# The Impact of the Integration of Makerspaces and Making Activities Into Engineering Design Education

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# Abstract

The increasing presence of makerspaces in university campuses is encouraging engineering educators to incorporate making activities and projects into their curriculum to support formal and informal learning, foster multidisciplinary learning environments, promote collaborative learning, and help students develop critical skills such as teamwork, problem-solving, creativity, innovation, entrepreneurship, and the ability to use engineering tools. Despite the growing interest in makerspaces in engineering schools, there remains a considerable gap in the literature providing in-depth analysis of the incorporation of makerspaces and maker curricula into engineering schools and its impact on students' learning. This dissertation contributes to filling that gap by exploring the integration of makerspaces into cornerstone engineering design courses.

I start by introducing the Maker Movement and the theoretical framework for the research. I then address two main research questions in this dissertation: (1) Does the integration of making projects and activities into engineering design education create opportunities for authentic learning environments? (2) What is the impact of certain non-cognitive attributes on students' learning in engineering design courses based on making projects and activities? Through a qualitative study of seven engineering students in two teams, I address the first research question by exploring how the integration of making projects and activities into a cornerstone engineering design course creates conditions that open possibilities for authentic learning of engineering design. I use grounded theory as the qualitative research methodology to explore the authenticity of students' learning experiences. Drawing on 14 semi-structured interviews conducted throughout the semester, I discuss the authenticity of the learning environment and students' experiences within it. I describe how situating formal design courses in a makerspace environment offers students an authentic design experience with opportunities to develop and practise authentic engineering skills and to solve problems that are similar to workplace problems, to develop their confidence in their design and problem-solving skills, and to expose them to multiple topics and disciplines. I also discuss the challenges students face as they complete their projects and the implications for engineering instructors who are interested in integrating making activities into their courses.

To address the second question, I investigate the impact of certain non-cognitive attributes on students' learning in engineering design courses centred on making projects and activities. I aggregate data from two engineering design courses — a first-year course and a second-year course — in fall 2018, winter 2019, and fall 2019. I use hierarchical regression to predict students' learning outcomes using measures of three non-cognitive attributes: Big-Five personality traits, grit, and learning goal orientation. The learning outcomes considered in the study are students' academic success, level of contribution to their projects, and project ownership. The results of the study include a discussion of how the Big-Five personality traits are associated with students' learning outcomes in design courses based on making projects. The results also indicate that grit as a higher-order structure does not predict students' academic success or performance in a socially situated learning environment that requires creativity and innovation. However, perseverance of effort, a subdimension of grit, is found to be a significant predictor of students' academic success. Also, students' adoption of a learning goal orientation positively predicts their academic success but has no impact on their level of contribution to their team's project. Moreover, the results indicate that the personality traits of agreeableness and extraversion along with students' adaptability to changes in life circumstances are associated with their development of intellectual and emotional ownership of their making projects. However, project ownership is not associated with students' academic success or level of contribution to their team's projects. Finally, I discuss the implications of the findings and results and provide recommendations for engineering educators who want to integrate makerspaces into their engineering courses.

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It was a great honour to work with Justine Boudreau and Chantal Rodier on several research projects on designing authentic learning approaches in makerspaces for engineering students. I hope we continue to collaborate in the future. Also, a huge thanks to the students who participated in the studies.

## Statement of originality

I hereby certify that all the work described within this thesis is the original work of the author. Any published (or unpublished) ideas and/or techniques from the work of others are fully acknowledged in accordance with the standard referencing practices.

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# Glossary

**Maker Movement**

Maker Movement refers to a grassroots movement of tinkerers, hackers, designers, and inventors who design, create solutions for immediate problems, and share their processes and products in digital and physical forums [1], [2], [3], [4].

**Making activities**

Making activities are creative activities using digital and physical technologies aimed at tinkering, learning, or creating artifacts [1]. Making activities can be focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented toward making a "product" of some sort that can be used, interacted with, or demonstrated [5].

**Makerspaces**

Makerspaces are defined as community spaces where members of all ages engage in creative activities either for professional gain or hobbyist pursuits [6].

**Cornerstone Engineering Design Courses**

Cornerstone design courses are first year design courses that are intended to expose first year engineering students to what engineers do while enjoying an experience where they could learn the basic elements of the design process by doing real design projects [7].

**Authentic learning**

Authentic learning is a pedagogical approach that aims to situate learning in real-life settings that allow students to encounter activities, tasks, and challenges with real-world relevance [8]. Lave and Wenger define authentic learning as a participation process within real communities of practice [9].

**Situated learning**

Situated learning theory emphasizes the idea that much of what is learned is specific to the situation in which it is learned [10] and that knowledge and skills are learned in contexts that reflect the way the knowledge will be useful in real life [11].

**Communities of practice**

Communities of practice are groups of people who share a passion for a topic, interact on an ongoing basis to deepen their knowledge and expertise, share information, insight and advice, and help each other to solve problems [12].

### Non-cognitive skills

Non-cognitive skills are personality traits that are weakly correlated with measures of intelligence, such as the IQ index [13].

### Grit

Grit is defined as an individual’s perseverance and passion for long-term goals [14].

### Project ownership

Project ownership refers to students’ feelings and assumption of intellectual and emotional responsibility over their learning in project-based learning environments [15], [16], [17].

### Stress

Stress is where an individual feels threatened by or under pressure from a certain situation; it has physical and emotional effects on us and can create positive or negative influence on the individual [18].

# Chapter 1 Introduction

## 1.1. Motivation

Recent developments in design and fabrication tools [19] along with the increased accessibility of affordable microcomputing kits and easy-access do-it-yourself (DIY) electronics [20] have increased people's engagement in making activities and projects [1]. These developments have coalesced into a public trend called the Maker Movement, a grassroots movement of tinkerers, hackers, designers, and inventors who design, create solutions for immediate problems, and share their processes and products on digital and physical forums [1], [2], [3], [4]. Signs of the start of the Maker Movement can be traced back to the launch of Make Magazine in 2005 and the first Maker Fare gathering in San Francisco in 2006 [2], [21]. Several societal trends have since contributed to the growth and popularity of the Maker Movement. In his discussion of the history of the movement, Blikstein [22] notes five trends that facilitated the growth of the Maker Movement in education. The first is demands from business organizations, governments, science academics, and international organizations for new curricula and better training for graduates to be able to function in the global economy. The second is various countries' interest in shifting their economies to knowledge- and innovation-based ones. Third, interest in developing new curriculum suited to the 21st-century economy led to the popularity and adoption of progressive education and constructivist learning theories. The fourth trend is the dramatic cost reduction in technologies used in fabrication and making. The fifth trend is the creation of new technological tools, and the improvement of existing ones, whether for children or for academic labs.

The Maker Movement consists of three key elements: a community of makers who engage, use, and produce artifacts, the production tools used by makers, and the makerspaces where the community of makers gains access to and uses new technologies [23]. Dale Doughetry [23], the founder of Make Magazine, defines makers as enthusiasts who play with technology to learn about it; out of this act of play, new ideas emerge — ideas that might lead to real-world applications or new business ventures. Makers often view themselves as outsiders [23] and are often idealistic and socially minded, aiming to change the world around them by seeking alternative ways to create, innovate, produce, and consume

[24]. Their mindset is playful, oriented toward growth, and collaborative, and they have a positive attitude toward failure, in that they see it as an opportunity for growth [5]. Makers love learning and doing, and are intrinsically motivated to explore, design, tinker, play, discover, problem-solve, and share their work [25], [4]. Many makers engage in making activities and projects for leisure purposes; however, some establish businesses from their creative work, which can have a variety of applications [24].

Making has always been at the core of humanity, as humans have long tinkered, created, and shaped tools, equipment, and shelter to sustain themselves [26]. However, now that making is no longer a common practice, the maker movement has motivated and inspired people to engage in making activities and projects [23]. Making activities are a blend of design and activities with personal meaning that embody a sense of playfulness, creativity, and autonomy [1]. Martin [5] defines making activities as "activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented toward making a "product" of some sort that can be used, interacted with, or demonstrated," while Sheridan and colleagues define it as "creative production in art, science and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products" [1]. Making in an educational context is a personal and social transformation that can be seen in the "difference between a child who is directed to perform a task and one self-directed to figure out what to do" [7, p. 10].

Participating in making activities is a form of social experience constructed around participation in a community of makers [23]. Makers engage in making activities in various spaces, such as community centres, classrooms, public library branches, incubators, and factories [24]. Making activities also offer promising approaches to engaging students in design and fabrication projects that expose them to design, programming, and problem-solving tasks [27]. The digital and physical fabrication tools used in making activities in educational settings include Scratch, Arduino, 3D printers, Raspberry Pi, Makey, and Minecraft [27].

## 1.2. The impact of the Maker Movement

The emergence of the Maker Movement has affected many domains and spheres of societal life. Its impact can be felt in education, the economy, healthcare, and the increase in accessibility to science fields [28]. The promise that the Maker Movement holds for education is its ability to "democratize access to the discourses of power that accompany becoming a producer of artifacts" [20, p. 500], encourage learning across disciplines [5], and attract students to study STEM disciplines [30]. Resnick and Rosenbaum [31] emphasize the importance of exposing students to educational programs that foster abilities and skills that can help students succeed in a world characterized by uncertainty and rapid change. They view success in the future as determined by an individual's ability "to come up with innovative solutions to unexpected situations and unexpected problems" (p. 166). They explain that formal education systems often adopt a top-down planning teaching approach that emphasizes the value of planning, analyzing options, and carrying out plans. This approach marginalizes students who are natural tinkerers [4]. Resnick et al. argue that to increase participation and foster innovation in science, technology, engineering, and mathematics (STEM) disciplines, educational systems should design curricula that appeal to tinkerers. Vossoughi et al. [32] also highlight the role that making can play in transforming what counts as learning. The emerging Maker Movement has the ability to transform education by providing students with more agency over their learning and offering more creative and stimulating experiences [23]. By empowering people to create high-quality craftwork and facilitating user-driven innovation [33], [34], this movement has helped its members increase their confidence in their technological skills [35], [36]. The Maker Movement has also been credited as being a potential transformative path to developing an interest in engineering [37], [5], as it provides for practical opportunities for the public to apply engineering principles in everyday life [38], [39], increases knowledge of production processes, and reduces the barriers of entry to markets [19].

Making as a pedagogical approach provides unique opportunities for educators to incorporate valuable pedagogies such as project- and problem-based learning that place the student at the centre of the learning process, to transform what counts as learning [32], to emphasize the importance of experimenting and tinkering, and to recognize the social aspect of learning as opposed to traditional models of education that see learning as a process of internalization on the part of the individual and neglect the relationships between the individual learning and society, the environment, and the world [40], [41]. In addition, making is a process of creative problem-solving and design that can help educators integrate the disciplines of science, engineering, and arts into educational programs and curricula [4]. Learning through making activities can also bridge a divide that exists between formal and informal education [29] and provide a platform that facilitates both theoretical and practical learning [36]. Vossoughi and Bevan [4] note that making as an educational practice can encourage students to participate in science programs by connecting learning activities to real-world applications and turning students into active producers of knowledge rather than passive consumers; it can also provide opportunities to build skills and improve critical thinking, reasoning, and innovation by contextualizing STEM topics in interdisciplinary, meaningful, and engaging activities and encouraging intellectual risk-taking and experimentation; and it can foster a supportive learning community by encouraging collaboration and sharing, while also helping students assume teaching and leadership roles. The incorporation of making activities into engineering courses has also been found to improve students' communication, collaboration, and teamwork skills; help students develop problem-solving and research skills; nurture entrepreneurial, leadership, and management skills; and introduce students to prototyping methods [36].

From an economic perspective, the Maker Movement has helped democratize innovation and technology through cheap hardware and easy-to-access digital fabrication tools [29]. It has also led to the emergence of bottom-up entrepreneurship and provided makers with access to capital through crowdfunding [39], [42]. These changes have led many makers to become entrepreneurs and, in turn, lead the further development of industrial robots, 3D printers, and smart devices [25]. There are three types of maker enterprises: micro-makers, whose activities contribute to a city's artistic and cultural vibrancy; global innovators, who contribute products, processes, and materials that aim to solve global problems; and emerging place-based manufacturers, who make products and contribute to employment growth [24].

Wolf-Powers et al. [24] suggest the Maker Movement has the potential to build urban creativity, spur innovation, and generate new employment opportunities. Maker enterprises help makers overcome production, finance, marketing, and supply chain challenges [24].

The Maker Movement has also significantly affected manufacturing, by leading manufacturers of all sizes to function concurrently and successfully, with the boundary between manufacturers and consumers becoming more blurred, partly due to consumers' increasing desire for personalized, customized products that pay attention to human aspects [28]. Anderson [2] described the Maker Movement as the perfect combination of inventing locally and producing globally, as this movement has placed high-tech digital fabrication tools in the hands of makers, who use the tools to create solutions for local problems, and then big factories all over the world reproduce these solutions. The Maker Movement is also contributing to ending the skills gap in manufacturing sectors by providing students with technical and life skills that were previously absent from formal education [28].

The Maker Movement's impact can also be felt in other sectors, such as healthcare. It has provided for transformative solutions in healthcare by allowing industry outsiders to contribute to health innovations. The movement has also led to solutions to health problems not addressed by market stakeholders, provided a platform to improve the design of health innovations through open-source collaborations, and created opportunities for patient-designed solutions [43].

### 1.3. Makerspaces as learning sites

The emergence of the Maker Movement has led to an explosion of makerspaces across the globe [1]. Makerspaces are informal sites for creative production in art, science, technology, and engineering, where people of all ages and experience meld digital and physical technologies to explore ideas, learn technical skills, and create new products [1], [23], [44]. These spaces "modify the conception of the traditional sites of production and recast the notions of studio, workshop, laboratory, gallery, and atelier into new settings for the integrated design, production, and distribution of products" [17, p. 6], [23]. Makerspaces are also commonly known as hackerspaces and FabLabs, and although the origins of each of these terms is distinct, the three terms refer to community workshops where members share tools and equipment to work on creative projects [6]. Makerspaces are primarily funded by donations and user fees and are equipped with a variety of tools that many makers could not afford. Accordingly, the Maker Movement and its associated makerspaces have brought high-quality craftwork within the reach of thousands, perhaps millions [33].

In the past decade, makerspaces have opened in museums and science centres [44], universities [46], [47], [48], libraries [49], [50], and independent non-for-profit organizations [29]. The presence of makerspaces in university campuses can be traced to the creation of FabLabs at the Massachusetts Institute of Technology (MIT) by Neil Gershenfeld in 2003 [29]. Today, the Fab Foundation supports the creation of new FabLabs around the world and provides resources for users of these spaces to generate designs and transform them into products with in-house fabrication tools [29]. Makerspaces in university campuses are often described as academic makerspaces to distinguish them from industry, community, and K-12 makerspaces [51]. Higher education institutions open makerspaces to create physical locations and social networks that support curricular and extracurricular activities, foster collaboration and peer-learning, offer an experiential learning environment [51], and help students build confidence through deep engagement in environments that provide access to exploration and fabrication technologies [52]. Moreover, academic makerspaces help blend traditional and digital skills with arts and engineering, creating a learning environment with multiple entry points for participants. This kind of environment leads to innovative combinations, juxtapositions, and uses of disciplinary knowledge, helping to break down disciplinary boundaries [3], [1]. Furthermore, makerspaces provide a model of technological professional development that promotes community-building and careful framing of the purposes and uses of tools, skills, and knowledge, while also allowing participants to see tinkering and reflective practice as essential aspects of the learning process [53].

In the literature available to date, makerspaces contribute to students’ learning by improving the active learning component in engineering programs [36]. They also promote collaboration and group work between students, allowing students to casually and fluidly work together in makerspace environments

[54], [55]. Academic makerspaces contribute to student retention and diligence by fostering innovation and entrepreneurship within the engineering curriculum. They engage corporate partnerships to ensure the transfer of knowledge gained through the undergraduate curriculum to real-world applications. As well, they help to establish a network of collaborations across the academic institution [56]. Academic makerspaces help students develop a broad set of skills that complement traditional engineering curricula, including teamwork, creativity, innovation, collaboration, critical thinking, project management and systems engineering [56]. Finally, academic makerspaces provide training for instructors, technicians, managers, and entrepreneurs [36].

### 1.4. Critique of the Maker Movement

The Maker Movement enjoys wide acceptance as a way to realize a revolution in educational practices [22]. It holds great promise to empower and encourage women and marginalized communities to participate in making activities [21], [36], by providing them with access to the support of a community of makers [57]. It is also helping to realize new opportunities to leverage STEM knowledge and practice alongside community wisdom and funds of knowledge to create a more just world [58]. But despite this promise, several critiques and concerns surround the movement.

The first critique is that its ability to transform education has been overhyped, in the same way that other educational technologies, such as laptops, tablets, and video-based learning were overhyped, when they first appeared. Second is that it might not change the perception of hands-on activities as being second-class learning activities associated with technical and vocational education [22]. Third, the dominant view of making has been criticized for being an American economic activity that is more aligned with corporate values than social change [32]. Despite the existence of many makerspaces that use available technologies for purposes outside intended systems of consumerism, Vossoughi et al. [32] say the mainstream discourse of the Maker Movement has much to learn from these makerspaces. They emphasize the need to reconceptualize making as “a pedagogical practice that is grounded in histories, needs, assets and experiences of working-class students and students of color” (p. 210). Fourth, Vossoughi et al. criticize the Maker Movement for its adoption of a narrow version of constructionism that excludes its social and cultural perspectives [32]. Fifth, the Maker Movement has been criticized for the absence of practices and knowledge of communities of colour and low-income communities from its discourse [58]. Sixth, the Maker Movement has also been criticized for placing little attention on sustained maker learning experiences and providing only limited critical engagement with the consequences of making and with its impact on family, history, location, and expanded community [58]. Vossoughi et al. [32] recommend that educators pay close attention to the cultural, historical, and political identities of students to try to design making activities that are relevant to them. They also insist that making should be regarded as one among many educational tools that intersect with other forms of learning and that making should not be the goal of educational practice.

### 1.5. Makerspace at uOttawa

Aiming to capitalize on the benefits that makerspaces bring to formal education institutions, the Faculty of Engineering opened its own on-campus makerspace in September 2014. The faculty intended to create a space that fosters innovation, promotes interdisciplinary projects, provides access to prototyping facilities, encourages and facilitates students' entrepreneurship, and allows students to realize their designs and acquire and practise new skills and knowledge. The makerspace is directed by my supervisor, but its day-to-day operations are managed by students. The makerspace was launched with a few pieces of technology such as 3D printers, Handibots (hand-held CNC routers), a few hand tools and computers in a 64 m$^2$ space. By the second year of opening, the Richard L'Abbé Makerspace had doubled in size, offered more advanced tools and equipment, and secured more funding from a variety of sources, including philanthropic donations and government funding.

The makerspace is now part of the Centre for Entrepreneurship and Engineering Design (CEED), which was created in 2015. Its facilities include seven different spaces for learning, building projects, and collaborating in teams. There are two learning facilities among the CEED facilities. The first is the Manufacturing Training Centre (MTC), which offers students free training workshops on traditional mechanical equipment, such as using saws, lathes, and milling machines, as well as welding and fabrication techniques. The second facility is the MakerLab, which provides students with structured learning experiences using digital prototyping facilities either in an engineering course or workshop setting.

Two facilities focus on enabling students to turn their ideas and designs into reality. The first space is the Brunsfield Centre, a student-led machine shop where student-staff and students design, fabricate, and test complex prototypes using traditional manufacturing equipment such as mills, lathes, bandsaws, drill presses, and welding and fabrication tools. Students must complete introductory training in the Manufacturing Training Centre before they can start using the Brunsfield Centre's resources. The second space where students can build their designs is the Richard L'Abbé Makerspace, which serves 2,000 students annually.

The other three CEED facilities focus on fostering a collaborative learning environment on campus. The Sandbox provides a collaborative space where students can work on small projects for formal courses, pre-professional competitions, or entrepreneurial projects. The Simon Nehme Design Commons is a collaborative space covered with whiteboards where students can pool talent, brainstorm, and develop creative ideas. The John McEntyre Team Space provides students working on large-scale projects with the space, resources, and infrastructure required to succeed.

From this point forward, "makerspace" refers to all CEED prototyping facilities. Undergraduate students of all years and graduate students are able to use the spaces to gain knowledge and skills, as the spaces are open to all students in the university, for eight hours a day, during the week. The Richard L'Abbé Makerspace is also open to the outside community on Sundays. All users can work on personal and school projects for free. The makerspace staff were originally undergraduate students but now include graduate students and recent alumni. All but one CEED space then moved into a new STEM building in 2018.

Through exposure to the makerspace, students can collaborate with like-minded peers and participate in a community where they will find a lifelong learning opportunity. The makerspace is open to students, with little restrictions on the use of equipment and participants for personal or academic making projects, offering students opportunities to join and sustain the makers community of practice and learn from it if they wish.

## 1.6. Statement of the problem

The integration of making projects and programs into the cornerstone design courses at the Faculty of Engineering at the University of Ottawa presented two research problems that I address in this thesis: the first research problem is exploring the authenticity of the learning environment; the second is identifying non-cognitive characteristics that impact students' learning and academic achievement in a learning environment based on making projects and activities. Despite the enthusiasm for the integration of making activities into education and the growing body of research on the opportunities making activities provide for engineering education, there has been little research on the development of making programs in engineering, and there remains a need for more in-depth analysis of students' learning experiences with making activities in formal educational contexts [27], [59]. Research on the Maker Movement also points to several research gaps.

