something similar to what you did with the robot today?

9. Describe a conversation with a group member that you feel was important to programming.

10. Describe how you worked together with a group member today to accomplish a task.

Appendix H: Data Coding Frameworks

Example Notebook Analysis Coding Framework

Green 1: ID ____________								
Date: ________________ Learning Day 1								
Passive (1)		Active (2)		Constructive (3)		Interactive (4)		Score
Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
Date: ________________ Learning Day 2								
Passive (1)		Active (2)		Constructive (3)		Interactive (4)		Score
Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
Date: ________________ Learning Day 3								
Passive (1)		Active (2)		Constructive (3)		Interactive (4)		Score
Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
Date: ________________ Learning Day 4								
Passive (1)		Active (2)		Constructive (3)		Interactive (4)		Score
Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
Date: ________________ Learning Day 5								
Passive (1)		Active (2)		Constructive (3)		Interactive (4)		Score
Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
Date: ________________ Learning Day 6								
Passive (1)		Active (2)		Constructive (3)		Interactive (4)		Score
Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
Date: ________________Competition Day 1								
Passive (1)		Active (2)		Constructive (3)		Interactive (4)		Score
Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
Date: ________________Competition Day 2								
Passive (1)		Active (2)		Constructive (3)		Interactive (4)		Score
Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
Date: ________________Competition Day 3								
Passive (1)		Active (2)		Constructive (3)		Interactive (4)		Score
Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
Total additional hours:								

Example Observational Analysis Coding Framework.

Challenge Day 1				
Date:				
Behaviour	**P**	**A**	**C**	**I**
Colour *(g, y, or p)*				
Totals				
Green				
Yellow				
Pink				

Appendix I: Exit Slip for Participants and Parents/Guardians

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Dear Participants and Parents,

On behalf of Mitacs, Cogmation Robotics, the University of Manitoba and myself, I would like to thank you for taking part in this study. I would like to provide you with some information regarding what evidence of learning we were looking for in your notebooks and in your group behaviours, and why we were looking for them.

A modern view of STEM education (science, technology, engineering, mathematics) focusses less on core ideas and more on multi-disciplinary skills that set students up for life-long learning. These would include collaboration and problem solving to enable them to process studies and new developments in fields that may not even exist yet. The Manitoba department of Education incorporates these values into "Cluster 0" of the science curriculum (2000, 2001). The National Research Council of the United States (2013) has stated that:

> …given the cornucopia of information available today virtually at a touch –people live, after all, in an information age– an important role of science education is not to teach "all the facts" but rather to prepare students with sufficient core knowledge so that they can later acquire additional information on their own.

Our study attempted to assess indicators of learning that are more in line with a modern direction of STEM, under the assumption that it will be more relevant to modern students, educators, and the corporations in relevant fields.

The *Interactive*, *Constructive*, *Active*, and *Passive* (ICAP) framework described by Michelene Chi and Ruth Wylie (2014) predicts that students will become more engaged with learning materials and learning will increase as the students progress from *passive* to *interactive*. Justification for the hierarchy of the ICAP framework is as follows: *Passively* learned material will only be retrieved when a very similar activity or is presented to the learner. *Actively* learned material can be retrieved as a new activity requires previously learned material to fill in gaps and assimilate into a new schema. *Constructive* learning not only retrieves previously learned information, but also revises it in the process to gain a better understanding. *Interactive* learning results as a consequence of reciprocally *constructing* knowledge with a peer. This would be exemplified in a conversation or an argument. One can say that learners in the *interactive* mode have achieved the most advanced level of learning.

At the end of the study, the notebooks will be analyzed for evidence of *interactive, constructive, active,* or *passive* learning behaviours according to ICAP criteria and will be correlated by a second examiner (Dr. Hechter). The frequency of each learning behaviour will be tallied, calculated as an average student score for every day for each group, and then charted. Quantitative analysis will show which treatment groups grew into higher lever learning behaviours.

During the last week of the study, the students from all groups were mixed into two teams to perform various challenges with the two physical robots that were provided for the study. Again, the frequency of each learning behaviour will be tallied, calculated as an average student score for every day for each group, and then charted. Quantitative analysis will show which groups performed at or progressed to higher levels of learning behaviours. Follow up interviews will be performed to see if the participant perception of the learning environment matched the data that we collected.

Before the study began, I did not fully explain to the participants which criteria we were looking for in the notebooks or in the group challenges because I wanted the results to be more organic and genuine. I hope this answers some questions that you may have had, but please feel free to contact me if you have any others.

Once again, thank you for your time.

-M. Zurba

Mitacs COGMATION ROBOTICS UNIVERSITY OF MANITOBA

Appendix J: Participant Interview Script

State date:
Inform participant that the interview will be audio recorded and eventually transcribed.
Ask if they understand and if this is ok.

Identify treatment group of participant.
Do not verbalize participant's name, remind them to try to avoid using other people's names.

1. Which of the following **more often** described your experience?
    i. I was just trying to memorize concepts
    ii. I wanted to learn more than I had time for
    - Probe: Describe an example of this type of experience

2. Which of the following **more often** described your experience?
    i. I mostly learned from online videos or tutorials
    ii. I mostly learned by conversing with my group mates
    - Probe: Can you remember something in particular that you learned this way?

3. Which of the following **more often** described your experience?
    i. I had a debate with a classmate on how to program the robot for a task
    ii. I often was making mental comparisons to other things I have learned
    - Probe: What do you still remember an experience like that?

4. After this study, how would you consider your programming skills of EV3's? Competent, weak, excellent, or something in-between?
    - Probe: Can you elaborate on why you think so?
    - Probe: What can you do with the EV3 robots now?

5. What do you think you could have learned more about?

6. What aspect of the learning environment (verbalize which one) contributed to you learning how to program the most? The students you worked with, the EV3 itself, or the virtual software?
    - Probe: Why do you think it helped?

7. Did you find yourself thinking about the robots outside of the lunch hours?
    - Probe: what were you thinking about?

8. [redacted] Collegiate is keeping the robots. Do you think you will keep with them on your spare time?

9. You were left to learn how to program on your own with virtually no instruction from me. What were you working on when things finally started to "click"? Please tell the story.

10. Are there any comments you could make about the learning environment you were in?
    - Probe: Did you feel the learning you did prepared you for the final challenges, even though you did not know what skills you would need?
    - Probe: What part of this experience most prepared you most for the challenges?