There remains a need for research that explores the types of making activities in education settings [4], [27] and provides an in-depth analysis of their impact on learning using measurable learning outcomes [27], [30], [60]. Research is also needed to guide engineering educators on how they can integrate the three elements of the Maker Movement — technology, community, and tools — into their programs [5], how they can incorporate making activities into their classrooms [30], and how they can create learning environments that encourage students to persevere in making activities and projects [61]. Moreover, this research needs to use interdisciplinary analysis methods that combine learning sciences with engineering education to guide educators while making curricula changes [60]. With these considerations in mind, the present research studies provide an in-depth analysis of students' learning experience in cornerstone design courses that have successfully incorporated making projects and activities and explores the impact of the making projects and activities on engineering students' learning outcomes. The guiding research questions discussed in this thesis are the following:

RQ1. Does the integration of making projects and activities into cornerstone engineering design facilitate the design of authentic learning environments?

RQ2. What is the impact of certain non-cognitive abilities on students' learning in engineering design courses based on making projects and activities?

### 1.7. Novelty and significance of the thesis

The Maker Movement has attracted a lot of attention from both universities and K-12 schools, as it has emerged as a significant driver for reform in formal and informal learning environments [5], [60]. Educational institutions are interested in several opportunities offered by the Maker Movement, including opening campus makerspaces, supporting project-based courses with the technology associated with the Maker Movement, and starting science, technology, engineering, arts, and math (STEAM) clubs [60]. Engineering schools have also been greatly interested in housing makerspaces and using them to examine pedagogical practices from a learning sciences lens to make curricular changes that can improve the state of engineering education [60]. The schools are also interested in integrating a maker component into their programs to attract a more diverse group of students, increase student retention and engagement, and improve student performance and grades [62]. Engineering educators also recognize learning activities that involve making can offer their students valuable benefits, such as helping students develop a maker mindset, giving them more agency, situating them in a learning experience that is relevant and interesting, and providing them with action-based and interdisciplinary learning environments [62], [28].

The significance of the research discussed in this thesis is that it provides engineering educators with evidence-based recommendations on how to integrate a maker curriculum into engineering courses. By investigating the authenticity of the learning environment offered by integrating making activities into engineering school, this research provides a deeper understanding of how makerspaces can enrich the engineering curriculum. Although several researchers have studied the impact of integrating making into educational environments [4], [23], [29], [40], [41], [36], [33], [34], [35], and some have discussed the authenticity provided in making activities and projects [26], [63], [64], [65], there has been no investigation of how making projects and activities can facilitate the design of authentic learning environments in an engineering curriculum context. Moreover, the research examines factors that contribute to students' academic success and learning in a learning environment based on making projects and activities. Overall, this interdisciplinary research approach that combines learning scienes with engineering education research has two main goals. The first is helping engineering educators understand what elements and characteristics of making projects and activities contribute to their students' learning, and what kind of challenges students face in such a learning environment. The second is exploring factors that influence and predict students' learning and achievement in maker-oriented learning environments. By helping engineering educators identify factors that can influence student learning, this research can help them to design interventions that improve their students' learning experience.

The data collection site for the studies in this research was uOttawa's makerspace. Leveraging the resources available in the makerspace, the faculty has integrated making projects and activities into two cornerstone engineering design courses, at the first- and second-year level. Both courses are client-centred and prototype-based. The students work in groups and get an opportunity to work with a real client from the Ottawa community. They meet with their client several times during the semester to determine their needs and receive feedback based on their conceptual drawings and prototypes. Teams are expected to generate three prototypes, with the final prototypes judged by external judges on the faculty's Design Day. All CEED facilities are leveraged in these courses, so the students learn about the different equipment in their labs. The uOttawa projects are usually biomedical, mechatronic, civil, or software in nature. They can include mechanical, electronic, hardware, and software parts. Depending on the type of project they are doing, students will use different equipment and tools in the makerspaces.

This thesis contributes to the growing academic literature on the Maker Movement's influence in education by providing a case study for the integration of making activities and projects into the formal engineering curriculum. Moreover, it contributes to the literature on authentic learning environments by identifying elements that engineering educators can consider when designing educational interventions aimed at offering students an authentic engineering experience using making activities and resources.

## 1.8.Structure of the thesis

Chapter 1 introduced my motivation to study the integration of the making projects and activities to engineering design education and the Maker Movement's societal impact. The chapter also discussed learning in the context of making and makerspaces. A review of the criticism that have been directed at the Maker Movement and the discourse around it have also been addressed. The chapter also introduced the setting where the research project was conducted. A problem statement was provided which addressed understanding students' learning experiences in maker-oriented cornerstone design courses and exploring the impact of certain factors on their learning and achievement. Chapter 1 also included a discussion on the significance of the research to the engineering education literature.

The next chapter introduces the theoretical framework by which the studies were conducted. A review of the literature on authentic learning and its' historical and theoretical backgrounds. Chapter 2 also includes a discussion of the features of authentic learning environments. The chapter also discusses making as an approach to learning. Chapter 3 presents the first study that addresses the first research question. The chapter begins with addressing the research design and conceptual framework of the study. Next, the methodology used in conducting the study is discussed. The chapter includes a detailed discussion of the study's research questions, participants, and data collection and analysis procedures. The chapter then presents findings of the study, and a discussion of the findings and their implications to engineering educators. Chapter 4 presents the second study which addresses the second research question. The chapter begins with a discussion of the background of the student characteristics considered for predicting students' learning in the course. The methodology by which the quantitative study was conducted is also addressed. The results of the statistical data analysis to answer the research question is presented. Then a discussion of the findings of the study is presented. Chapter 5 presents a synopsis of the studies conducted and connects their findings and implications to necessary future research efforts required to fill other research gaps in the literature about making with an engineering design context.

# Chapter 2 Theoretical framework

The research in this thesis explores the authenticity of the learning environment created by integrating making projects and activities into engineering design courses and studies the impact of certain non-cognitive abilities on students' learning and academic success in these courses. To answer the research questions and guide the research design, I review the literature on authentic learning and the learning theories behind this pedagogical approach. This chapter provides a definition of authentic learning and discusses constructivist and situated learning theories, which provided me with the guiding theoretical framework for the studies in this thesis. I then discuss features of authentic learning environments and making as an approach to learning. I conclude this chapter with a discussion of the research conducted for this thesis.

## 2.1. Authentic learning

Authentic learning is defined as a pedagogical approach that situates learning tasks in real-world environments and, in doing so, provides opportunities for learning that allow students to experience the same problem-solving challenges in the curriculum that they will face in their daily endeavours [1, p. 402]. Examples of authentic learning approaches include personalized learning, project-based learning, and community-based learning [67]. Activities in an authentic learning environment are coherent, meaningful, and purposeful [68]. They reflect the complexity of knowledge and its construction and practice in real life [69], [70]. Authentic learning environments offer opportunities for learners to construct knowledge collaboratively, explore multiple roles and perspectives, access expert performances, reflect on what they are learning, find mentorship and guidance, and articulate their ideas [69], [70]. These learning environments open opportunities for learners to cultivate skills that are difficult to cultivate on their own, such as the judgment to recognize reliable and unreliable information, patience to follow longer arguments, creative ability to recognize relevant patterns in unfamiliar settings, and flexibility to work across disciplinary and cultural boundaries to generate innovative solutions [70].

Moreover, authentic learning environments enable students to practice critical thinking, problem-solving, and public speaking skills [67].

Standards of authentic learning and achievement stem from a belief that education should extend beyond the transmission of isolated facts and skills to enable the development of in-depth understanding and complex problem-solving skills that are valuable to both students and society [71]. Wehlage, Newmann, and Secada [72] developed standards for pedagogy and achievement as a research tool to guide school reform. They define authentic achievement as “intellectual accomplishments that are worthwhile, significant, and meaningful” [30, p. 23]. Their vision for authentic achievement entails the construction of knowledge through disciplined inquiry using prior existing knowledge and striving for in-depth understanding to produce discourse and products that have value beyond success in school.

In the context of engineering education, authentic learning models have been used to replace traditional approaches — which expose students to simple, unrealistic hands-on activities as part of a guided engineering challenge — with authentic approaches that give students opportunities to use industry-quality materials, tools, and resources to solve authentic engineering problems [73]. The use of authentic learning models in engineering design courses also provides ideal opportunities to engage students in authentic engineering communication through meaningful assignments that reflect situations that engineering students might encounter in the workplace [74]. Moreover, in engineering education, authentic learning models are used to provide students with multiple opportunities to deliberately practise their skills on authentic tasks [75].

The word authenticity in the literature of learning and curriculum is used in the context of exploring the nature of learning that assists students in becoming independent contributors to some field or discipline [76]. There has been a lot of debate around the word *Authenticity* and what it means and for whom [77]. Table-1 provides a summary of interpretations of the authenticity of a learning environment in the literature. Authenticity includes the learning of relevant things, isomorphic skills, and accurate information, but it goes beyond these attributes to encompass the context in which such skills and information are appropriately applied to everyday life [78].

There are several views on what qualifies a learning environment to be authentic. One view is that the degree to which learning environments can be considered authentic depends on the similarity of the learning activities to real activities of the target domain. Brown et al. [68] clarify the distinction between authentic and other school activities by defining authentic activities as coherent, meaningful, and purposeful activities that are identified as the ordinary practices of the culture. Another perspective on the authenticity of learning environments comes from Tochon [79], who argues that learning situations can be deemed authentic when they succeed in engaging with the students' lived experiences; authenticity for Tochon lies at the potential associations that emerge from the intersection of students' prior knowledge and experience and their lived experience as they try to capture meaning from their experience. Tochon's [79] view of authenticity focuses on a learner-centred approach, although it might not meet the definition of authentic learning as put forward by Brown et al. [68] or Lave and Wenger [9], who focus on the importance of real activities and participation in a community of practice.

Another view of the authenticity of the learning environment argues that authenticity lies in the learner's perceived relations between the activities they are carrying out and the use value of these practices [77]. Barab et al. [77] argue that the authenticity of the learning environment is a dynamic, emergent process that occurs as the learners engage in activities and practices that are of value to themselves and to others in a community of practice. They also argue that authenticity manifests itself in the flow and interactions among the learner, the task, and the environment [77]. Moreover, they argue for a co-evolutionary model of authenticity that allows the emergence of a learning environment through negotiation of all parties and that is relevant to both the learner and the real-world practitioner. In this model, real-world tasks can apprentice the learner into actual, real-world environments [77, p. 59].

Herrington and Herrington [80] argue that the authenticity of a learning environment is determined through the cognitive authenticity — the promotion of realistic problem-solving — of the learning activities. They argue that authenticity goes beyond mere similarity to real situations. Wang et al. [81] conducted a systematic literature review to critically review conceptualizations of authenticity as principles for design engineering curriculum; they define four types of authenticity discussed in the engineering education and general education literature: context authenticity, which is occupied with creating a context that is similar to daily life experiences; task authenticity, which focuses on situating students in environments that challenge them to make decisions in practical contexts; impact authenticity, which refers to attempts to connect formal learning environments with experiences that have an impact out of school; and finally personal/value authenticity, which tries to situate students in a learning environment that has value to them on a personal level. Impact authenticity is the type of authenticity discussed the least [81].

TABLE 1 - SUMMARY OF INTERPRETATIONS OF AUTHENTICITY IN THE LITERATURE

| Definitions of Authenticity | Relevant research |
|---|---|
| Learning activities need to be similar to those of the target domain to be deemed authentic | Brown et al. [68]<br>Petraglia [78] |
| Authenticity entails learner’s participation in meaningful authentic activities as part of a community of practice | Lave [9] |
| Learning activities need to engage students’ lived experiences to be considered authentic | Tochon [79] |
| Authenticity emerges from the use value of the learning activities to the learner and target practice domain | Barb [77] |
| For learning activities are authentic if they promote realistic problem which entails immersing students in engaging and complex tasks | Herrington [80] |

The need for authenticity in education has led to the development of major theories and pedagogical frameworks, such as the use of simulations, cognitive apprenticeship, and problem-based learning [81]. This need has also led to the adoption of this pedagogical approach in various disciplines, such as engineering education [82], [83], [84], nursing clinical training [85], teacher education [86], [77], legal education [87], literature studies [88], English as a second language [89], translator and interpreter training [90], and various other disciplines. Trends in engineering education to promote the development of professional skills and competences in addition to providing technical instruction have motivated engineering educators to design authentic learning environments [83].

Instructors have been incorporating authentic learning approaches into their curriculum because it increases students' motivation to learn by situating them in a learning environment where they can relate more meaningfully to the material and can gradually be integrated into communities of professional practice [91]. In addition, authentic learning environments bring many other benefits to students' learning, including legitimizing learning by doing [77], exposing students to multidisciplinary problem-solving and critical thinking situations [82], supporting the transfer of knowledge to real-life problem-solving [92], placing students at the centre of the learning environment [81], and encouraging collaboration among students [89]. Moreover, authentic learning environments tend to improve students' attitude and excitement level [77], and they shift the learning process from merely memorizing procedures and facts to learning through first-hand experience about professional capabilities such as personal responsibility, teamwork, ethics, client care, and risk management [87]. In an engineering education context, authentic learning environments can even lead to an increase in retention in engineering schools [81].

## 2.2. Theoretical background of authentic learning

The concept of authentic learning emerged in the late 19th century as a commitment to create a theoretical bridge between the political and economic desirability of making schooling available to the masses and retaining its aura of intellectual elitism [78]. Prior to that, for the most part, western education was seen as a way for learners to be socially and intellectually bettered so they could join a society's elite or be productive [78]. The emergence of the dialogue around the authenticity of learning can be traced to American educational reformers Francis Wayland Parker and John Dewey, pioneers of the Progressive Education Movement. Dewey was influenced by the American school of thought known as pragmatism and contributed significantly to it [78]. He argued that philosophy must be practically useful in people's lives rather than just an intellectual endeavour [93]. Dewey thought of education as the active and continuous processes by which a social group fosters, nurtures, and cultivates its immature members into its own social form; in the broadest sense, he defined education as the means of supporting the social continuity of life [41]. He believed the greatest dilemma that educational philosophy faced at the time was maintaining a balance between formal and informal modes of education [41].

In rejecting the dichotomy between elite-idealist and vocational education [78], Dewey argued that the role of education in a democratic society “is to do away with the dualism and to construct a course of studies which makes thought a guide of free practice for all and which makes leisure a reward of accepting responsibility for service, rather than a state of exemption from it” [3, p. 141]. He wrote that formal education is confronted with the danger of its abstract nature and being remote from real experiences in the world [41]. He also noted that students in traditional schooling systems are treated as theoretical spectators and are too often engaged in absorbing knowledge rather than having fruitful meaningful experiences [41], and he argued that educational institutions should ensure the proper training of youth to enable them to participate in adult practices and professions [41]. In Dewey’s view, school is a special social environment that should present learners with a learning environment that allows them to interact with their natural and social surrounding so they can construct meaning from their learning experience and so what they learn becomes an instrument for further learning [5, p. 148].

Dewey believed learning is a social process through which human beings grow up in a social medium, learn and develop their minds, and redirect and reconstruct accepted beliefs through social intercourse sharing in the activities embodying beliefs [41]. He noted that the “very process of living together educates, enlarges and enlightens experience, stimulates and enriches imagination, and creates responsibility for accuracy and vividness of statement and thought” [3, p. 6]. Knowledge is the result of thinking, which Dewey defined as “the intentional endeavor to discover specific connections between something we do and the consequences which result, so that the two become continuous” [39, p. 151]. For Dewey, thinking is a process of inquiry that starts when things are incomplete, uncertain, doubtful or problematic, leading the thinker to observe these conditions and then form and elaborate on a conclusion [3, p. 80–83].

Experience was central to Deweyan thought [78]. He stressed that even a humble experience is capable of generating and carrying any amount of theory or intellectual content, but when a theory is separated from experience, it is not possible to be comprehended by the learner [41]. Dewey argued against traditional conceptions of experience at the time that claimed experience is beyond logical reasoning, past and given, isolated and specific, subjective, and viewed as an epistemological concept in which the purpose is production and acquisition of knowledge [93]. He argued that there is no conscious experience without thinking and reflecting, and that experience is future oriented and continuous, consisting of a series of connected situations that are part of the objective of the human condition, ontological, and based on the transactional relation between the subject and the world [93].

Dewey argued that giving learners the chance to engage in physical activities, whether for play or work, engages their native tendencies to explore, to manipulate tools and materials, to construct, and to give expressions to joyous emotions. In turn, this engagement reduces the artificial gap between school and life outside school, motivating students to explore more materials and processes and to form cooperative associations to share knowledge in a social setting. For Dewey, the integration of play and work activities into the curriculum creates conditions for the process of "knowledge-getting" to be purposeful [41].

The teacher's role in the authentic learning pedagogical model is that of a facilitator [92]. Dewey's [41] thoughts on education clearly indicate his vision for the role of teachers to control the environment in which the learner acts and hence feels (p. 13). The teacher's mission should be to engage students in activities that allow them to develop their technical skills, receive immediate satisfaction from their work, and prepare them to use these skills in the future; the teacher must also ensure that these activities contribute to the students' intellectual and social development (p. 107). The teacher has to create the conditions that can call the learner's mind to a situation that will present itself outside school, thereby interesting learners and engaging them in activities of ordinary life and occupations; these situations need to be new, uncertain, or problematic and yet sufficiently connected with existing habits to call out a response that can accomplish perceptible results [41]. He noted five conditions for these situations to offer students an educative experience: first, students need to be situated in activities that are continuous and interesting; second, a genuine problem should develop within the situation; third, students should be equipped with the information needed to make observations necessary to deal with the problem; fourth, students should be responsible for developing solutions on their own; fifth, students should have the opportunity to test their ideas through application to make meaning of them and discover their validity [41].

The re-emergence of authenticity as a cornerstone of a social-sciences-informed theory of learning and education can be attributed to the reintroduction of constructivist and situated learning theories in the second half of the 20th century [78], [77], [83], [69], [90]. Constructivist learning theorists define learning as a process of active and rational construction of knowledge [94], [95], while situated learning theory argues that learning occurs in the activities of daily living [96] and the process of becoming a member of a sustained community of practice (CoP) [40].

### 2.2.1. Constructivist learning theory

Conventional learning theories view learning as an unproblematic process by which a learner internalizes knowledge, whether discovered, transmitted from others, or “experienced in interaction” with others, and where knowledge is an integral, self-sufficient substance, theoretically independent of the situations in which it is learned and used [9]. These conventional views of learning create a dualism of mind and body that results in seeing bodily activity as an intruder. In contrast to these theories, constructivist learning theories define learning as a rational and active process of constructing knowledge — whether in the learner’s mind or in the public disciplines of knowledge [94] — that occurs as the learner engages with the world, rather than being a passive recipient of knowledge [97]. Knowledge then becomes everything that is without question and is taken for granted in people’s interactions with one another and nature [21, p.160] and that is gained by meaningful construction, interaction with others, and the use of necessary learning materials in certain social contexts [55], [98]. Vygotsky’s [99] sociocultural theory has contributed to the development of constructivist learning theories; his work recognizes the impact of the social experience on individuals’ thinking and understanding of the world and stresses the importance of focusing on the external social world of the learners to understand their development [100]. Vygotsky analyzed the relationship between learning and development and recognized that learning is necessary for developing culturally organized, specifically human, psychological functions [99]. Vygotsky conceptualized the relationship between development and learning in what he called the zone of proximal development, which he defined as “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” [97, p. 86]. Similar to Dewey, Vygotsky also emphasized the role of everyday experience in learning, although he used the term culture instead of experience; he conceptualized two levels of culture: one that emerges from everyday concepts, and one that emerges from scientific concepts [101].

Savery and Duffy [102] argue that the constructivist learning theory has three main propositions: first, what we learn is a function of the content, context, and activity of the learner; second, the goal of the learner determines “what the learner attends to, what prior experience the learner brings to bear in constructing an understanding, and, basically, what understanding is eventually constructed” (p. 31); third, the social environment is critical to the development of the learner’s understandings and the body of knowledge.

The two different approaches to constructivism are based on the lenses used to view it [103]. The first is social constructivism, which is a theory that views bodies of knowledge or disciplines as human constructs, not object representations of the external world. Social constructivism suggests that the ways in which people form understanding and formal knowledge about their world have been shaped by power, the economy, and political and social factors [103]. The second is psychological constructivism, which is concerned with the development of a learning theory that suggests individual learners actively construct meaning around phenomenon and that these constructions are idiosyncratic and depend on the learner’s past knowledge; it also conceptualizes the construction of a body of knowledge as a rational process of negotiation and dialogue between individuals within groups that results in agreement about a description of a phenomenon [103]. Honebein [104] notes that designers of constructivist learning follow seven pedagogical goals: provide a learning experience that allows students to take primary responsibility for determining the topics or the subtopics in the subject they pursue, the methods for how to learn, and the strategies to solve problems; provide students with activities and problems that expose students to multiple perspectives or alternative approaches to solving problems; provide authentic contexts for learning; encourage student ownership of the learning process and allow students to determine their issues and directions to solve them; provide a learning environment that supports scaffolding and peer learning; use resources that provide multiple modes of representation to offer a rich learning experience; and help students develop self-awareness of their knowledge construction process.

### 2.2.2. Situated learning theory

Similarly, situated cognition and learning theories argue that learning and cognition are fundamentally situated in the activities that produce knowledge and view these activities as an integral part of what is learned [105]. From a situated learning theory viewpoint, activities provide students with experience that is important for subsequent actions [68]. The theory emphasizes the important interdependent roles of activity, concept, and culture in learning and argues that none can be understood without the others [68]. It also emphasizes the role that context plays in establishing meaningful connections between the learner's experience, knowledge, and skill and in providing a framework for learning [92]. Brown et al. [68] perceive learning as a process of enculturation where people, consciously or unconsciously, adopt the behaviour and belief systems of new social groups. Learning then depends on situations and complex social negotiations [68]. From a situated learning theory perspective, knowledge is a product of the activity and situations in which it is produced [68] and continuously evolves with each new situation and activity to a "more densely textured form" [25, p. 33], [40]; knowledge is provisional, mediated, and socially constructed [106], [107] and is embedded in "doing" rather than accumulated [108].

Lave and Wenger [9] use the concept of legitimate peripheral participation as an analytical framework to understand learning. Using their framework, they conceptualize learning as an evolving form of membership in a CoP [9]. Wenger et al. [12] define communities of practice as groups of people who share a passion about a topic, interact on an ongoing basis to deepen their knowledge and expertise, share information, insight, advice, and help each other to solve problems. As learners enter a CoP as newcomers and participate in the practices of the community, they develop their identities, learn, and construct knowledge and develop a sense of belonging and commitment to the CoP [9]. Learners develop and move from being newcomers to old-timers as they move toward full participation in the sociocultural practices of the CoP. Learning from the CoP lens is generated “through the situationally specific actions of members acting in concert, shaped by what the community pays attention to and what it does not, and realized in the negotiated meaning given to practice situations” [107, p. 116]. Learning thus implies becoming a new person and becoming able to participate in new activities, perform new tasks, and master new understandings. In this definition of learning, activities and practices of the community, tasks and functions, and concepts and culture are all interdependent and can’t be totally understood without the other [105], [9]. The relationships between them arise out of and are reproduced and developed within social communities that consists of systems of relations between persons [9]. Learning from this viewpoint becomes neither wholly subjective nor fully encompassed in social interaction, and it is not constituted separately from the social world of which it is part of [9]. In this view of learning, knowing is “a relation among communities of practice, participation in practice, and the generation of identities as part of becoming part of ongoing practice” [106, p.157] and the learners’ engagement in a learning activity entails an extension of their knowledge beyond the immediate situation [110].

From Lave and Wenger’s perspective, there are two types of curricula: a learning curriculum and a teaching curriculum [9]. A learning curriculum consists of situated opportunities for the improvisational development of new practice; it also consists of a field of resources in everyday practice viewed from the perspective of learners. This type of curriculum evolves out of participation in communities of practice and is a characteristic of them. It is through participation in communities of practice that learners realize there is a field or an application for the mature practice of what they are learning to do. Learners learn through participation in the practices of a CoP and adopt the culture of the CoP through legitimate peripherality [9]. In contrast, a teaching curriculum is one that is constructed for the instruction of newcomers.

Collins [11] noted four benefits to pedagogical approaches based on situated learning. First, students learn the conditions in which the knowledge they construct is applicable, allowing them to determine and apply what they learned when faced with new challenges and situations. Second, students learn the uses and implications of knowledge by seeing how it is used in different and real settings. Third, students are encouraged to innovate when placed in learning environments that challenge them with real problems. Fourth, students store knowledge in forms that are usable in novel contexts when the knowledge is learned in the contexts of its uses.

Situated cognition and learning theories draw attention to a number of the limitations of conventional cognitive theories [110]. First, conventional cognitive theories distinguish learning from other human activity and define it as a process of internalizing knowledge. Situated learning theory, on the other hand, does not see a distinction between learning and other human activities. Brown et al. [68] note that learning and acting are indistinct, as they view learning as a continuous, lifelong process resulting from participating in activities and situations [68], [110].

Second, conventional learning theories of cognition assume a uniform body of knowledge is internalized transmitted or transferred and do not address the invention of knew knowledge. In contrast, situated learning theory argues that learners engage in the production of knowledgeability as a flexible process of engagement with the world — it emphasizes the difference in goals, interests, activities, and circumstances of interested parties in terms of what constitutes knowing [110].

Third, situated learning theory acknowledges the heterogeneous, multifocal character of situated activity, as every activity or situation is constituted by different people with different contextual social positions, interests, and perspectives on conflict arising from different locations [110]. These views on the multiplicity of actors engaged in activity together and their interdependencies and relations of power challenge the homogeneity of community, culture, and participants assumed by conventional cognitive theories [110]. This recognition of the multiplicity of the actors in any activity has implications for the study of learning, mislearning, and power conflicts, as researchers are more likely to focus on examining the disagreements and the difference in interests and priorities between the multiple actors in learning environments than on examining the truth or error of some knowledge claim [110].

Finally, conventional learning theories consider mislearning or “failure to learn” to be a result of the learner’s inability or refusal to engage in learning [110]. From the situated learning theory perspective, “failure to learn” or mislearning is socially situated and produced [111] and cannot be understood without considering the interests of all involved participants [110]. From this perspective, failure to learn within formal education systems becomes a problem that is a product of these systems and the social practices of educational professionals who assign learners into socially arranged identities [112]. This view of the “failure to learn” phenomena questions the meaning of “consensus” and “error” and also draws attention to several other factors that contribute to mislearning, such as embarrassment, anxiety, the delegitimization of learning or the learner, and “the retarding effects of denying learners access to connections between immediate appearances and broader, deeper social forces” [108, p. 207].

Another contribution to the authentic learning pedagogy is Hill and Smith’s [113] authentic learning theory. They studied the learning environment of a manufacturing technology course that they described as having all six essential elements of their theory of authentic learning. *Mediation* refers to the use of cultural tools by human beings when engaged in action of various forms. *Embodiment* recognizes that in learning, the body is as central to the activity as the mind; cognition, perception, cultural tools, and action therefore all work together in the learning process. *Distribution* contends that learning is not limited to the individual — rather, it is distributed among others. *Situatedness* recognizes the situated nature of knowledge and cognition discussed by Brown et al. [68] and Lave et al. [9]. *Motivation to learn* refers to the idea that people’s motivation to learn comes from their will to survive as a biological and cultural entity and from signs of value they receive from the surrounding culture. Finally, the *multiple literacies* element recognizes that learners have multiple skills and competencies that can be fostered across a variety of contexts.

## 2.3. Features of authentic learning environments

Herrington et al. [66] conceptualized a framework for the design of authentic learning environments. Their framework proposes that for a technology-based learning environment to be authentic, it has to have nine characteristics: an authentic context, authentic activities, access to expert performances and the modelling of processes, multiple roles and perspectives, collaborative construction of knowledge, reflection, articulation, coaching and scaffolding, and authentic assessment.

### 2.3.1. Authentic context

Situating students in authentic contexts is central to situated cognition and learning theories [68], [9]. The goal in authentic learning environments is to situate students in an authentic context that reflects the cognitive demands of everyday situations, guides the learner to situational resources, presents problem-solving situations related to real-life practices, and supports the transfer of knowledge to real-life problem-solving [92]. Authentic contexts should be comprehensive and reflect the way knowledge will be used in real life [114]. They also need to provide purpose and motivation for learning, as well as a sustained and complex learning environment that can be explored at length [114].

### 2.3.2. Authentic activities

Authentic learning environments need to offer students learning activities that reflect the kind of activities that people do in the real world and that are completed over a sustained period of time [114]. Authentic activities need to be ill-defined activities with real-world relevance [80]. Dewey [41] stressed that students should be presented with problems that are relevant to those of people living together in society, and where observations and information will develop social insight and interest. He explained that this principle is maintained when students begin with “active occupations having social origin and use and proceed to scientific insight in the materials and laws involved, through assimilating into their more direct experience the ideas and facts communicated by others who have had a larger experience” (p. 201). He also emphasized the importance of engaging students in activities with a purpose that exposes them to real knowledge. He explained that exposing students to active occupations introduces them to activities that can tap into their instincts at a deep level and are saturated with facts and principles having a social quality (p. 109). Herrington and Kervin [114] note that authentic learning environments should allow students to explore a resource with all the complexity and uncertainty of the real world; students should have a role in selecting the learning activity and how it is broken down into smaller tasks, selecting which information is relevant to find the proper solution for the problem or project.

### 2.3.3. Access to expert performances and the modelling of processes

Situated cognition and learning theories and, similarly, the authentic learning approach draw characteristics from apprenticship systems of learning [114], [68], [9]. From the perspective of these theories, students and apprentices learn as they gain access to expert performances [68], [9]. For authentic learning environments to replicate learning in real-life contexts, they must provide students with access to expert thinking and performances, allowing students to observe the task before it is attempted, to access the modelling of processes [114]. When students have access to expert performances, learning becomes a process of enculturation, given that when "they have a chance to observe and practice *in situ* the behaviour of members of a culture, people pick up relevant jargon, imitate behavior, and gradually start to act in accordance with its norms" [66, p. 34].

### 2.3.4. Multiple roles and perspectives

Authentic learning environments need to encourage and facilitate students' adoption of multiple roles and perspectives while working on an authentic task or a problem [8]. Brown et al. [68] noted that for students to successfully complete any task, they need to understand the many different roles required to carry out that cognitive task. When students are offered an opportunity to explore multiple roles, perspectives, and ideas, they can learn to explore the problem from the point of view of multiple stakeholders [115], [114].

### 2.3.5. Collaborative construction of knowledge

Situated cognition and learning theories argue that knowledge is socially constructed [68]. Since most complex problems are solved in collaboration among many groups of people, authentic learning environment have to situate students in learning environments that promote collaborative learning [66]. Collaborative learning is defined as an instruction method in which learners at various performance levels work together in small groups toward a common goal [116]. Learning environments that feature collaborative learning result in an "intellectual synergy of many minds coming to bear on a problem, and the social stimulation of mutual engagement in a common endeavor. This mutual exploration, meaning-making and feedback often leads to better understanding on the part of the students, and to the creation of new understandings as well [114, p. 12].

Collaborative learning aims to encourage students to assume responsibility for working together and to build knowledge collectively [118]. In their study of the impact of collaborative learning on students' development, Cabrera et al. [119] found that collaborative learning harnesses the ability of students to advance their personal development, understanding of science and technology, appreciation of the art, analytical skill gain, and openness to diversity. Collaborative learning also creates an environment where preconceptions are confronted through positive, productive interactions between students of different backgrounds. It can also help realize the general education goal of promoting active and responsible citizenship in a democratic society. Moreover, as students work together in groups towards a common goal, they develop leadership and teamwork skills as they learn to negotiate differences, resolve conflicts, and build agreements that honour all voices in a group [117]. Compared with individualistic learning, collaborative learning results in higher achievement and greater productivity, more caring, supportive, and committed relationships, and greater psychological health, social competence, and self-esteem [116].

### 2.3.6. Reflection

Authentic learning environments need to provide students with opportunities that enable meaningful reflection [115]. For students to be able to explore a subject in depth and understand it, they need access to rich learning experiences that can provoke their curiosity and help them identify problems and create solutions using thinking strategies and building habits [120]. Experience alone is not key to learning; rather it is reflection that turns experience to learning [41], [121]. Boud et al. [122] define reflection as the generic term that describes "intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations" (p. 19). John Dewey pointed out the importance of reflective thought on experience by describing how it is the process that gives rise to a distinction between what we experience and how we experience it; reflection implies a concern for the issue at hand and the outcome of the course of events [41]. Incorporating reflection as an element of an authentic learning environment helps students develop thinking dispositions naturally [120], facilitates in-action reflection — as students complete their authentic task or project — through reflective exercises [123], and enhances students' ability to focus during experiential learning experiences when working in group settings, in turn making the group more productive [124].

### 2.3.7. Articulation

Herrington and Herrington [115] note that authentic learning environments need to provide students with opportunities to articulate and argue their ideas and positions. Articulation refers to the act or process of converting a thought or idea into something that is communicable to others [125]. Articulation also entails the process of formation, awareness, development, and refinement of thought [115]. Research from Mercer and Littleton [126] on the impact of dialogue on children's learning provides empirical evidence for the beneficial influence of language-based social interaction on learning. They found that the quality of dialogue between the instructor and the learners and among learners is of significant importance to learning and educational attainment [110, p. 99]. They argue that by “harnessing the power of talk” for reasoning and learning, students are more able to engage sociably and effectively with others and are empowered with the necessary creative reasoning capabilities needed to face the challenges of the future [126].

### 2.3.8. Coaching and scaffolding

Situated learning theory and authentic learning environments need to situate students in learning contexts and tasks that facilitate collaborative learning that enables students to assist each other in constructing meaning and knowledge and where instructors can provide support for students' learning [92], [115]. Wood et al. [124, p. 90] define scaffolding as “a process that enables a child or a novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts.” The concept of scaffolding is closely related to the Vygotskian concept of the zone of proximal development [128], which he defined as the distance between the actual developmental level as determined by independent problem-solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers [112, p.38]. The concept of the zone of proximal development has inspired pedagogical approaches that provide support for tasks that are later performed without assistance [9]. Coaching, on the other hand, involves directing learners' attention, reminding them of overlooked steps, providing hints and feedback, challenging and structuring the ways to do things, and providing additional tasks, problems, or problematic situations [92]. Herrington and Herrington [115] explain that authentic learning environments provide coaching, at critical times, and scaffolding, in which the instructor or more capable peers help students complete the tasks they are unable to complete on their own.

### 2.3.9. Authentic assessment

Assessments of learning outcomes are authentic when they are used to examine student performance in worthy intellectual tasks [129]. Authentic assessment tools require students to use similar competencies, knowledge, skills, and attitudes to complete authentic tasks and projects that are situated in contexts similar to real-life professional environments [66], [130]. These tools also need to be seamlessly integrated with the learning activities [66].

Gulikers et al. conceptualize five dimensions of authentic assessment that can vary in their degree of authenticity [130]:

1. An authentic task allows students to integrate knowledge, skills, and attitudes as professionals do, situates students in complex situations similar to those of professional practice in the domain, and results in the students' ownership of the task and reaching a solution [129].
2. The physical context should reflect the way knowledge, skills, and tools will be used in professional practice [68], [129].

3. The social context should offer students an opportunity to collaborate to reach a solution [66], [130], [129].
4. The result should be either a quality product or performance that can allow the student to demonstrate their abilities in the relevant competencies and to share their work with other people [129], [130].
5. Criteria and standards should give students a clear understanding of how their performances will be judged [130].

Authentic assessment tools have positive impacts for students and teachers because they provide students with more clarity than traditional assessment tools provide about their obligations [129] and offer them an opportunity to use thinking processes that are used by experts to solve problems [130]. Authentic assessment tools also give teachers more confidence in their assessment tools by providing meaningful and useful results for improvement [129] and ensuring that the tools used to measure students' learning reflect the competencies that need to be assessed [130].

### 2.4. Making as an approach to learning

Hands-on, practice-based learning is not foreign to engineering education. As recently as the middle of the 20th century, engineering education was based on practice, and engineering curriculum consisted of machine shop, drafting and surveying classes, and apprenticeship learning [131], [132]. Changes after the Second World War to how research in engineering was funded and to the questions engineers were tasked with answering [132], along with experiences during the Second World War that revealed gaps of knowledge that engineers had when compared with physicists in relation to solving unusual problems [133], influenced several changes in engineering education, including a shift from a hands-on and practical emphasis to an engineering science and analytical emphasis [131], [134]. For some time, engineering educators were a mix of older distinguished engineering practitioners and younger engineering scientists, but by the 1970s, as older practitioners retired, they were replaced by engineering scientists [131].

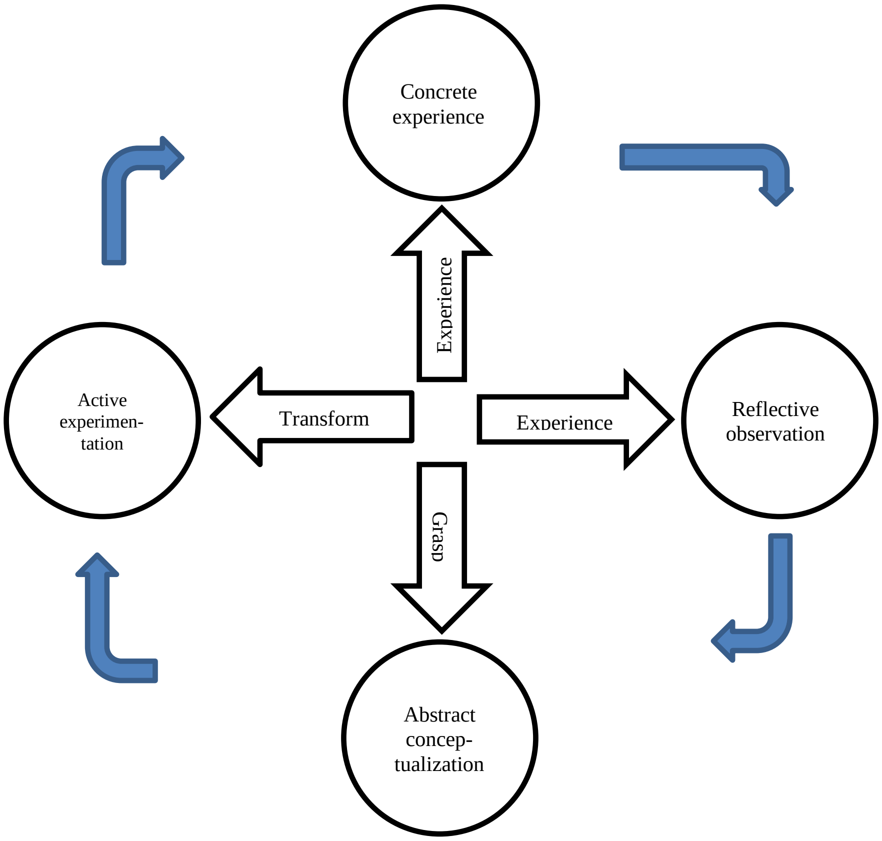
In the past couple of decades, however, there has been a growing interest in better preparing engineering students for their professional life in the 21st century. Among these efforts are those aimed at reforming the curriculum to provide more experiential and active learning and providing students with integrated learning experiences that "lead to the acquisition of both disciplinary knowledge, personal and interpersonal skills, and product, process, and system building skills" [114, p. 22]. Making activities present a unique opportunity for engineering educators to reintegrate experiential learning opportunities into the engineering curriculum [135], [136].

Making as learning approach is not a new phenomenon. Learning theories such as Lave and Wenger's situated learning [9], Dewey's pragmatism, and Papert's constructionism [31], [28], [29] have stressed the importance of situated experience and practice in learning. Constructionism stems from Piaget's constructivist learning theory [28] and is linked to Dewey's learning theories that frame learning as a process of constructing knowledge through the act of making [55] and the product of play, experimentation, and authentic inquiry [29]. Constructionism is also linked to Brown et al.'s [68] and Lave and Wenger's [9] situated cognition and learning theories, which argue that knowledge and learning is situated in the activities and situations in which they arise [137]. Constructionism extends constructivist learning theory by looking at how learners construct meaning, understanding, and knowledge as they build external artifacts [138], [139]. From the constructionist perspective, as learners use media, tools, and technologies, they build literacies and relationships with each other, with the tools they use, and with knowledge, all in the process of designing or making an artifact [140], [137].

Stager [55] notes that the Maker Movement's emphasis on learning through direct experience, hands-on projects, and tinkering signals its link to constructionist learning — even if its members are not aware of the relationship. Makers engage in tinkering activities that are defined as playful, exploratory, and iterative processes of working on or engaging with a problem or a project without a clear goal or purpose [31]. Makers take a bottom-up approach, where they start by exploring materials until a goal emerges from their playful explorations, or where they might have a goal but not a roadmap of how to reach a solution. They therefore continually experiment, iterate, and adapt, with multiple plans based on their interactions with the materials and/or the people they are working with [31]. Moreover, learning while engaging in making activities is deeply embedded in the experience of creating something shareable beyond the thoughts and ideas of the maker [1], [55], an idea that falls in line with constructionist learning environments that allow students to construct, share, and collaboratively reflect on external artifacts [138].

Making as a learning pedagogy also resonates with experiential education because it facilitates hands-on, iterative, and self-directed learning [31], [62]. The American organizational psychologist David Kolb developed a firm theoretical basis for experiential learning that shows how experience is translated into knowledge through reflection, and how this knowledge is used for active experimentation and the choice of new experiences [141]. Kolb defined experiential learning as “the process whereby knowledge is created through the transformation of experience” [142]. He conceptualized experiential learning theory as a dynamic view of learning based on “a learning cycle driven by the resolution of the dual dialectics of action/reflection and experience/abstraction” [143]. This learning cycle consists of four adaptive learning modes: concrete experience, reflective observation, abstract conceptualization, and active experimentation [142]. The learning cycle describes how concrete experiences form the foundation for observations and reflections, which are assimilated into abstract concepts from which new implications are drawn. Learners then actively test these implications and use them to guide their new experiences [143]. Figure 1 presents Kolb’s experiential learning cycle. Learning arises from the tension between the four modes of the learning cycle [142].

FIGURE 1 - KOLB'S EXPERIENTIAL LEARNING CYCLE [139]



Making's relationship to situated learning theory can be observed in a makerspace context as makers learn through participation in a community of practice of makers and move to become full practitioners through legitimate peripheral participation [29]. Situated learning theory argues that learning is an integral part of social practice in the lived-in world [9]. The theory is based on apprenticeship learning and uses the concept of legitimate peripheral participation to explain how a learner moves from being a novice to an expert in a community of practice through an enculturation process as they participate in the practices of the community [138]. In their study comparing three makerspaces, Sheridan et al. [139] found that makers learn as they engage in a community of practice of makers where the broad activity of making becomes the main domain. Learning through making reaches across the divide between formal and informal learning, pushing educators to think more expansively about where and how learning happens [29]. Learning in a makerspace provides a diverse set of learning arrangements: formal learning opportunities can be observed in the form of workshops and equipment training, while students explore creative opportunities and useful communal resources; and informal opportunities for learning can be observed in personal and collective projects [139]. Sheridan et al. [139] note that these learning opportunities represent multiple entry points for participation in a multidisciplinary learning environment, which makes the learning environment more authentic [139]. Makers seek valuable and meaningful problems and use tools, materials, and resources to investigate viable solutions, representations, and innovations — all of which is in line with situated learning and cognition theories in terms of situating learning in authentic contexts [137].

Constructionism and situated cognition share several characteristics, such as their focus on the authenticity of the learning environment, their encouragement of students' ownership of the learning environment, and their focus on project outcomes rather than tests. But they also differ in a number of ways. Situated learning theory emphasizes community-centred learning environments that engage students in activities with well-defined goals that measure the learners' success through their transition to a full membership. Constructionist learning theory, on the other hand, emphasizes learner-centred environments that engage students in activities with ill-defined goals and that measure the learners' success by their development of emergent skills [138].

In a making context, students explore a phenomenon, test ideas, and respond to feedback from other makers as they work to create an artifact. As their creations change over time, their thinking and understanding of the subject and material evolves [144]. Learning in a making context deepens the learners' engagement through active participation, increases student motivation through the purposeful and evolving pursuit of an idea, promotes innovation by facilitating students' exploration of new tinkering strategies that emerge through exposure to and play with tools, materials, and phenomenon, and increases solidarity between learners as they collaborate to design and create artifacts and share their work with other learners [144]. Litts [137] studied youth makerspaces to explore empirical evidence of learning in a makerspace context and found that makers use multiple disciplinary practices, technical skills, and domain expertise in their making process and design stances through their making products. She also found that makers used valued practices from well-established fields such as brainstorming, iterating, and communicating [137]. Moreover, she found that youth makers used technical skills and domain knowledge throughout their making processes [137].

## 2.5. Research for this thesis

The two studies discussed in this thesis contribute to the research gap in the integration of making curriculum into formal education settings and to the lack of empirical studies — especially quantitative ones — of the impact of making on learning outcomes. This research sheds light on the integration of making activities into formal engineering curriculum and will help guide educators in adopting making activities. In doing so, it addresses the concerns Blikstein [22] has raised about the Maker Movement being a technological trend similar to laptops, tablets, and video-based learning.

The guiding conceptual framework used to answer the questions posed in this thesis rely on Lave and Wenger's situated learning theory and Herrington et al.'s [66] authentic learning framework. Both fall under the constructivist learning theory umbrella, which argues that learners construct knowledge. Maker education provides educators with an opportunity to design learning environments based on situated learning and constructionist learning theories. A few studies have described the integration of making activities into engineering curricula. One study explored how making activities are integrated into courses at the Faculty of Engineering at Arizona State University. In a robotics course, students created a robot using a kit they purchased, and in an engineering statistics course, students created physical or media-focused artifacts that could provide context to their understanding of practical statistics [145]. In an interesting approach to the integration of making activities into engineering curricula, Texas A&M University at Qatar has integrated making activities into the technical writing component of its curriculum by asking students to develop a prototype in an area of engineering design using rapid prototyping tools and then complete several writing and communication assignments, in an effort to provide problem-based assignments that make the technical writing course more relevant and prepare students for their capstone course [146].

The introduction of maker activities and maker pedagogies in engineering education is an especially promising innovation in teaching [135], [27], [147]. Integrating making activities into formal educational settings helps to create learning environments that place learners at the centre of the learning process as they turn from passive consumers of knowledge into producers. Making activities also help increase students' self-efficacy [27] and interest in STEM fields [4]. Moreover, making activities provide a powerful context to introduce real-world problems into the engineering curricula [135] and integrate the socio-emotional and disciplinary dimensions of learning [4]. Furthermore, the incorporation of a maker curriculum into engineering education gives students an opportunity to participate in problem-solving, programming, design, and fabrication activities [27], exposes them to design-based activities that teach digital literacy and design thinking, and supports students' ability to deal with failure and engage in the reflection and iterative processes that are integral to design projects [148].

Despite the enthusiasm for the integration of making activities into education and the growing body of research on the opportunities making activities provide for engineering education, there has been little research on the development of making programs in engineering, and there remains a need for a more in-depth analysis of students' learning experiences with making activities in formal educational contexts [27], [59]. The rise in the number of makerspaces in university campuses, coupled with the increasing interest in incorporating making activities into engineering curriculum, led me to conduct two studies that can help engineering educators better understand the impact of these activities on students' learning. The first study in this thesis examines if the incorporation of making activities and projects in introductory engineering design courses creates conditions that open possibilities for authentic learning of engineering design. The second explores the impact of certain non-cognitive abilities on students' learning outcomes in engineering design courses based on making projects and activities.

In the coming chapters, I discuss the authenticity of the learning environment of introductory engineering courses based on making projects and investigate students' success in these courses. To answer the dissertation's research questions I conducted a qualitative and a quantitative research studies. Qualitative research methods aim to achieve deeper understanding of a phenomenon, culture or a group and produce rich and valuable data that reveal and leave the study participant's experience and perspectives intact [149]. Quantiatiave research methods explore social variables to predict a social phenomenon and produce factual, reliable outcome data that can be generalized to a larger population [149]. Combining both methods results in reaping the benefits of each research method and neutralizing their weaknesses [150]. Moreover, utilizing both qualitative and quantitative methods helps in gaining a deeper understanding of the learning environment constructed by integrating making projects and activities to engineering design courses.

In both research studies, my view of the authenticity of the learning environment is similar to the description from Barb et al. [77]: that and authentic learning environment requires the learners' buy-in, and that it is an emerging process that occurs as learners engage with learning activities that are valuable to themselves and to a community of practice. I also take into account that for learners to consider the learning activities valuable, the learning environments have to engage the learners in complex, multidimensional problems that have real-world relevance and clear applications [151].

## 2.6. Summary of Chapter

Chapter 2 began by introducing and defining the authentic learning model and explored its application in an engineering education context. Then, the historical and theoretical background of the authentic learning model is discussed. A brief background of constructivist and situated learning theories was discussed in this section. Next, features of authentic learning environments were introduced. Moreover, a discussion of how making activities relate to constructivist and situated learning theories followed. Finally, the theoretical framework used to answer the research questions in this dissertation was discussed.

## Chapter 3 The integration of a maker program into engineering design courses

This chapter addresses my first research question. I explore if the introduction of making projects and activities into engineering design courses creates conditions that open possibilities for authentic learning of engineering design. Further, I seek to understand the challenges that students face in courses that have successfully incorporated making projects and activities. I discuss my research design, conceptual framework, research questions, methods, and validity. I then proceed to discuss the findings of the study.

### 3.1. Research design

The research addressed in this chapter has two aims. First, to understand engineering students' learning experience in an environment structured around making projects and activities. Second, to identify challenges and any unique phenomena that students experience through their participation in this learning environment. The purpose of the study is to provide engineering educators with field research about the integration of making projects and activities into engineering curriculum that could improve their educational practices and programs. On a personal level, as an engineer myself, I wanted to engage with engineering students to understand their own thoughts and ideas about their experience in engineering school.

To achieve these goals, a qualitative research methodology was used in answering the research questions. Qualitative research is a "situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that make the world visible. These practices transform the world. They turn the world into a series of representations, including field notes, interviews, conversations, photographs, recordings, and memos to the self" [149, p.225]. Qualitative research helps us deepen our understanding of how things work and the rich complexity of a phenomenon, how it is understood and experienced by multiple respondents, how it interacts with other factors and issues in their lives, and how and why the same events can be viewed differently by multiple stakeholders [153]. Mertens [152] noted two possible reasons for working with qualitative methods. The first is the researcher's view of the world. she noted three paradigms that warrant the use of qualitative methods: constructivist views, transformative views, and practical views. The second reason relates to practical reasons that might require the use of qualitative methods. These reasons include the nature of the research question, when the program understudy is based on humanistic values, when no reliable and proper quantitative method is available to achieve the research goals, and when the researcher wants to add depth to a quantitative study [152]. The types of research questions that might require a researcher to use qualitative methods are:

- When the aim of the research is to explore a process, implementation, or a development of a program
- When detailed, in-depth information is needed about people or programs
- When the research focuses on diversity among, characteristics of, or qualities of people
- When the research tries to understand participants' beliefs or actions [152]

Maxwell [154] describes five intellectual goals and three practical goals that qualitative research can help achieve. The intellectual goals include understanding participants' perspective of events, experiences, situations, and actions that are evolved with or engaged in; understanding the particular context in which participants exist and act and its influence on their actions; understanding the process by which events and actions unfold; generating new theories and identifying unanticipated phenomena and influences; and developing casual explanations for processes, events, and actions that are developed from field research. The practical goals that qualitative research can help achieve include generating results and theories that are understandable and experientially credible to the participants and the research's audience; conducting research that aims to improve existing practices, programs, or policies; and engaging in active, participatory, collaborative, or community-based research [154]. Moreover, qualitative research has an additional advantage over quantitative research in that its flexibility permits the researcher to follow leads that emerge throughout the data collection process [155].

In this study, the researcher's world view is a constructivist one where learning is viewed as an active and rational process of constructing knowledge as the learner is engaging with the world [97]. Also, the research questions addressed in this study aim to generate an in-depth understanding of students' learning experience within an educational program – cornerstone engineering design courses based on making projects and activities. For all these reasons, a qualitative study design seemed to be the right approach to accomplish the goals of my study.

### 3.2. Conceptual framework

I ground my work in the learning theories discussed in Chapter 2 that view learning as a process of social construction of knowledge [106], [107]. Here, I conceptualize students' learning of engineering design as a process of constructing new ideas, thoughts, and experiences about engineering design through their interaction with peers, instructors, clients, members of the making community of practice, and most importantly making tools and activities that the learning environment situates them in. From this conceptual stance, I hypothesize that making as an educational activity that can help engineering educators design authentic learning environments.

The purpose of this research is to explore the use of making projects and activities as a vehicle for designing an authentic learning approach to teaching and learning in engineering design at the first- and second-year levels of an engineering program. Authenticity in the context of this research is conceptualized as an emergent process that requires the learner's buy in and participation in activities that are valuable to themselves and to a community of practice. I explore students' learning experience in the course through a qualitative study that identifies what students learned in the course and what challenges they faced. Ultimately, my hope is to improve the courses and assess the value of integrating making activities into the engineering curriculum.

### 3.3. Research questions

To answer the first overarching research question in this thesis (Does the integration of making projects and activities into cornerstone engineering design facilitate the design of authentic learning environments?), this chapter addresses two guiding research questions:

1- Does the introduction of making activities and projects create conditions for an authentic learning environment of engineering design?

2- What challenges do engineering students face in a learning environment based on making projects and activities?

### 3.4. Methods

To answer the study's research questions, I use grounded theory methods, which allowed me to explore my ideas about the data through analytic writing from the beginning of the study and helped me direct, manage, and streamline data collection and construct an original analysis from the data [155]. Grounded theory methods present systematic yet flexible guidelines for collecting and analyzing qualitative data to construct theories that are "grounded" in the data themselves [155], [156]. In qualitative research, the researcher is the data collection instrument [23, p. 247] and the relationships the researcher develops with the participants are the means by which the research gets done [154]. Hence, prior to the discussion of the methods used in the study in detail, the reader deserves to know the identity, interests, and motivations of the researcher and author of this dissertation, who conducted the interviews, and the nature of the relationships I developed with the participants of the study. As a doctoral candidate, I have done research on establishing makerspaces in engineering schools and their impact on forming student-maker communities of practice, and this research led to my interest in understanding students' learning experiences and challenges in engineering courses that have successfully integrated making projects and activities. Eventually, I aspire to provide research that can help engineering educators integrate making programs into their curriculum by providing an in-depth understanding of students' learning experiences and challenges in courses that have successfully integrated a making program into undergraduate engineering courses.

I followed several strategies to address any biases. First, I created and followed interview protocols for all the interviews I conducted with the students. Also, interview transcripts were shared with the participants of the study. To ensure the credibility of the study and address biases resulting from my own experiences, I conducted debriefing sessions with my supervisor and with another professor of engineering design at the University of Ottawa to discuss my notes and observations from my interactions with the students. Furthermore, I introduced myself to the participants as a researcher helping the makerspace student management team. I explained to the students that my work aims to improve the course under study and students' learning experiences in the makerspace. I also explained to the participants that I am not a member of the course's instruction team and that their participation in the study would in no way affect their performance in the course. When I started the study, I did not know any of the participants, and I planned to interview the students on a weekly basis and establish a relationship in which they would be able to share with me the details of their learning experience and progress in the course. As time passed during the semester, my relationship with the participants evolved to a friendly advisory relationship. As they worked to complete their projects, they would share with me their frustrations with the course under study and with other academic or university commitments. I often directed students to access the resources available to them, namely, resources in the makerspace or members of the course's instruction team. This kind of relationship allowed students to feel freer to share their feelings, experiences, and ideas with me.

In introducing myself as an alumnus of an engineering school and as a professional engineer, I tried to establish grounds for a relationship between me and the participants in which they could share their excitements and frustrations about being engineering students. The relationship I tried to build with the participants was similar to what Milligan [157] describes as an "inbetweener," where my identity as I started showing up at lab sessions to interview the students in the makerspace was given to me by the student community. Students and teaching assistants alike knew that my presence in the makerspace as they were working on their making projects was for research and course improvement purposes. McNess et al. [158] argue that the location of the researcher relative to the researched — whether the researcher is an outsider or an insider — relies constantly on the evolving life of the researchers, their perception of the world, academic scholarship, their previous experiences, and their prior knowledge and interpretation of what they see and experience of the context to be researched. They note that researchers are neither complete observers nor complete participants, but often working in that "third space" in between, as they are both inside and outside the learning environment and inside and outside the phenomena under investigation [153, p. 311]. In building this kind of relationship with the students and the instruction team, I was able to develop a relationship between myself and the students based on trust and friendship [157].

### 3.4.1. Participant selection

Sampling for qualitative research depends on three principles: the researcher's techniques and skills at collecting data; the ability to locate ideal participants who have been through, or observed, the experience under investigation; and the use of targeted and efficient sampling techniques that help the researcher seek the best examples of the phenomenon they are studying [159]. In conducting this study, I wanted to explore engineering students' learning experience in a course based on making projects and activities, hence it was critical to the success of the study that the students who were invited to participate could help me understand the learning experience of engineering students with different backgrounds so that I would be able to gain insight into the kind of learning that different students achieve in a making context. For this reason, I used purposive sampling as my sampling technique, as it allowed me to invite participants to the study according to their knowledge and the type of information needed to answer the study questions [159].

Purposive sampling is useful in situations where one needs to reach a targeted sample quickly and where sampling for proportionality is not the primary concern [153]. In conducting this study, I had limited time to select the sample I would be observing and following during this course. Teams form by the second week of the course, and students start learning and working on their projects immediately. Also, to include and examine the learning experience of various engineering students, I used heterogeneity sampling, a type of purposeful sampling technique used when the researcher aims to include all opinions or views [153]. The sample design was constructed to represent the diversity of the engineering student population at the University of Ottawa, with teams selected to be diverse in terms of their engineering discipline, gender, and academic achievement as measured by the students' self-reported cumulative grade point average (cGPA).

The course selected for this qualitative study was the second-year cornerstone design course. The course was offered in several sections, as hundreds of students register for the course every semester. Each section had a different instructor who gave a weekly lecture, as well as two weekly lab sessions. The section chosen for this study was selected because the instructor, Dr. Hanan Anis, is also my PhD supervisor.

The course's instructor allowed me to attend labs and meet with students as they were building their prototypes. I chose to follow the Tuesday lab session because it fit with my schedule. I started attending the lab session in the second week of the semester, as soon as the students had formed their teams. The Tuesday lab session had four teams. I informed the students of the purpose of my study, the type of data collection processes that I would be conducting during their lab time, and the confidentiality and anonymity of their participation in the study. I assured students I would share recordings or transcripts of the interviews I conducted during my study with them. The course's teaching assistant and project manager were in the lab as I was presenting my study to the students in the selected lab section. I then proceeded to administer an initial survey of all students in the lab section (n = 18) asking students their name, gender, previous engineering design course experience, identification as makers, year of study, and engineering discipline. Table 1 presents the demographics of the students in the lab section. Of the 4 teams (18 students) in the lab session, I decided to follow 2 teams (n = 7), (female = 3; male = 4). I limited the sample to teams in one lab section because different lab sections have different teaching assistants and project managers, and I wanted to make sure the instruction team was consistent for all the participants of the study. The initial survey questions are presented in Appendix A.

The participants selected for this group were chosen to represent the disciplines available in the Faculty of Engineering. I chose students from both genders, from the first- and second-year programs, and from different engineering disciplines. I also considered students' identification as makers to understand the experience of those who identify as makers and those who don't. I also wanted to make sure the sample varied in terms of academic performance to understand if the learning experience in the course is similar for students with high and average academic achievement. I conducted the interviews and discussions with students during their lab hours in the MakerLab. Table-3 provides a summary of information from the initial survey about the students selected to participate in the study.

TABLE 2 – DEMOGRAPHICS OF THE STUDENTS IN THE LAB SECTION CHOSEN FOR THE STUDY

| Variable | Category | Frequency |
|---|---|---|
| Maker identity | Yes | 12 |
|  | No | 6 |
|  |  |  |
| Prior engineering design training | Yes | 15 |
|  | No | 3 |
|  |  |  |
| Year of study | First year | 1 |
|  | Second year | 15 |
|  | Third year | 1 |
|  | Fifth year | 1 |
|  |  |  |
| Engineering discipline | Computer engineering | 1 |
|  | Civil engineering | 12 |
|  | Chemical engineering | 2 |
|  | Bio-medical engineering | 1 |
|  | Electrical engineering | 1 |
|  | Mechanical engineering | 1 |

Team Mystique:

The first team I followed was working on a project as part of the Make-a-Wish foundation, a program that aims to realize wishes for children with critical illnesses. The team chose to work on a project that asked them to create a guitar that would allow a girl who is paralyzed on one side to learn how to play the guitar. The technologies involved in creating the device included microcontrollers, programming, computer-aided design (CAD), and 3D printing. The students knew each other, and all four of the team members were high-achieving students who told me they chose to work together because they trusted each other to commit to the project work.

- Lisa (all names are pseudonyms): a second-year civil engineering students who had taken the first-year cornerstone design course in her first year of study at the Faculty of Engineering. Lisa did not share her cumulative grade point average (cGPA) with me. Lisa registered for the course because she had enjoyed the first-year cornerstone course and because her friends were going to take the course, so she could pick her own teammates.

- Dean: a third-year software engineering student who had also taken the first-year cornerstone design course in his first year of study at the Faculty of Engineering. Dean reported a cGPA of 9.40 out of 10. Dean had not completed his second-year elective course, and so he chose this course as an elective because he had enjoyed the first-year cornerstone design course and he wanted to work with John, since they had worked together in the previous cornerstone course. His learning goals were that he wanted to develop his electronics and programming skills with hands-on experience.
- John: a second-year civil engineering student who had taken the first-year cornerstone design course in his first year of study at the Faculty of Engineering. He reported a cGPA of 8.00 out of 10. John wanted to improve his technical skills, learn how to put things together, and improve his computer-aided design (CAD) skills.
- Nora: a first-year engineering student who had transferred from the Faculty of Sciences to the Faculty Engineering this year and registered for both cornerstone design courses at the same time. Nora did not share her cGPA with me. Nora had no expectations walking into the course. Her motivation to take the course was because it was part of her program. She did, however, want to learn about 3D printing and about designing and creating an object.

Team Sunday Funday:

The second team I followed was working on creating a wheelchair assist device that would help a wheelchair user to self-propel herself using the device instead of using her arms. The technologies involved in creating the device included microcontrollers, programming, and 3D printing/machining. The students chose each other because they were friends.

- Oscar: a second-year civil engineering student who had taken the first-year cornerstone design course in his first year of study at the university and reported a cGPA of 7.8 out of 10. Since

Oscar had already taken the first-year cornerstone design course, he knew what he was signing up for. He expected to learn a lot and thought the course would teach him to "put yourself in other people's shoes."

- Tim: a second-year civil engineering student who had taken the first-year cornerstone design course in his first year at the Faculty of Engineering. Tim reported that his cGPA was 6.8 out of 10.
- Anna: a second-year mechanical engineering student. She had never previously participated in any design course. Anna did not share her cGPA with me.

Students had two options to choose from as their elective course for this semester, and they chose this course over Engineering Economics because they thought they would learn a lot while helping someone. They also indicated that they did not like the scheduling of the other offered course, which had a three-hour evening lecture.

TABLE 3 - PARTICIPANTS' RESPONSES TO INITIAL SURVEY

| Participant | Gender | Year of Study | Engineering Discipline | Past Design Experience | cGPA |
|---|---|---|---|---|---|
| Team Mystique | | | | | |
| Lisa | Female | 2nd Year | Civil Engineering | Yes | Didn't share |
| John | Male | 2nd Year | Civil Engineering | Yes | 9.4 |
| Nora | Female | 1st Year | Biomedical Engineering | No | Didn't share |
| Dean | Male | 3rd Year | Software Engineering | Yes | 8.0 |
| Team Sunday Funday | | | | | |
| Ana | Female | 2nd Year | Mechanical Engineering | No | Didn't share |
| Oscar | Male | 2nd Year | Civil Engineering | Yes | 7.8 |
| Tim | Male | 2nd Year | Civil Engineering | Yes | 6.8 |

### 3.4.2. Data collection

I collected the data reported in this study over the course of the fall semester of the 2018-2019 academic year. I conducted seven semi-structured interviews with each team. Semi-structured interviews are a qualitative method of interviewing used when the researcher knows enough about the topic and domain to identify the interview questions [160]. They consist of a series of questions the interviewer plans to ask that the participant may respond freely to, along with further questions that arise from the participant's responses to the question stem [160]. The semi-structured nature of the interviews allowed for conversations that helped students reflect on their experiences in the course and discuss how their projects were progressing. The total time for these interviews was 100 minutes for Team Mystique and 80 minutes for Team Sunday Funday. Interviews were audio-recorded in the campus makerspace and transcribed verbatim in the same week they were conducted. Interview transcripts were shared with the students in each team, and the students were offered the opportunity to make changes or omissions after receiving the transcripts.

In conducting the semi-structured interviews, I followed Charmaz's [155] intensive interview method as the data collection method for the study because it enables an open-ended, in-depth exploration of an aspect of life that is of interest to the researcher and that the interviewee has substantial experience with and insight into [161]. In-depth interviewing is suitable when the researcher is interested in understanding the lived experience of other people and what they make of that experience [162]. The intensive interview method was chosen because it allows the researcher to collect data that go beneath the surface of the described experience, inquire about the participants' thoughts and ideas, revert back to earlier events or discussions in the interview, transition between topics, request more detail or explanation, and clarify the participants' ideas and thoughts to ensure accuracy. Before starting any of the interviews with the students, I created an initial interview protocol that I followed in the first interview. This protocol was modified frequently before the following interview to account for any thoughts or questions that I had after the previous interview or that emerged from the debriefing sessions with my supervisor and the other faculty member. In forming all of the interview questions, I followed the criteria that Charmaz and Belgrave [161] outline for grounded theory interview questions: the interview questions were designed to be open-ended and sufficiently general to cover a wide range of experiences while also narrow enough to allow the participants to discuss their specific experience. Follow-up questions were aimed at exploring students’ experiences and challenges in detail.

Initially, I built rapport with the participants and introduced the study objectives to them. In the first interview with each team, I asked participants to introduce themselves and describe their project choice and how they formed their groups, which allowed students to talk about their personal learning objectives, motivation to work on the project, and past experiences in a collaborative learning environment. I also asked students if the team had a leader and whether they had decided on a plan to distribute the work among each other. Throughout the semester, I asked students in every interview what they thought about their progress in the course, day-to-day activities related to the project, interactions with the client and the course’s instruction team, plans for the project, team dynamics, lessons learned from their project experience, and any challenges they were facing. Asking about these themes in every interview allowed the students to describe their learning experiences as they were going through each phase of the design process. In the last interview with each team, I asked students about the final feedback they had received from their client and the course’s instruction team, their intent to continue working on the project, the lessons they had learned from the course, their identification with engineering design, and what recommendations they had to improve the course.

I followed several strategies and used several types of software to ensure that all audio-recordings, interviews, and memos were kept in an organized system. All interviews were audio-recorded and saved in an external drive. Interviews were transcribed on MS Word, and a copy of the transcription was uploaded to my university account Google Drive. I made sure interviews were properly labelled with the name of the team and the week and date of the interview. Initial notes and memos were written on the document uploaded to the Google Drive. Once the data collection was completed, all interview transcripts were migrated to NVivo software for analysis. Notes prepared for debriefing sessions with my supervisor were created on Google Sheets documents and stored in my Google Drive.

### 3.4.3. Data analysis

Based on the nature of the study question, grounded theory was used as the qualitative analysis strategy [155]. Grounded theory methods allow for systematic yet flexible guidelines to analyze qualitative data to construct theories grounded in the data [155]. I wanted to allow the ways and processes in which students learn emerge from the data rather than make assumptions about their learning process. Grounded theory researchers collect data and analyze it simultaneously from the initial phases of research [161]. I started analyzing the data as soon as I started the interviews with the students. I conducted the data analysis using NVivo software and kept notes on the software, on Microsoft Excel spreadsheets, and on paper. Grounded theory coding consists of at least two phases: an initial phase that involves a close reading of the data collection and analysis, remaining open to all the possible theoretical directions indicated by the reading of the data; and a focused coding phase, where the researcher synthesizes and explains larger segments of data [52]. To analyze the interview transcripts, I started the initial phase of coding using the structural coding method by applying either a content-based or conceptual phrase to segments of data that related to the research questions [163], [164]. Structural coding is useful when semi-structural data collection protocols are used [164]. Structural codes are also helpful to categorize the data and as an initial coding step. Before beginning the structural coding of the interview transcripts, I developed a start list of codes from the main research questions, based on my conceptual framework, on criteria for authentic achievement from Wehlage, Newmann, and Secada [72], on elements of an authentic learning environment from Herrington, Reeves, and Oliver [66], and on general skills I hypothesized that the students would hone as they designed and constructed their project. Then, to break down the interview transcripts into discrete parts and compare them for similarities and differences [164], I followed up with process coding (to indicate simple observable activity or general conceptual action [164]) and in vivo coding (using the words or phrases used by participants as labels for codes to capture the essence of what the participants were saying [165]). Throughout the data analysis process, I constantly refined the codebook as I analyzed the interview transcripts to examine if the codes I had developed fit the study objectives and research questions. Each code was defined to explain what data the code represents [165]. After establishing my final codebook, I conducted a test of inter-coder reliability according to Miles and

Huberman [163, *p.* 64]. I invited a researcher who was a master's student, not part of this study, and new to the codebook to independently code two randomly selected interviews (14% of the data); inter-coder reliability was 84.8%. The final codebook can be found in Appendix C.

I then proceeded to code the data inductively, creating sub-codes and modifying those on the original list. To transition to the second phase of the coding process, I performed code mapping, where I reorganized codes into a select list of categories. To gain insights into my findings and identify patterns and connections in the data, I merged similar codes and created categories of categories to create three central themes:

- Authentic achievement codes: I created this category to understand how students constructed new knowledge and used existing prior knowledge in completing their project, as well as how they articulated concepts and ideas they were learning and what values they assigned to their learning experience (i.e., construction of new knowledge: skills, research, etc.; value: experiential learning, help someone, etc.; disciplined inquiry: articulation, in-depth understanding, etc.).
- Impact of the learning environment on students' skills codes: I created this category to capture all codes that could indicate students' improvement in technical and soft skills. The codes captured in this category included attributes related to problem-solving and design skills (i.e., ideation, dealing with uncertainty, meeting design constraints, reflection, and collaborative and peer learning).
- Challenge codes: I inductively created challenge codes to capture students' perceived challenges in this learning environment (i.e., time management, stress, and communications with the client).

In developing concepts and ideas about the students' learning experience, I looked to build relationships between the data in different categories of codes and compared the learning experiences and challenges of the students in each team. To compare the learning experiences of students in both groups, I compared their progress in the design process of their projects, challenges, time spent on the project, meeting frequency, and project management styles. Finally, I summarized the study codes and findings and discussed them during debriefing sessions. I revised my findings, identified patterns and themes, and discussed the findings in the context of engineering design education. I stopped data collection at the end of the semester before the final exam of the course.

### 3.4.4. Strategies to ensure the trustworthiness of the study

To ensure the trustworthiness of the qualitative study, I employed the strategies outlined by Shenton [167] for the pursuit of a trustworthy study. Shenton [167] proposes strategies that can meet Guba's [168] four constructs for a trustworthy qualitative study: credibility, transferability, dependability, and confirmability.

To ensure the credibility of the study, I used data collection and analysis methods and strategies that are in line with grounded theory. I had familiarized myself with the setting and the teaching environment of the study by conducting several studies in the years preceding this academic year in the makerspace and in similar courses. Despite the use of purposive sampling strategy to select participants in the study, the selection of the lab section was random. Furthermore, the student teams were selected to have the diversity required to represent the population of engineering students and to answer the research question. Moreover, although I used interviewing as the only data collection method because it was suitable to understanding students' learning experience, I also used triangulation of the data sources by conducting the interviews in a group setting and often exploring each student's individual opinion and own experience.

To further ensure the credibility of the study, I used several tactics to encourage the participants' honesty and to ensure willing participation, such as asking participants if they would be willing to be interviewed throughout the semester and informing them that the interviews would be audio-recorded. Written consent was also obtained from all participants in the study. In addition, I had no institutional power over the participants, such as being a member of the course's instruction team or being introduced to the students by a member of the course's instruction team. These tactics helped ensure that only those who were genuinely willing to participate in the study and offer data freely were included in the study [167]. They were also made aware that they could withdraw from the study at any time. When approaching students for each interview, I asked them if this was an appropriate time to conduct the interview and if they preferred another time. The use of a semi-structured interview method allowed me to probe students for detailed data and to ask them about topics and questions addressed in previous interviews to ensure that there were no contradictions in their answers and also to track changes in their responses as they were going through the design and fabrication process of their product. In the debriefing sessions with my supervisor and the other engineering design professor, I was able to discuss my ideas, widen and refine my vision of the data, gain a different look and understanding of the data from instructors of engineering design, and constantly refine the interview questions for the next interview.

To ensure the transferability, dependability, and confirmability of the findings of this study, I have provided a rich description of the context and location of the study, the learning environment, the participants, and the methods used to collect and analyze the data.

## 3.5. Findings

In these findings, I discuss elements of the students' authentic achievement, the impact of the learning environment on their design and problem-solving skills, challenges they faced while working on their projects, and differences between student teams. The analysis is organized by the elements of authenticity in learning experiences.

### 3.5.1. Authenticity of the learning experience

Situating an introductory engineering design course in a making context provided students with a unique and rich learning experience that allowed them to explore various topics from different backgrounds. Through independent and collaborative learning activities, students practised skills, learned new concepts, and improved their level of expertise with a particular technology of interest to them. Team Mystique's making project exposed them to topics such as programming, mechanical systems, computer-aided design (CAD), electronics, and the design of musical string instruments. Team Sunday Funday's project exposed them to the design of mechanical systems. This experience allowed the students to learn about new concepts, seek deep understanding of these concepts, and communicate their ideas and conclusions by creating original physical objects.

The context and the activities that students were situated in helped them practise technical skills such as sketching, 3D modelling and printing, using CAD software, programming, designing printed circuit boards (PCBs), and working with machining tools. These technical skills were not limited to the course's makerspace workshops, as students also had to learn to use extra digital and physical fabrication tools that could help them develop their prototypes. Moreover, throughout the course, students practised concepts and skills they had learned in school. Students used software skills they had learned in previous courses to create sketches and build prototypes. Anna from Team Sunday Funday used her knowledge of mechanical elements design and CAD software from a course she took on mechanical design in the previous semester to make her designs. Dean from Team Mystique used his knowledge of C and Java Script programming languages to build software for his team's product. Nora, the only first-year student among the participants in the study, learned new skills that she had not been exposed to before. In all of the cases above, students learned new skills or applied skills they had studied in school by being situated in a learning environment that forced them to be outside their comfort zone.

> *"Personally, I have gotten a lot better with Arduinos and codes, so understanding how to work with all the different things that you need to keep in mind — the volts, the motors you use and whatnot, but nothing earth-shattering, just like getting more comfortable with stuff that I have known theoretically but never applied"* — A conversation with Dean (Team Mystique) about what he has been learning in the course.

I observed that making activities encouraged students to engage in collaborative and peer learning. Students in both teams worked together to research, brainstorm, discuss, and sketch multiple concepts in the ideation phase. Team Mystique divided their final concept into subsystems and assigned each subsystem to a team member, although the students still helped each other design their respective subsystems. As students were designing their subsystems and making their prototypes, they had to consider the compatibility of their designs with their team members' designs.

> *"Everyone has a system, and we are all kind of helping with each other's systems. It's not like we go off to the corner and do s***. We come back, and we brainstorm together, and we try to work as a group, and we try to talk about the input systems together a lot. A lot of that comes to me as well, since I am programming for the group, so everything has its*

> *inputs and outputs through the Arduino, except for the one cord component, so I have been doing a lot of throwing out of ideas and trying to give the perspective of the programmer — what avenue they are going to take for their designs of the subsystems."*
> — A conversation with Dean (Team Mystique) about his team's work distribution strategy.

On the other hand, Team Sunday Funday worked collectively on their prototypes but did not follow a particular work distribution system. Students often met during the week at a convenient time to work on their project, often assigning tasks at their meetings.

> *"Interviewer: What did you guys do in the past two weeks?*
> *Oscar: We've been meeting doing deliverables, talking about our project,*
> *Interviewer: Is there any system for task distribution that you are following?*
> *Ava: No, and I think we should*
> *Oscar: We just get together and do things, but what we should do is individual things."*
> – A conversation with team Sunday Funday about the distribution of tasks among team members.

Team members who were more experienced with the use of making technologies trained novice students to use tools in the makerspace and helped them with their designs. For example, students in Team Mystique taught each other 3D modelling in CAD, programming, and electronics. Lisa and Dean helped Nora learn how to create a design in CAD software and 3D print an item. Dean also helped John wire electric motors. Students also often exchanged knowledge related to their engineering disciplines with other team members from different disciplines. Project managers — students who work at the makerspace and have taken the course before and demonstrated excellent leadership and technical skills — also shared information about creating prototypes, such as knowledge about mechanical systems and configurations, options for materials and tools to use, and where the students could source the materials required to complete their prototype. They also helped students deal with the stress caused by approaching deadlines and moderated students' expectations of their final prototype. It should be noted that students felt they needed to have a physical item or a concept before they could reach out to their project manager for information or help.

The activities students engaged in to complete their making project allowed them to play multiple roles, as they had to participate in activities where they had to identify and think as interviewers (when they met with their client), as programmers, as designers, as leaders and team members, as engineers, and as problem-solvers. Students also had multiple opportunities to demonstrate their ideas and artifacts to their peers, instructors, and clients using sketches, CAD models, physical prototypes, and presentations.

The values students assigned to their project work were not limited to academic success in the course. Students thought the course was helpful for their engineering careers because it provided them with real design experience that exposed them to hands-on, practical engineering activities. Another value that students assigned to their project was the help they felt they were providing to their client by solving their problem. Team Mystique was motivated to share their design with others online so it could be reproduced. For Team Mystique, completing the project and creating a guitar for their client — Nora's sister — had a personal value, as they were motivated to realize her dream; they felt they had raised her hopes and they had to deliver on their commitment to the extent that they pledged to work and improve their product after the end of the semester.

> *Interviewer: "Why did you guys register for this course?"*
> *Oscar: "Because you choose between this course and [Engineering] Economics, and in this course, you learn a lot and you are helping someone at the same time, so it's a win-win."* — A conversation with Oscar (Team Sunday Funday) about the reasons he registered for the course.

I observed that introducing making activities into this cornerstone design course and situating the course in a makerspace setting provided elements of the authentic learning environment framework [169]. First, the making activities helped the instructor construct authentic context and infuse authentic tasks into their curriculum. Second, making and learning in this makerspace environment was collaborative and offered students opportunities for mentorships and scaffolded learning.

> *"I guess I am learning time management and how to work in a team because a lot of people come from different backgrounds or even programs." — A conversation with Anna (Team Sunday Funday) about what she is learning in the course.*

Making in this makerspace environment also helped the instructor construct a learning environment for students with different levels of expertise, because making technologies offer the makers multiple entry points to the technology. Third, students were situated in a typical engineering environment that exposed them to multiple perspectives where they needed to plan and organize tasks, source materials, communicate with individuals from different backgrounds, and encourage other students to share and articulate their ideas and designs with peers and the world. Fourth, the learning environment based on making activities offered the instructor opportunities to adopt various authentic assessment techniques, such as client, peer, and project manager evaluations.

### 3.5.2. Impact of the authenticity of experience

The making activities that students engaged in throughout the project allowed them to practise skills in a real engineering setting. I observed that students constructed meaning related to the engineering design process, problem-solving, and teamwork.

#### 3.5.2.1. Living the design process

The design problem that students in both teams worked to solve was an ill-defined problem of a real client with an accessibility need from the local community around the university. Students had to empathize with their client's needs to define a problem statement, listen to their client to understand their needs, and uncover design constraints related to their client's requirements, their team budget, the time frame of the course, and their own technical abilities and expertise.

Students developed their concepts at the beginning stages of the project collaboratively, as each member in both teams developed their own sketches and ideas first before the members came together to consolidate their ideas to develop final concepts. Students in both teams then discussed their final concept with their client in their second client meeting. The ideation strategies that students used included research, benchmarking other existing solutions and ideas online, watching videos, talking with their client, and consulting with their project managers. Students sketched their ideas and created a first prototype that was used as a demo to gather feedback on their ideas from their client, then later used to further develop their ideas. They continually redefined their conceptual design as they gained more understanding of the problem and their design constraints.

> *Interviewer: "How did you guys come up with this concept?"*
> *John: "It was a variety of things. When we first heard of the project, we researched. We were studying videos of other things that people have come up with and read articles, and we said, 'OK, we can take some of that and adapt it for this particular situation.' Plus, our own ideas — such as the foot — were adapted from stuff we have seen from other projects that were not related. So, it was an amalgamation of a bunch of different things we have seen before."* — A conversation with Team Mystique about their team's conceptual design.

*"Oscar: We are going to make two ideas: the main one that our client wants and, just in case it falls through, we are going to have a little backup project, and it's a lot simpler. So hopefully we are going to fit them both in time"* — A conversation with Team Sunday Funday about their team's conceptual design.

Prototyping was heavily present in students' discussions of their learning experience. Students constantly created prototypes to visualize and think about the details of their final prototype, to communicate ideas with each other or with the client, to understand how all the elements of their designs fit together, and to keep track of the elements of their designs and their specifications.

As students were going through the continuous process of refining their designs, they reflected on the importance of the conceptual design phase and of considering the manufacturability of their designs and the evolutionary nature of design. Students in Team Mystique said they had not taken the ideation phase of the project seriously, while students in Team Sunday Funday struggled with problem-solving at the ideation phase. At the final stages of the project, students from both teams said they realized there was a relationship between the time and significance they awarded to their ideation and conceptual design phase and the number of iterations they had to go through later in the design process.

*Interviewer: "What are the lessons learned from last week?"*
*Lisa: "To not look down on evolutionary design and just to always be flexible."…*
*Interviewer: "When you say 'we should have done better planning,' what would you have fixed?"*
*Dean: "I think we could have seen some of the pivots that we had to make just by being a bit more proactive there, and I think this is a bit my fault as much as anyone if not more."*
*Lisa: "I want to add to that. We were exceptionally haphazard with the design criteria and conceptual design deliverables. We were like, 'we know what we are doing — we will make s*** up to make it look like we did research and stuff,' where really our research was for show and for the deliverable. I feel like we could have caught some of these issues if we had taken those two specific deliverables a little more seriously."*
— A conversation with Team Mystique about their reflections on their design process.

The making nature of the project also exposed students to the ambiguity inherent in the design process [7], [170]. Students indicated that at the beginning of the design process, sources of uncertainty came from missing information — either from their client or because they felt they lacked the knowledge to build a solution for their client's problem. The latter contributed to the students' lack of confidence in their skillset to meet the client's needs at the beginning of the project and increased their feelings of uncertainty. At later stages of the design process, uncertainty stemmed from challenges in sourcing materials to create prototypes and students' perception of their ability to meet design deadlines. The students coped with uncertainty by constantly seeking information, trusting each other, and developing conceptual designs that could easily be modified to accommodate changes.

> "*We don't have a lot of solid relevant skills and experience, and our uncertainty is really in 'can we physically execute this?' Who knows? Who knows if we will figure it out? But probably, yes.*"
> — Dean (Team Mystique) describing why he was feeling uncertain at the beginning of the project.

#### 3.5.2.2. Solving an authentic problem

The learning experience helped students practise and improve their problem-solving skills by forcing them to encounter and solve unfamiliar problems. This helped them become more comfortable with taking risks and cope with ambiguity by actively defining the problem, seeking information, adapting to changes, managing stress, and using subject knowledge to create solutions.

This approach of providing the students with the autonomy to define their client's problem, to frame their own project's scope, and to constantly revise their concepts and designs — all while gathering feedback from their project manager and their client — increased students' confidence in their problem-solving skills. Engaging students in making activities to create a product that solves a client's real problem encouraged them to empathize with the user of their design, which helped them to define their problem, gather feedback, and work to integrate it back into their designs. It also allowed students to improve their communications skills by learning to communicate their ideas with both technical and non-technical individuals. The interaction with a real client also motivated students to persist to complete their project and find a solution for their client's problem.

The nature of the making project allowed students to develop and practise activities that are similar to those practised by engineers — that is, activities that are complex and both technical and social. Students recognized that solving a problem is a process that requires research, creativity, iteration, teamwork, planning, and reflection. Students conducted research throughout the course to explore existing solutions, set specifications, find answers to the smaller technical questions they were encountering, fill knowledge gaps, learn about the use of certain engineering tools, and search for materials that could be used to make their prototypes. They also constantly used sketching, digital, and physical engineering tools to visualize concepts and create prototypes to present to their class, to their client, and for their final Design Day presentation. I noticed that students with different levels of expertise had suitable entry points to technologies in the makerspace that allowed them to contribute to their team projects. For example, Nora had never built or tinkered with any 3D models, so she used TinkerCAD, an entry-level browser-based platform for 3D modelling known for its simple interface, while Lisa, who had prior experience with 3D modelling and CAD, used the more advanced software Fusion360. Both students were able to contribute to their team's project in a useful way. Other activities that students engaged in included preparing for meetings and presentations with the clients and the project manager, developing concepts and specifications, solving problems, planning, writing reports as part of the course's requirements, procuring supplies, and navigating design constraints.

As students created their prototypes, they were constantly observing, testing, and creating relationships between concepts they knew. They were also learning how to solve their client's problem. For example, John, a second-year civil engineering student from Team Mystique, had to learn about simple electric motor systems to help his team build their second prototype. He researched types of motor systems and learned how to calculate the required power of the electric motor. As he learned about electric motors, he had to test his design and assess its suitability with other subsystems that his teammates were designing. Moreover, as students applied the concepts they were learning, they were constantly challenged to develop a deeper understanding of these concepts and domains of knowledge. Dean from Team Mystique initially thought he was going to use codes available on GitHub (an online software development tool) developed by other software developers and tweak them slightly to run his team's guitar. However, when he came to customize the code to his application, he realized there were too many computational libraries involved to run the code he had found on GitHub on his operating system, which in turn encouraged him to learn more about data transfer between an Arduino microprocessor and a Microsoft or Linux operating system.

Another observation was that students constantly reflected on their progress, the scope of their project, how they were managing their time and the learning environment, and how the course compared with other courses. Reflection was also a critical element in Team Sunday Funday's efforts to complete their project, as they fell behind in the design process and the course's deadline, and noticed they were not spending enough time working on their project due to other commitments and priorities. As a result of their reflection on their performance, they increased the time they were spending on the project, and one of the team members stepped up to assume leadership of the team. Members of Team Mystique reflected on their collective and individual performances: they reflected on their own progress against their team's project plan and the course's deadlines, each team member's weekly contribution, the technical problems facing the team, their performance in each of the design processes, and the evolution of their design from concept to final prototype.

### 3.5.3. Challenges

Although situating this cornerstone design course in a making environment helped students improve many of their soft and technical skills, students still faced several challenges in this learning environment. These challenges can be classified in four categories: time management, stress, makerspace challenges, and challenges related to communications with the client. Table 2 shows the coding for the challenges that students faced throughout the course, together with the frequency of times a student or group of students raised the challenge, the number of students who experienced the challenge, and the number of interviews in which the challenges were discussed.

TABLE 4 - FREQUENCY OF CHALLENGE THEMES THAT EMERGED FROM INTERVIEWS WITH THE STUDENTS

| Challenge code | Frequency | No. of students who experienced this challenge | No. of interviews out of 14 |
|---|---|---|---|
| Time management | 20 | 7 | 8 |
| Stress | 33 | 7 | 8 |
| Makerspace challenges | 11 | 7 | 5 |
| Communication with the client | 3 | 3 | 2 |

Students in both teams struggled with managing the time they had to complete their projects. Due to the multidisciplinary nature of the learning environment, students in each team were in different engineering disciplines and years of study, which meant that each had a different course program with varying course loads. Some students were registered for six courses, while others were registered for four only courses. Therefore, in each team, each student ranked their project differently on their priority list. Some students had more time to dedicate to working on the project, while others were occupied with assignments and midterms in other courses. Most complaints came from students in the second-year civil engineering program about their struggle to find time to work on their project because they were occupied with requirements in other courses. Moreover, students in both teams thought the course load in this engineering design course was heavy.

Factors that delayed students in their iterative process of creating and improving their prototypes included the following: procurement of materials and parts to create their prototypes due to shipping delays or searching for a local supplier for a particular item; long wait times to use makerspace tools at the end of the semester, as many Faculty of Engineering students use the makerspace equipment and tools for other courses; and the need to “learn while making,” as students had to learn new technical skills and concepts and solve unfamiliar problems before they could start creating or assembling an item.

Another challenge for students was experiencing high levels of stress. Students said they were stressed because they felt overwhelmed with the heavy workload of the project and other courses. They were also stressed about the uncertainty associated with solving engineering design problems, particularly finding information and resources to solve problems. Deadlines also caused students a lot of stress, specifically the final deadline — their presentation on Design Day. Iterations late in the prototyping phase also caused stress because students felt they were not going to be able to deliver a product for their client. Finally, meeting the client’s expectations with a functional prototype was also a source of stress for the students. Table 3 presents the coding for each factor that contributed to students feeling stressed, together with the frequency of times a student or group of students raised the challenge, the number of students who experienced the challenge, and the number of interviews in which the challenges were discussed.

TABLE 5 - FREQUENCY OF FACTORS THAT CONTRIBUTED TO FEELINGS OF STRESS, AS EXPRESSED IN THE INTERVIEWS

| Challenge code | Frequency | No. of students who experienced this challenge | No. of interviews out of 14 |
|---|---|---|---|
| Workload | 6 | 6 | 5 |
| Uncertainties | 3 | 4 | 3 |
| Deadlines | 9 | 7 | 6 |
| Expectations | 6 | 5 | 5 |

*"I am getting more afraid. I am feeling the time crunch, seeing the days count down. Doomsday is approaching. I think, at this point, my biggest fear is less something won't be ready for Design Day — because I am sure we can bring something out … to present. We are all competent people, and he [Dean] did sales all summer. The thing that I am more worried about is that if this isn't totally functional by Design Day, I am worried that we are all going to be too busy, too distracted, etc., to get this to a point where the client really wants, and we kind of got her hopes up a lot throughout this whole process. And I am worried that we are not going to present her with something that is what she wants. … And nothing is worse than letting down a child."*
*— A conversation with Lisa (Team Mystique) about the reasons she is feeling stressed.*

*Interviewer: "What are the sources of stress?"*

*Tim: "It's just the uncertainty of the materials — like, we went to the store today and we didn't find what we wanted, so now we don't know what we are going to make everything of."*

*Oscar: "We are going to other stores tomorrow because we want to get them, but there is always that uncertainty — what if we don't find it there, and then, oh boy, we have to look somewhere else. The problem is how are we going to find it, where is it going to be."*

— A conversation with (Team Sunday Funday) about their sources of stress.

Situating the students in a makerspace environment to construct their prototypes also presented the students with several challenges, such as the limited operating hours of the makerspace, as students wanted to spend many hours working on their projects in the last two weeks of the semester but the makerspace closed at 8 p.m. Students also faced logistical difficulties with sourcing materials and parts. As well, students faced difficulties with accessing the makerspace equipment and tools at the end of the semester, because the demand to use the makerspace's resources rose due to the increasing number of courses that had integrated the makerspace into their curriculum, which led to many of the faculty's students using the space for course work, in addition to ongoing personal projects.

Finally, students experienced challenges with communicating their ideas with their clients. Because the theme for course projects was accessibility, both clients had a disability that made communicating ideas with the client or gathering information and feedback from the client challenging and required the presence of a third party who had a close relationship with the client to facilitate the communication process.

### 3.5.4. Differences between teams

Throughout the semester, I observed several differences between the two teams in how they executed their projects. These differences were present in students' motivation towards the project, in strategies used in each of the project's design phases, in team dynamics, and in time management. Table 4 presents my observational differences in the design process followed by each team.

The project selection process for each team was different, since Team Mystique had proposed their own client and had a personal connection to the client's problem, while Team Sunday Funday selected their project from a list proposed by the course's instruction team. The difference in how each team selected their project affected the level of motivation for the project. Team Mystique felt very motivated to solve their client's problem and expressed interest in continuing to work on their prototype after the semester, going so far as to post their design online in the hopes that it would be improved by a wider community of designers. On the other hand, Team Sunday Funday did not express interest in continuing to work on the project after the semester and indicated that their project wasn't high on their priority list because they had other courses in their engineering program that needed their attention. Another factor that detracted from Team Sunday Funday's interest in continuing to work on the project after the semester was that they thought there were already available products in the market that might solve the client's problem.

Through the design phases, each team adopted different work strategies. During the conceptual design phase, Team Mystique developed one concept that was ambitious and did not consider the design constraints of the project, while Team Sunday Funday developed two concepts to present to their client. During the prototyping phase, Team Mystique developed several prototypes and communicated with their client frequently; each member of the team was responsible for developing their own prototype for the subsystem they were responsible for. Meanwhile, Team Sunday Funday started the prototyping phase later in the course due to their focused attention on other courses.

These differences in how each team completed their project stemmed partly from differences in team dynamics and how they managed their project and time. Team Mystique selected a leader by the second week of the course and developed a project plan that had more aggressive deadlines than the course's deadlines. The leader, Dean, was a third-year software engineering student whose role included helping everyone with their designs, assigning tasks to each team member, following the team's progress, and designing his own subsystem. Conversely, Team Sunday Funday did not pick a leader or follow a plan to complete their project. Midway through the project, as students were struggling to create their prototypes, one student, Tim, naturally emerged as the leader and started organizing the team's tasks. The students in Team Sunday Funday also struggled with breaking down tasks into smaller ones and with prioritizing their tasks. It should be noted that all of the students in Team Sunday Funday were from the second-year program, and this might have been a factor in them not assigning a leader for their team at the beginning of the project.

TABLE 6 - OBSERVATIONAL NOTES ON STUDENTS' PROGRESSION THROUGH THE DESIGN PROCESS

| **Interview No.** | **Academic week of the semester – interview date** | **Progression through the design process during the semester** | | **General observations** | |
|---|---|---|---|---|---|
| | | **Team Mystique** | **Team Sunday Funday** | **Team Mystique** | **Team Sunday Funday** |
| 1 | Week 2 – October 2, 2018 | Empathize / problem definition / conceptual design phase | Empathize / problem definition | - Students split their design into subsystems and assigned each subsystem to a team member<br>- Students assigned a leader for their team<br>- Students developed an aggressive schedule to finish their project that accommodated each student's | - Students didn't assign a leader for their team<br>- Students didn't distribute the work among each other; instead, they said they would meet weekly on the weekend to work on their project<br>- Students indicated there is no leader for the team |

| | | | | | |
|---|---|---|---|---|---|
| | | | | commitments in other courses | |
| 2 | Week 4 – October 16, 2018 | Conceptual design phase | Empathize / problem definition | - Students reached out to the project manager for help with the technical details of their conceptual design<br>- During this week, students were mostly engaged in problem-solving activities related to their conceptual design | - Students struggled with problem-solving related to technical elements of developing a conceptual design (finding the appropriate mechanism)<br>- Students didn’t communicate with their project manager |
| 3 | Week 6 – October 30, 2018 | Prototyping | Conceptual design phase | - Students noted that they felt they were behind their own aggressive schedule but were meeting the course’s schedule | - Students hadn’t started the prototyping stage<br>- Students didn’t approach their project manager for help<br>- Students indicated that they were prioritizing other engineering courses |
| 4 | Week 7 – November 6, 2018 | Prototyping | Conceptual design phase | - Students had to pivot their design<br>- Students noted that they were behind their own aggressive schedule but were meeting the course’s timeline | - Students pivoted their design once they started thinking about building their first conceptual design<br>- Students started communicating with their project manager<br>- Students increased the time they were spending working on the project<br>- Tim emerged as the leader of the team |
| 5 | Week 9 – November 20, 2018 | Prototyping | Prototyping | - Students encountered delays in the delivery of several parts and materials they ordered<br>- Students had to request extra funding for their project; their request was approved by the instructor | - Students started prototyping and sourcing materials<br>- Students struggled to source some of the materials they needed for their project<br>- Students realized had they spent more time and focus on their project in the beginning of the semester, they would have been able to finish their prototype earlier |

| | | | | | |
|---|---|---|---|---|---|
| 6 | Week 10 – November 27, 2018 | Development of final prototype | Prototyping | - Students started working on the final stage of their final prototype – coding<br>- Students expressed excitement for Design Day and indicated that they thought they could win the best project prize | - Students completed sourcing all materials for their project and started assembling the prototype |
| 7 | Week 12 – December 10, 2018 | Development of final prototype / completion of project / Design Day presentation | Development of final prototype / completion of project / Design Day presentation | - Students noted that they realized that had they spent more time in the conceptual design phase and taken it seriously, they would have built a better project<br>- Students noted that they will continue working on their project in the following semester on their own time | - Students noted that they are not going to continue working on the project after the completion of the course |

## 3.6. Discussion

I discuss the implications of the findings of this study for understanding how integrating a making program into an introductory engineering design course can create the conditions for an authentic learning environment. I also discuss the implications of our findings for the design of authentic learning environments for teaching engineering design.

### 3.6.1. Authenticity of the learning experience

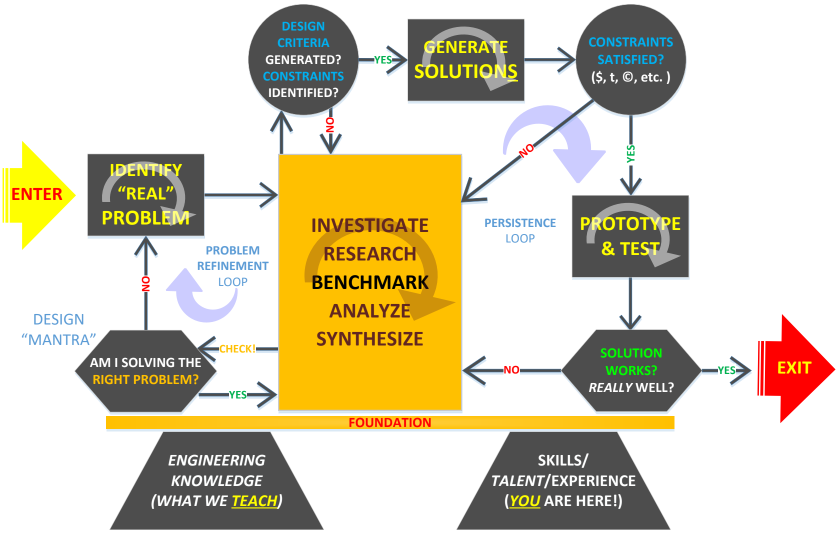
Authenticity of the learning environment is discussed in engineering education literature in four main categories: context authenticity, task authenticity, impact authenticity, and personal/value authenticity [81]. Ethnographic studies on professional engineers have defined engineering design as a social process that goes beyond the work of a creative engineer at a workstation to include many stakeholders, such as production and marketing personnel, purchasing and finance professionals, clients and contractors [171], [170]. Through the making experience in this course, students participated in activities where they had to communicate with the user of their product to understand their needs and define their problem. They also had to draft a budget for their project and secure an approval from their project manager, procure materials and parts from suppliers independently, create multiple prototypes, plan schedules and milestones, and distribute tasks among each other. These activities exposed students to a learning experience where their work was not limited to technical activities such as drafting technical drawings and reports; rather, their work extended to multiple organizational activities of ongoing reconciliation, persuasion, negotiation, and management [172], [173].

Students engaged in authentic design tasks when they used sketches and prototypes to communicate ideas, gain understanding, and solve problems. Studies of professional engineering practices describe the way engineers use sketches on both paper and CAD interfaces to grapple with ideas and communicate with others [172]. Students in both teams used hand sketches to develop initial conceptual designs and moved to using CAD models, 3D printed physical prototypes, or models made out of cardboard to visualize their designs, solve problems they were facing during the design process, figure out how elements of their design fit together, visualize modifications to their design, and communicate ideas with their client and project manager and gather feedback from them. The availability of 3D printers and other rapid prototyping equipment in the makerspace empowered students to transform their designs to three-dimensional reality in a matter of hours after creating them on CAD software [174], allowing students to progress quickly on the design of their final product. The introduction of making activities into the engineering curriculum therefore also contributes to preparing engineering students for changes in the engineering profession stemming from the use of new technologies in engineering work, such as the increasing use of computational technologies [172] and the increasing use of rapid prototyping technologies, which have a strong impact on productivity by accelerating product development [175], [176], [177].

Another observation about the making projects that students had to complete is that they resembled workplace projects in the sense that they were ill-structured and complex. Also, they had multiple possible solutions, vague constraints that included non-technical limitations, distributed knowledge, and unclear goals [178]. Students were challenged with a product design problem where they had to work both independently and collectively to direct and monitor their own learning and identify the knowledge they needed to solve the problem and make their final prototype. Based on this learning environment, I observe that the Maker Movement has the potential to connect and prepare engineers of the future to work with and for constituents rather than corporations on some of the planet's biggest problems, including climate change, sustainable energy, and famine [172], given that these problems are complex and pose multiple constraints.

The design process that students followed was influenced by the iterative engineering design process. Through this process, students go through a problem refinement loop where they empathize with their client, conduct adequate research on the problem, and complete the loop by defining the problem and establishing their project's design criteria. Students then proceed to concept development and finally to the persistence loop, where they prototype their design and test their prototypes until their design meets they client's needs. (See Figure 2.)

FIGURE 2 - THE ITERATIVE DESIGN PROCESS



Students in both teams started the design process by meeting with their client and defining the problem. They then started generating ideas and solutions. Within the first three weeks of the semester, they developed empathy in the first client meeting, defined the problem, and generated ideas. Once students decided on the concept they wanted to pursue, they developed their first prototype and met with their client for the second time to gather feedback. Students in both teams proceeded to think, ideate, and solve problems related to realizing their conceptual design after meeting with their client. It should be noted that each team arrived at this phase at a different time during the semester, as Team Sunday Funday was exceptionally late to develop their first prototype, while Team Mystique went through the empathy, problem definition, and ideation to developing their first prototype by the fourth week of the semester. After meeting with their client for the second time, students started working on their detailed design. At this stage, students encountered technical problems that prompted them to seek help from their project manager. The project manager helped each team solve these problems by suggesting ideas or different technical approaches. The involvement of the project manager at this stage of the design process resulted in major design pivots for both teams. Once the students settled on their final detailed design, they started sourcing and manufacturing parts and elements of their design to build their final prototype. Students in Team Mystique were first to arrive at this stage, while students on Team Sunday Funday reached out to the project manager and produced their second prototype later. Students then met with their client for the third and last time to gather feedback on the prototype. They used this feedback to produce their final prototype, which they presented at the Faculty of Engineering’s Design Day.

The students’ realization of the importance of the problem definition phase and conceptual design phase to the success of their design project was an indication of their progression from novice designers to more experienced ones. Throughout the course, students in both teams continued to gather information and redefine their problem and scope of work. Both of these observations point to similarities with expert performances in engineering design [179]. Moreover, I noticed that situating students in a learning environment with authentic tasks and contexts gave them an opportunity to spend hours practising their skills and reflecting on their work and what they were learning, in turn helping them to proceed towards more advanced performance.

For Team Mystique, the object of the design itself heavily influenced the structure of the design process and the division of labour within the team. The product was divided into multiple subsystems, which were allocated to team members depending on each member's expertise, engineering discipline, and learning objectives. This allowed each student to take responsibility for their own design process while working collectively with the other team members to make sure all the systems were compatible. The outcome of the students' authority over their design process was a noticeable high level of motivation and enjoyment of the learning experience and the project work. In Team Mystique, each student came up with a brand name for their system, and they all agreed on a product name. For Team Sunday Funday, the delay they experienced in meeting their deadlines, especially at the beginning of the project, was partly due to their failure to break down their product into smaller systems, organize tasks accordingly, and distribute tasks among the team members.

The multidisciplinary nature of the making projects and of the student teams meant that students were exposed to different worlds of technical specializations and, therefore, to knowledge, modes of thinking, dialects, metaphors, instruments, and crafts beyond their engineering discipline in order to solve their client's problem. Moreover, similar to how engineers progress from novices to professional engineers through peripheral participation (by first participating in simpler tasks, guided by senior colleagues) in the workplace [178], first-year students and novice makers were guided by students with more experience with making technologies, by senior students, and by project managers in the use of equipment and tools in the makerspace, in scaffolded learning of 3D modelling and CAD, and in learning engineering concepts that were new to them.

The making projects also challenged students with four main types of design constraints: human constraints, such as the client's needs and ability to communicate them with the students, as well as the students' own limited knowledge and expertise at the time; technical constraints, such as those faced by John while designing and selecting electric motors for his subsystems and by Dean as he was designing software to be compatible with his teammates' subsystems; cost constraints, such as those experienced by both teams as they chose between options and trade-offs for their designs; and time constraints, such as those experienced by both teams to meet the course's deadlines. As students were making their prototypes, they realized these constraints could often be solved through negotiation. Given that Team

Mystique had to create multiple iterations of their designs as they worked on their project, they ran out of budget and had to negotiate with the course instructor for extra funding for their project. This is a true characterization of engineering design constraints: although they might be numerous and wide-ranging, they are constantly reconstructed [171], [180].

The making nature of the projects and the presence of tangible artifacts allowed students to reflect on their work and whether their solutions were working or not. Moreover, as students progressed in completing their making projects, they constantly reflected on their progress relative to the course's deadlines. However, I observed that my presence in the learning environment and the interviews might have encouraged some of the students' reflection activities. This observation led me to notice that the course did not design for reflection activities that would allow students to evaluate and improve their performance in order to complete their project. One of the criticisms of project-based learning approaches in general is that students fall short of seizing on the opportunities for deep learning due to their tendency to focus on the action part of the learning environment and their failure to reflect on their learning [181]. Reflection is "the practice of periodically stepping back to ponder the meaning to self and to others in one's immediate environment about what has recently transpired" [176, p. 11]. Reflection is an important human activity in which people recapture their experiences, think about them, and evaluate them [122]. Reflection leads to an understanding of experiences that might have been overlooked in practice and provides a basis for future action [182]. Raelin [182] notes five advanced skills — beyond communication skills — that can be developed in a project environment and contribute to reflective discourse: being, speaking, disclosing, testing, and probing. The skill of being refers to an ability to open up to experience and be vulnerable in the sense that one doesn't rely on defending oneself against feedback. The skill of speaking refers to articulating a collective voice from within. The skill of disclosing refers to sharing doubts or passions. The skill of testing refers to a process of collective open-ended inquiry to uncover new ways of thinking and behaving. The skill of probing refers to direct inquiry of one member at a time to find out facts, reasons, assumptions, inferences, and possible consequences of a given suggestion or action. Although the making projects in the course provided an environment that offered opportunities to develop these skills, instructors should design for specific reflection activities to ensure that students dedicate some time to reflect on their learning and progress.

The making projects gave students a glimpse of the impact of the engineering profession on society. I also observe that making projects that offer personal and value authenticity provide more opportunities and motivation for independent learning, as in the case of Team Mystique, where the students were motivated to complete their project primarily to improve their client's quality of life. My observation is in line with the argument from Wang et al. [81] that projects deliver authentic education most effectively when they are close to the students' own life, answer personal questions that the students have, or satisfy the students' or their community's needs.

### 3.6.2. Implications for creating an authentic learning environment for engineering design

I found that the making nature of the projects entailed important elements that are necessary to construct an authentic learning environment for engineering design, such as access to the multidisciplinary nature of engineering design, as well as engagement in social and organizational activities that are at the core of engineering design and offer an adequate level of ambiguity to familiarize students with navigating design problems as future engineers.

As I described in section 2.3, Herrington's [169] framework for designing authentic learning environments outlines nine elements that are necessary in any authentic learning environment: authentic context, authentic tasks, access to expert performances, access to multiple roles and perspectives, collaborative learning, reflection, articulation, coaching and scaffolding, and authentic assessment. My findings enable me to elaborate on a few of these elements to help engineering educators construct authentic engineering design learning experiences.

First, an authentic engineering design context must provide students with an ill-defined design problem with unclear constraints that can help students familiarize themselves with the inherent ambiguity of engineering design projects. The presence of a real client, an object of design, the possibility for multiple solutions, and the students' authority to decide on the learning path they want to follow to reach a solution are all essential for fostering an authentic engineering design context for the learning environment.

Second, the tasks that students participate in should not be limited to technical activities. Rather, they should extend to other organizational activities, such as breaking down a project into smaller tasks and distributing the workload among team members. Third, to facilitate effective collaborative learning, there should be a clear distribution of roles among the student team members. This can be achieved easily if there is diversity in the level of expertise and backgrounds within the team. In a previous study I conducted to compare the impact of team formation methods on student achievement, I found that the choice of team formation method — self-assignment or instructor assignment — did not have an impact on student academic achievement in the course [183]. Therefore, I recommend that instructors form student teams keeping diversity of expertise and background in mind.

A new element that I perceive as essential to constructing an authentic engineering design learning experience and characteristic of making activities is access to multidisciplinary learning opportunities [3], [55]. Given that design is a social activity that includes multiple participants — each with different technical backgrounds that have distinct language and instruments — authentic learning environments must introduce students to this intrinsic feature of engineering design [171]. Moreover, the learning environment should provide opportunities where students can explore the roles of multiple stakeholders involved in an engineering design project, such as project managers, suppliers, contractors, clients, and investors.

#### 3.6.2.1. Stress as a main challenge

One of the main challenges facing students in this learning environment was constantly feeling stressed. The relationship between stress and a designer's creativity is complex. Low-stress-inducing situations have been found to contribute to increases in creative performance, while high-stress-inducing situations contribute to decreases in creativity; moreover, contexts that are characterized as uncontrollable decrease creative performance [184]. Also, mental effort at low and medium stress levels is stronger than mental effort at higher stress levels [185]. Sources of stress in the course under study can be classified into two main groups: sources related to workload and sources related to the students' perception of their ability to provide a useful prototype to their client. Nguyen and Zeng [181, p. 76] argue that students' stress is positively related to workload and negatively related to mental capacity — workload being defined as tasks assigned to a student, and mental capacity being defined as students' own knowledge and skills required to complete the tasks assigned to them. How students react to their workload differs from one student to another and depends on each student's particular circumstances; similarly, since learning within a making context involves an array of different topics and multiple participants with different backgrounds, different skills, and varying levels of expertise, student stress levels will vary.

Byron, Khazanchi, and Nazarian [184] find that some stress is necessary to induce creativity. But for learning environments where making is central, ensuring that students have a sense of control over their workload and their mental capacity is vital to ensuring that students go through a positive learning experience where stress does not hinder their creativity. Although the course in this study used scaffolding strategies to help students develop the skills required to complete their prototypes, more consideration should be given to the workload in such a learning environment and to balancing that workload with students' workload in other courses.

#### 3.6.2.2. Authentic achievement in engineering design courses

Student achievement in this authentic engineering design learning experience depended on several factors that expanded beyond the standards for authentic achievement of Wehlage, Newmann, and Secada: construction of new knowledge, disciplined inquiry, and value beyond school [72]. I observed that students' capability to deconstruct the design project into smaller subsystems and to further break down tasks was essential to their progress and success. Also, their ability to plan, organize, and prioritize tasks was essential to their ability to meet deadlines. Moreover, students' ability to distribute tasks and roles among one another and assign a leader to the team who could take the lead on managing the project and help organize tasks was crucial to their achievement and enjoyment of their learning experience. Furthermore, their ability to manage their time on the project and their time between this cornerstone design course and other academic commitments was vital for them to be able to manage their stress level and enjoy their project work.

These observations lead me to argue that a new element should be added to the disciplinary inquiry element of the conceptualization of authentic achievement. Wehlage, Newmann, and Secada [72] define disciplined inquiry as cognitive work that relies on the use of a prior knowledge base, strives for in-depth understanding of the subject knowledge, and communicates ideas and thoughts in an elaborate manner. This definition fails to capture the social and organizational nature of the design process and the learner's ability to solve a design problem and produce a tangible solution. For students to accomplish an authentic achievement in engineering design, they have to learn to navigate the uncertainty of the social and organizational facets of the design process. Social facets include the uncertainty inherent in team environments, where multiple team members are working together and have to trust each other's ability to perform and solve problems, as well as the uncertainty in dealing with a client. Organizational facets refer to demonstrating an ability to organize, plan, and prioritize activities in a multidisciplinary design project.

### 3.7. Conclusion

In this chapter, I described students' learning experiences in an engineering design course that was situated in a makerspace environment and had making activities as a central theme. I found that the integration of making activities into engineering design courses offers students an authentic design experience that exposes them to a diverse set of topics and increases their confidence in their design and problem-solving skills. Making activities also give students opportunities to perform in ways similar to what will be expected of them as professionals. The integration of making activities also has the potential to steer undergraduate engineering curricula to offer more contemporary images of the engineering profession that are creative, collaborative, and more oriented towards agendas of social good.

## 3.8.Limitations

The research conducted in this chapter is limited by the fact that it was conducted only in an introductory engineering design course. Thus, care should be taken before generalizing these findings to more advanced engineering design courses. Although students in a final-year capstone design course based on making projects might experience similar challenges, I would hypothesize that their learning objectives, interests, experience, and challenges might be a little different.

# Chapter 4 Predicting academic success of engineering students in authentic learning environments using non-cognitive attributes

## 4.1. Introduction

With the advent of the Maker Movement, many universities and engineering faculties have established their own makerspaces on campus [47] to provide for a learning environment that can complement their engineering design curriculum [27], [46] and that can address the need for more experiential learning opportunities in engineering schools [135], [136]. The opening of academic makerspaces in engineering schools can provide authentic learning opportunities that expose students to engineering activities [169], [70] and increase students' enjoyment of the learning experience [186]. Moreover, makerspaces can provide an opportunity to integrate learning experiences based on situated, distributed, and sociocultural theories of learning, which can help engineering schools offer equitable and inclusive engineering curricula [187].

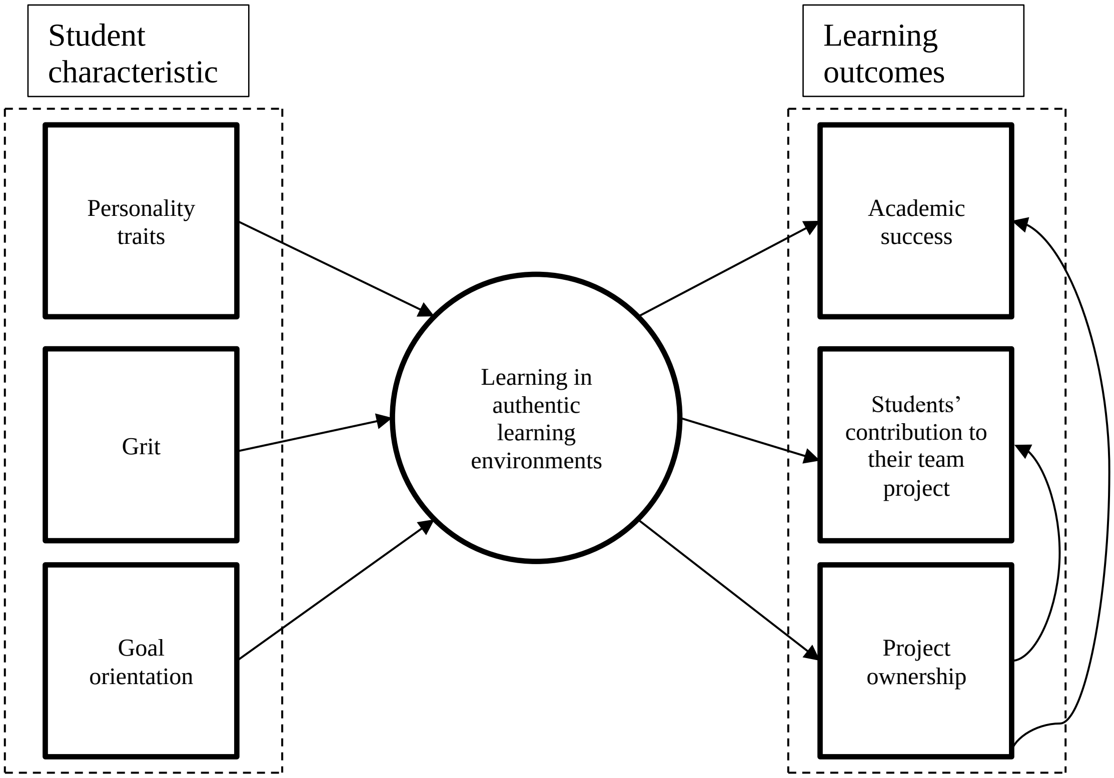
Given that engineering educators are designing and implementing educational programs and interventions that integrate making activities into their courses, there is a need to examine factors that affect students' performance in these educational programs. This part of the thesis examines whether and to what extent certain characteristics predict students' contribution to their team's project, academic success as measured by their final marks in the course, and development of project ownership in an authentic learning environment. The students' characteristics considered in this study are Big-Five personality traits, grit, and goal orientation. This study contributes to the engineering education literature by examining the impact of certain characteristics on students' learning in a cornerstone engineering design course based on making projects and activities. Since learning in a makerspace is based on a collaboration among a community of makers, the results of this study can provide guidance to engineering educators who want to create teams of students that collectively have the characteristics that are important for the team to successfully complete their project [136].

### 4.2. Background

Although cognitive measures, achievement tests, and grades are predictive of performance and important life outcomes, they can explain only part of the variance of these outcomes [188]. Performance depends on effort, cognitive ability, and motivation, although the importance of each differs by task [189], [188]. Recent studies have brought attention to several non-cognitive attributes as potential predictors of academic performance, such as study skills and habits, emotional intelligence, learning strategies, and grit [190], [191]. The research in this thesis examines the predictive ability of three non-cognitive measures — students' personality traits, grit, and goal orientation — on three academic outcomes of learning in an authentic learning environment: student's contribution to their team's projects, academic success, and project ownership. Figure 3 presents the research hypothesis.

As discussed in Chapter 2, authentic learning, grounded in theories of constructivism [99], is an approach that views learning as a complex, challenging process of situating students in activities where they construct their own understanding of new concepts and practices through social negotiation and shared responsibility and by integrating their previous and current experience, their research, and the resources they have access to [192], [193], [83]. Authentic activities are defined as coherent, meaningful, and purposeful activities that are considered to be ordinary practices of the culture or domain of knowledge and through which members, regardless of their level of expertise, construct the meaning and purpose of the domain's activities through negotiations among past and present members [68]. In authentic activity, knowledge is situated in realistic contexts that allow students to feel a sense of belonging to the domain of knowledge, enjoy the challenge and the work, and gain explicit and tacit understanding of the roles played by practitioners in the domain of study or practice [194]. Challenging students with complex projects that motivate them to work hard and coordinate their efforts also reduces social loafing, the phenomenon of a reduction in students' motivation and effort when working collaboratively compared with when they work individually [195], and increases team members' interdependence [196].

FIGURE 3 - RESEARCH HYPOTHESIS



### 4.2.1. Main Research Questions

RQ1: Do measures of students' characteristics (personality traits, grit, and goal orientation) predict students' learning outcomes (peer assessment marks, final marks and project ownership)?

RQ2: What is the relationship between the students' characteristics (grit, personality traits and goal orientation)?

RQ3: Is there a relationship between students' learning outcomes (project ownership and final mark or peer assessment mark)?

### 4.2.2. Non-cognitive measures

#### 4.2.2.1. Personality traits

The concept of personality includes generalizations about human nature and explorations of individual differences [197]. Roberts defined personality traits as "relatively enduring patterns of thoughts, feelings, and behaviours that reflect the tendency to respond in certain ways under certain circumstances" [198]. Throughout this chapter, I use the term personality traits to refer to personal characteristics that are not captured by measures of cognitive ability [188].

Evidence of the impact of an individual's personality on academic success and life outcomes has been well studied. For many outcomes, personality measures explain more of the variance in performance than do measures of cognitive ability [188]. Studies have shown highly replicable association between students' personality and their academic performance [199], [200], [201] and occupational outcomes [197], [202]. Personality traits are primarily measured using self-reported questionnaires [188]. The most recognized measure of personality traits is the Big-Five personality model, which is based on personality from the view of the observer [197]. This personality model uses statements that people make about themselves and then empirically determines the links between their self-descriptions and their reputations [197]. This measurement model represents a central approach to the trait theory of personality [201]. The model's appeal is due to three values: it provides for an assessment tool that integrates a wide array of personality constructs, thus facilitating communication between researchers from different disciplines; it provides for a comprehensive, unified, and relatively universal construct that encompasses most of the variance in personality constructs; and it provides for an efficient global description of personality [189], [203], [204]. The model has been translated into more than 40 languages and can be used by children as young as 10 years old [205]. The Big-Five model of personality traits consists of five factors [206], [207]:

- Openness to experience: a trait that describes individuals who are imaginative, cultured, intellectually curious, broad minded, behaviourally flexible, non-dogmatic, and sensitive to art and beauty. Openness is positively associated with learning goal orientation [208], achievement motivation and desire for self-improvement [209], and SAT verbal scores, and weakly associated with academic performance [199].
- Conscientiousness: a trait that describes interpersonal behaviour related to organization, diligence, and will. Out of the Big-Five personality traits, Conscientiousness has been found to be the most robust predictor of academic performance [188], [199], [210], as it is found to be a strong predictor of GPA [200], [211], college grades [199], retention in engineering school [191], academic performance [210], foreign language proficiency [212], academic motivation [213], achievement motivation [209], and learning goal orientation [208].
- Extraversion: traits related to sociability, activity, and tendency to experience positive emotions of happiness and joy. Extraversion is positively associated with learning goal orientation [208], engagement in learning [209], desire for self-improvement [209], and extrinsic motivation [213]. Extraversion is negatively associated with avoidance performance goals and fear of failure [213].
- Agreeableness: also described as likeability, a trait that is associated with traits of forgiveness, trust, flexibility, cooperation, sympathy, and tolerance. Agreeableness usually has high predictive validity with academic performance in learning environments that demand student interactions and cooperation [214].

- Neuroticism: defined as an individual’s tendency to experience psychological distress such as embarrassment, depression, worry, insecurity, guilt and anxiety. Neuroticism is positively associated with avoidance performance goals and fear of failure [213] and with retention in engineering schools [191], and it has a small positive association with academic performance [209], [210]. On the other hand, neuroticism is negatively associated with achievement motivation [209].

With the exception of research on conscientiousness, previous findings in this area of research are mixed due to different associations of the five personality traits with academic performance at different age and educational groups, different definitions and assessments of academic performance and success in the literature, and different time lapses between the collection of predictor and criterion data [215]. Through this study, I focus on examining the association between the Big-Five personality traits and undergraduate engineering students’ learning in authentic learning environments.

#### 4.2.2.2. Grit

Among the non-cognitive measures considered in this study, the construct of grit has attracted the most interest and attention, captured public imagination, and influenced education policy through multiple bestselling books and articles about the importance of grit in determining an individual’s success in life [216], [217], [218]. This received attention is also due to claims made about grit: that the construct of grit represents both passion and perseverance for long-term goals, that it not only predicts success and performance but is also the secret to success, that it is a stronger indicator of success than other predictors, and that interventions designed to raise the grit level of students are likely to lead to success. [218].

Grit, initially conceptualized by Duckworth et al. [215, p. 1087] as perseverance and passion for long-term goals, is a relatively new construct associated with goal-oriented behaviour [220]. Initially conceptualized within personality theory and described as similar to conscientiousness (as defined as one of the Big-Five personality traits) or self-control [221], [222], grit entails “working strenuously toward challenges, maintaining effort and interest over years despite failure, adversity, and plateaus in progress” [219]. Recent studies claim grit is a better predictor of success outcomes than IQ [219]. In these studies, grittier individuals are found to progress further in their education, make fewer career changes [14], be less likely to drop out of their life commitments [223], have higher grade point averages (GPAs) [14], [224], report higher levels of both purpose commitment and positive affect [225], and be more likely to engage with their work than less gritty individuals [226].

Grit consists of two dimensions: perseverance of effort (Grit-PE) and consistency of interest (Grit-CI) [219], [227]. The Grit-PE dimension is defined as “individuals’ tendencies to keep working towards long-term goals” [219] and is found to strongly predict academic adjustment, college grade point average, college satisfaction, sense of belonging, faculty-student interactions, and intent to persist, while being negatively related to intent to change majors [228]. Grit-PE also predicts indicators of self-regulated learning and past and present academic achievements [229]; predicts end-of-year grades for middle-school students regardless of previous academic performance [230]; predicts students’ anticipated grade of a course at the beginning of the semester [231]; predicts grades for high-school and college students [221]; and is related to lower rates of depression [232], [233]. The Grit-CI dimension, defined as “individuals’ tendencies to pursue the same or similar activities over time” [219], is found to predict career changes in adults [14], [228]. The perseverance of effort dimension is increasingly found to have a stronger predictive validity over academic and non-academic outcomes than consistency of interest [228], [227].

Advocates for grit as a better predictor of success are in line with proponents of the importance of the role that deliberate practice plays in the development of expertise [234]. Ericsson et al. [234] argue that high levels of deliberate practice are necessary to attain expert level performance (p. 392) and that the reason for the difference in performance between higher performers in a certain domain and normal adults is a “life-long period of deliberate effort to improve performance in a specific domain” (p. 400). It should also be noted that recent studies on the role of deliberate practice have concluded that although deliberate practice is necessary to achieve mastery level performance in a domain, it is not sufficient to explain variance in performance between experts and normal individuals in a certain domain [235], [236], [237]. MacNamara et al. [237] found that deliberate practice had greater impact when the activities were predictable.

The study of engineering is hard for incoming students, as it presents them with various academic challenges that require high levels of persistence and self-discipline [238]. Due to these challenges, engineering programs are considered to be vulnerable to non-completion [239]. These challenges have encouraged engineering education researchers to explore psychological factors that influence students’ achievement in engineering programs [239], including the influence of grit in the engineering student population [238]. In their examination of the role of engineering identity and belonging to engineering in fostering students’ grit, Verdin et al. [240] found that both subdimensions of grit — perseverance of effort and consistency of interest — are affected by engineering identity and feelings of belonging to engineering. McDermott et al. [241] examined the relationship between grit and programming attainment and found a statistically significant association between grit and academic success in an introductory programming course.

Jaeger et al. [54] investigated the effects of grit in engineering students at Northeastern University and found that grit is not associated with students' SAT scores. Interestingly, they found that students' consistency of interest fluctuates significantly throughout their academic journey, and that there were no significant differences in grit between senior students and students at other academic levels. They reasoned that this might be due to their small sample size of senior students who were recruited for their study, as well as the impact that going through an exhausting capstone course might have had on senior students' responses. They also found that athlete students demonstrated higher levels of grit than other students, and chemical and mechanical engineering students had higher grit levels than students in other engineering disciplines. Moreover, they found that female students have higher levels of grit that male students. However, there are mixed results in the literature examining grit and gender, as some researchers have found that females have more grit than males [12], [54], [55], while other studies concluded that grit was not associated with students' gender [56], [57], [6]. Bazelais et al. [242] studied how grit affects pre-university students' performance and success in a physics course and found that the construct of grit did not have any predictive validity over past student achievement and concluded that prior academic achievement is the most reliable predictor of student success in college.

Although research on grit is still in its infancy [243], the grit model conceptualized by Duckworth et al. [219] as a higher construct that consists of two components, consistency of interest (CI) and perseverance of effort (PE), has received some criticism. Muenks et al. [221] note that both components of the grit scale overlap to a degree with constructs already developed in the self-regulation and engagement literature. They also note that no research has been published on the effectiveness of grit interventions in making students grittier to persist through challenges and difficulties they face to attain their long- or short-term goals. However, recent studies have confirmed Duckworth's conceptualization of grit in that its components do not reflect a single psychological construct; rather, both subscales represent independent constructs [220], [221].

The research discussed for this thesis is in part concerned with understanding what role grit plays in predicting students' learning in authentic learning environments. I hypothesized that grittier students would persist and contribute more to their team's projects, achieve higher final marks in the course and higher project ownership level.

#### 4.2.2.3. Goal orientation

Goal orientation is an integrated pattern of beliefs that leads to different approaches and behaviour in relation to achievement-type activities [244]. In research on learning, goal orientation refers to two classes of goals that individuals pursue in the domain of intellectual achievement: performance goals (in which individuals aim to gain favourable judgment of their abilities) and learning goals (in which individuals aim to improve their abilities) [245]. Individuals with a performance goal orientation view effort and achievement as an indication of ability, while those with a learning goal orientation view them as an indication of one's learning and mastery strategies [245]. These differences in cognition based on an individual's goal orientation can influence their own reactions and behaviours to success and failure when conducting a task [245]. Individuals with a high learning goal orientation persist and enjoy challenges, while individuals with a performance goal orientation are more likely to withdraw from a task that challenges their ability and lose interest [246]. A learning goal orientation is also linked to positive motivational beliefs, the quality of a student's cognitive engagement and planning, and regulating learning [247].

I included goal orientation as a predicting variable for students' learning in an authentic learning environment due to the positive relationship between students' goal orientation and their behaviour and motivation in academic settings. I hypothesized that students with a learning goal orientation would contribute more to their team's project, attain greater academic success, and develop higher ownership levels of their projects than those with a performance goal orientation.

### 4.2.3. Learning outcomes

Assessing learning in authentic learning environments requires assessment methods that can measure development in critical 21st-century skills, such as teamwork skills, negotiation skills, and planning and organizational skills. Authentic assessment also entails self-evaluation and reflection on one's own performance and achievement [248]. Assessment methods of students' skills in project-based engineering design courses include student portfolios and design journals to assess design achievement, the use of a panel of experts composed of engineering faculty or practising engineers to score the quality of products created by the students, and the use of verbal protocol analysis to evaluate the design process students use. A combination of these approaches is also used to assess junior engineering students' skills in team-based design courses [249], [250]. The learning environment studied for this thesis used a combination of summative and formative assessment methods to evaluate and provide quick feedback to students to improve their performance and skills. Both formative and summative assessments are important in devising an assessment strategy to evaluate students' work and ensure continuous improvement of the engineering design education received by the student, as both provide valuable feedback for evaluation, for improvement, and for accreditation [249]. In the study discussed in this chapter, I am concerned with three learning outcomes: students' academic success as measured by grades, students' individual contribution to their team's project as measured by peers, and their development of project ownership.

#### 4.2.3.1. Academic success

In this study, academic success was assessed using students' final marks in the course. Students' final marks were based on midterm grades, final exam grades, and their final project mark. Project marks were calculated based on the marking of project deliverables that students had to submit weekly throughout the semester in each phase of the project, as well as peer assessment marks and feedback from the project's client, which helped to provide the students with an authentic learning environment that will resemble their professional practice after they graduate [251]. Using a client assessment rubric had several advantages: it helps students prepare for interactions with clients, it facilitates structured meetings with clients, it provides a way to evaluate student performance, and it gives clients a formal structure to document student performance [251]. The client's evaluation occurred during Design Day as the students presented their final prototype. Using a rubric that account for 55 of the team's final project grade, clients evaluated the final prototype based on how well it answered their needs and evaluated their interaction with the students. It is important to involve the clients in the assessment process because they are best able to judge whether the product meets their needs. The clients also have a unique perspective on the student's professional conduct and how well the students communicated their ideas to them..

#### 4.2.3.2. Students' contribution to their team's project

The courses under study used peer assessment as an authentic assessment tool to measure each students' contribution to their team's project. Peer assessment has been defined as "an arrangement in which individuals consider the amount, level, value, worth, quality, or success of the products or outcomes of learning of peers of similar status" [20, p. 250]. In peer assessment, students evaluate themselves and their peers' contribution to the project work. Peer assessment is credited with increasing students' confidence in their own performance [253], enhancing the learning experience of students [254], helping students reflect on their learning and enhancing the quality of the final product [255], [253], [256]. Also, providing students with feedback allows them to learn about their own effectiveness in a group setting, provides a mechanism to give individual grades to students working in teams [257], and reduces social loafing because students are aware that their group contribution is going to be assessed [254].

In incorporating peer assessment and feedback into the courses under study, instructors followed guidelines from Cestone et al. [255] for implementing peer assessment and evaluation by providing a lecture on teamwork skills and conflict management at the beginning of the course and by using periodic formative assessment by asking students to evaluate themselves and their peers midway through the course. The first peer assessment, which is not considered in calculating students' final marks (and not considered in this research), is used by the instruction team to identify struggling teams to solve their problems and to motivate students to contribute equally to the project work. It enables each student to improve their skills by receiving feedback from their peers. It also prepares students to provide constructive feedback that helps their peers develop their skills and increases their team's effectiveness.

#### 4.2.3.3. Project ownership

The third outcome considered in this study is project ownership. Ownership in an education context refers to students' assumption of responsibility of their learning process, commitment, engagement, loyalty, sense of belonging, and self-identification with their educational program or project [258], [15]. Project ownership is a complex term that involves the students' response to an educational environment [15], [16]. The construct of project ownership includes aspects of engagement, agency, personal connection, the recognition of community and disciplinary value, and positive emotive responses [15], [17]. Project ownership as a variable has two factors: the content factor and emotional factor [16], as it includes not only personal connectivity, agency, problem-solving, social interaction, and a sense of personal achievement but also increased emotional feelings (either positive or negative) for the educational experience [17].

Students' development and experience of project ownership results from a complex interaction between the students and the educational environment [15] and depends on several factors, including their control over decision-making, their personal agency, and the amount of responsibility they have in the learning environment [259]. Three features of a learning environment contribute to students' development of project ownership: discovery, iteration, and collaboration. Iteration and collaboration are responsible for developing their emotional ownership of their projects [260]. A growing sense of project ownership helps students to become more tolerant of obstacles and to persevere when facing challenges [61], [261], in turn increasing their self-efficacy and motivation [261], encouraging them to pursue a long-term career in science [15], and helping them to achieve a better understanding of the unpredictability of scientific research [15]. Moreover, ownership of the learning process can serve as a stimulus for problem-solving and self-directed learning [102].

Studies of course-based undergraduate research experiences argue that providing students with more agency in their learning process will lead to positive outcomes, such as increasing students' resilience and encouraging them to pursue a career in sciences. In this study, students were situated in an authentic learning environment that allowed them to select their projects and make decisions related to the development of their prototypes. This learning environment provided for an ideal opportunity to investigate the relationship that students' Big-Five personality traits and grit have with their development of intellectual and emotional project ownership. In addition to being seen as a learning outcome, project ownership can be seen as a predictor of students' project ownership academic performance. Finally, aspects of personality traits may also be related to developing a sense of project ownership.

### 4.3. Study purpose and design

The research tests the role of three non-cognitive attributes — personality traits, grit, and goal orientation — in explaining academic success in authentic learning environments. Specifically, I examine whether personality traits, grit, and goal orientation can predict students' contribution to their project teams as measured by their peer assessment, students' final marks, and their development of intellectual and emotional project ownership in an authentic engineering design course.

The need for the research discussed in this chapter emerged after making projects and activities were integrated into cornerstone engineering design courses at the Faculty of Engineering at the University of Ottawa. Situating students in learning environments where making projects and activities are central provided for an experiential, hands-on learning experience. However, the integration of a maker curriculum into engineering design courses presented instructors with the challenge of identifying factors that influence students' learning.

There is a lot of evidence in the literature that personality traits can predict academic success and be useful in designing learning environments that increase students' engagement, facilitate their learning process [262], are matched to students' relative strengths [215], and help educators identify students who are likely to underperform [263]. Based on the published evidence about the impact of personality traits on academic performance, I initially started the study trying to investigate the predictive ability of students' Big-Five personality traits and grit on students' individual contribution to their team project and their academic success. The initial stages of the research (Phase 1) focused on answering the following two questions:

1(a) What is the relationship between engineering students' grit, as measured by the Short Grit Scale (Grit-S) questionnaire developed by Duckworth et al., and their personality traits?

1(b) Do measures of students' Big-Five personality traits, grit, and goal orientation predict students' peer assessment marks and final marks?

After an initial analysis of the data, I introduced the construct of project ownership to the study to examine the role that students' development of project ownership plays in predicting their individual contribution to their team projects and their academic success. Also, Phase 2 expanded on Phase 1 by examining the impact of students' personality traits and grit in the development of intellectual and emotional project ownership. In phase 2, I made some additions to the data collection instrument. The changes included adding the project ownership construct to the study's questionnaire and adding a more up to date measure of the grit construct. The guiding research questions I answer in Phase 2 are the following:

2(a) What is the incremental validity of the Triarchic Model of Grit Scale (TMGS) over and beyond the Big-Five personality traits in predicting students' project ownership, peer assessment marks, and final marks, specifically compared with the Grit-S scale and the VIA persistence scale?

2(b) Is there a relationship between students' development of intellectual or emotional project ownership and their individual contribution to their team's project or their final marks in the course?

2(c) Is students' goal orientation associated with their development of feelings of intellectual and emotional ownership of their team's project?

### 4.4. Phase 1 of the research

In Phase 1 of this research, I examined whether students' Big-Five personality traits, grit, and goal orientation are predictive of their contribution to their team's project in an authentic learning environment as measured by their peers' assessment and their academic success as measured by their final marks in the course. Specifically, the following research questions were examined:

1(a) What is the association between students' grit and their personality traits?

The first question I explored was how personality traits of the Big-Five model relate to students' grit as measured by the Short Grit Scale (Grit-S) developed by Duckworth et al. [14]. I predicted that students' grit increases when the levels of openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism increase.

Based on the extant literature, I hypothesized that the personality traits of openness, extraversion, and conscientiousness would be positively associated with students' grit level. I also hypothesized that neuroticism would be negatively associated with grit.

2(b) Can student personality traits, grit, and goal orientation predict students' peer assessment marks and final marks?

The second question I considered in Phase 1 explored students' Big-Five personality traits and grit as predictors of their individual contribution to their teams as assessed by their peer assessment mark and their final mark in the course. I hypothesized that a personality profile high in conscientiousness and openness to experience would be positively associated with higher final marks in the course and peer assessment. I also hypothesized that agreeableness would be associated with peer assessment scores based on the argument from Farsides et al. [215] for the relationship between this trait and academic success in educational settings that promote collaborative learning. I also hypothesized neuroticism would be negatively associated with students' final marks and peer assessment marks. Finally, I hypothesized that grit would be positively associated with students' final marks and peer assessment marks.

### 4.4.1. Method

In this research, I used a quantitative research design with the students' Big-Five personality traits, grit, and persistence as predictor variables and their peer assessment and final marks as a dependent variable. Quantitative research is concerned with collecting and analyzing numerical data [153]. Quantitative research has two main types: studies aimed at discovering casual or correlational relationships between variables, and studies aimed at describe a phenomenon [152]. This study aimed to discover if any relationship exists between certain student characteristics and their learning outcome in a design course based on making projects and activities. For this reason, qualitative research methods were used in conducting the study. The study adopted a survey design with a cross-sectional design which involves exploring the characteristics of a group in a point in time [152]. Cross-sectional designs are appropriate to use when the researcher is interested in conducting exploratory research where the patterns of relationship between the variables are unknown [264].

Before collecting any data, ethical approval for the research was obtained from the University of Ottawa's office of research ethics and integrity review board (uOttawa Ethics Approval File: H03-16-03). Participants were recruited from the Faculty of Engineering at the University of Ottawa. To qualify for the research, students had to be registered in an engineering design course that was offering students an authentic learning experience. The research needed a minimum sample size of 106 participants based on Tabachnick et al. [265] rules of thumb for cases-to-IVs ratio $N \geq 50 + 8m$ (where m is the number of IVs).

#### 4.4.1.1. Participant and data collection

I invited participants who were engineering students registered in first- and second-year engineering design courses that offer an authentic learning environment. Students were asked to complete an online questionnaire that included several demographic questions, a measure of their grit level, and an item related to their goal orientation. Students' personality traits were assessed as part of the course curriculum.

Data for this research were collected in the 2018 fall semester, 2019 winter semester, and 2019 fall semester. Of the 532 students who were invited to participate in the research, 349 full-time engineering students agreed. This sample of 349 consisted of 81 (23.2%) female participants. By year of study, 166 students were first-year students, 131 were second-year students, 26 were third-year students, and 25 were fourth-year students. The principal researcher shared the questionnaire links with the students at the beginning of the semester. Participation was voluntary. Students were not incentivized to participate in the research. Students were also free to elect to not participate without being subject to any penalties; they were also made aware that they could choose to be removed from the study at any time, and data related to them would be deleted.

#### 4.4.1.2. Measures

##### 4.4.1.2.1. The Big-Five personality traits

To give instructors in the engineering design courses a sense of the students' Big-Five personality traits, all students complete an online questionnaire developed by the Individual and Team Performance (ITP) lab at the University of Calgary [266]. The questionnaire is based on Goldberg's [267] International Personality Item Pool (IPIP). The measure consists of 24 items for each of the Big-Five personality traits. The tool uses a five-point Likert scale ranging from 1 (very inaccurate) to 5 (very accurate). The measure intends to capture the same content as the NEO Personality Inventory [206]. The mean reliabilities for these scales based on the sample data in the IPIP database (N = 21,588) were 0.76 and 0.87 for facets and factors, respectively [268].

Students’ Big-Five personality traits are assessed as part of the course’s curriculum. This exercise is part of the team building phase at the beginning of the course. I collected the Big-Five personality traits data pertaining to the students who elected to participate in the research.

#### 4.4.1.2.2. Grit

I administered a three-page questionnaire to students in the second week of the semester. The first page presented students with the consent form, which outlined the purpose of the research study and its conditions; students who agreed to the research’s terms and condition proceeded to view and complete the questionnaire. The second page contained demographic questions that asked students their names, year of study, gender, and what course were they registered in. The third page contained the eight-item Grit-S scale (also called the Short Grit Scale) developed by Duckworth and Quinn [14] to measure the students’ grit levels.

In Duckworth and Quinn’s validation study of the Grit-S scale [13], the perseverance of effort factor and consistency of interest factor showed adequate internal consistency of αs = .82, .70, .77 respectively. The scale consists of two factors: the first measures consistency of interest, and the second factor measures perseverance of effort. Respondents indicate their extent of agreement with each item on a 5-point scale with responses ranging from “1 = not at all like me” to “5 = very much like me”; items 2, 3, 5, 7 and 8 were reverse coded. Grit scores were calculated by averaging students’ responses to each item.

#### 4.4.1.2.3. Goal orientation

In addition to the Grit Scale, the study question included a one-item scale to assess students’ goal orientation. Students were asked about which concerns were more important to them in choosing courses — performance concerns or challenge-oriented learning concerns. The item is part of a goal choice measure developed by Dweck [269].

#### 4.4.1.2.4. Peer assessment

In the first- and second-year design courses considered for this study, peer assessment and feedback were gathered using the tool developed by the Individual and Team Performance (ITP) lab at the University of Calgary [270]. The tool is hosted at www.ITPmetrics.com, an online software platform that offers free research-backed team-based assessment and is funded by the Government of Canada [271]. The peer assessment tool — which is based on Ohland et al.'s [272] Comprehensive Assessment of Team Member Effectiveness [270] dimensions: communication, commitment, knowledge, skills and abilities, standards, and keeping the team on track — invites students to rate their peers on a five-point Likert scale and provide them with anonymous feedback on the five team member competencies that are associated with team effectiveness: commitment to the team's work, communicating with team members, having a strong foundation of knowledge, skills and abilities, emphasizing high standards, and keeping the team on track [271]. The tool provides each student with a peer rating average score that ranges from 0 to 5. The tool generates a report that presents students with anonymous feedback from their peers. Students then use this report to develop an action plan to improve on their strengths and weaknesses. A team debrief session is held during one of the lab sessions.

#### 4.4.1.2.5. Academic success

Students' academic success in the first- and second-year design courses is assessed by looking at their final course grade, which consists of their project mark adjusted to account for their individual contribution to their team's project using their peer assessment mark, midterm and final exam's grades and their client's assessment of their work.

### 4.4.2. Results

The following section provides a full discussion of the data collected, a summary of the descriptive statistics, statistical analysis of the data, and the results in relation to the research questions and hypotheses. The descriptive data collected to answer the Phase 1 research questions (using data collected in both Phase 1 and Phase 2) are presented first. I then proceed with reporting the results for each research question. I chose a standard significance level of α = .05 for all statistical inferences. Table 7 presents results of the Shapiro-Wilk test for normality. The Shapiro-Wilk test was developed to test departures from normality for small sample sizes [273]. The variables assessed in the study were not normally distributed as assessed by the Shapiro-Wilk test, a test that assesses whether a distribution of scores is significantly different from a normal distribution; a significance level less than 0.05 indicates a deviation from normality [274].

TABLE 7 - OVERVIEW OF THE SHAPIRO-WILK TEST FOR STUDY VARIABLES

| | Open-ness | Conscien-tiousness | Extra-version | Agree-ableness | Neuro-ticism | Grit | PE | CI | Peer assess-ment | Final marks |
|---|---|---|---|---|---|---|---|---|---|---|
| Shapiro-Wilk test statistic | .975 | .975 | .925 | .927 | .988 | .989 | .978 | .969 | .854 | .858 |
| *p* | .000 | .000 | .000 | .000 | .021 | .012 | .000 | .000 | .000 | .000 |

In conducting this analysis, I followed Cohen's [275] guidelines for describing the relationship between the independent variables and the dependent variable. Cohen [275] describes ($r = 0.1$) as a small effect size, ($r = 0.3$) as a medium effect size, and ($r = 0.5$) as a large effect size. However, Cohen stresses that researchers should describe their effect sizes relative to their literature and their own field's appropriate standards and operational definitions. Although Cohen's guidelines and descriptions might not accurately describe the impact of effect sizes in the area of research on academic performance and outcomes, as even an effect size described as small by Cohen's guidelines might have large impact on practices and students' performances, researchers have used Cohen's guidelines widely in the literature [190]. For this reason alone, I am using Cohen's guidelines to stay consistent within the area of research.

1(a) What is the association between students’ grit and their personality traits?

A Pearson product-moment correlation coefficient was computed to assess the relationship between students’ personality traits, grit, peer assessment marks, and final marks. Table 8 presents descriptive statistics and intercorrelations among all study variables. Grit had a statistically significant, moderate positive correlation with conscientiousness ($r = .320$, $p < .01$), a small positive correlation with extraversion ($r = .126$, $p < .05$), a small positive correlation with agreeableness ($r = .144$, $p < .05$), and a moderate negative correlation with neuroticism ($r = -.301$, $p < .01$). Perseverance of effort had a statistically significant small positive correlation with conscientiousness ($r = .198$, $p < .05$) and agreeableness ($r = .186$, $p < .05$) and a statistically significant small negative correlation with neuroticism ($r = -.295$, $p < .01$).

TABLE 8 - MEANS, STANDARD DEVIATION, AND BIVARIATE CORRELATIONS FOR GRIT, SELF-REGULATED LEARNING, AND ACHIEVEMENT VARIABLES

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 Openness | - | | | | | | | | | |
| 2 Conscientiousness | .000 | - | | | | | | | | |
| 3 Extraversion | .376** | .057 | - | | | | | | | |
| 4 Agreeableness | .193** | .313** | -.184** | - | | | | | | |
| 5 Neuroticism | .075 | -.416** | .111 | -.372** | | | | | | |
| 6 Grit-S | -.048 | .320** | .126** | .144* | -.301** | | | | | |
| 7 Perseverance of effort | -.111 | .198** | -.080 | .186** | -.295** | .751** | | | | |
| 8 Consistency of interest | .055 | .257** | .284** | .006 | -.115 | .661** | .002 | | | |
| 9 Peer assessment | .126* | .015 | .113 | .006 | .125 | -.003 | -.060 | .063 | | |
| 10 Final mark | .111 | .061 | .113 | -.093 | .143* | .000 | -.101 | .114 | .523** | |
| Number | 262 | 262 | 262 | 262 | 262 | 346 | 346 | 346 | 302 | 349 |
| Mean | 2.11 | 2.92 | 2.32 | 2.74 | 2.09 | 3.38 | 3.11 | 3.55 | 4.42 | 80.5 |
| Standard deviation | .153 | .208 | .211 | .178 | .181 | .562 | .842 | .742 | .543 | 9.73 |
| Cronbach’s Alpha | - | - | - | - | - | .731 | .632 | .729 | - | - |

* $p < .05$ , ** $p < .005$ ,*** $p < 0.0005$

Consistency of interest had a statistically significant small positive correlation with conscientiousness ($r = .257$, $p < .01$) and extraversion ($r = .284$, $p < .01$). Grit and both of its subdimensions had no statistically significant correlation with students’ peer assessment marks or final marks in the course. Peer assessment marks had a statistically significant positive small correlation with openness ($r = .126, p < .05$). Students' final marks had a statistically significant positive small correlation with neuroticism ($r = .143, p < .01$). There was a statistically significant moderate positive correlation between students' final marks and their peer assessment marks ($r = .523, p < .01$); however, this relationship is because peer assessment marks are factored in calculating student's final marks.

The results of the bivariate correlation analysis indicated that grit and its subdimensions were correlated with some of the Big-Five personality traits. Accordingly, I followed up with a standard multiple regression to examine the relationship between students' grit scores and their personality traits. The dependent variable was students' grit score, while the independent variables were the personality traits of openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism. There was linearity as assessed by partial regression plots and a plot of studentized residuals against the predicted values. There was independence of residuals, as assessed by a Durbin-Watson statistic of 2.002. There was no evidence of multicollinearity, as assessed by tolerance values greater than 0.1. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values. There were no studentized deleted residuals greater than ±3 standard deviations, no leverage values greater than 0.2, and no values for Cook's distance above 1. The assumption of normality was met, as assessed by a Q-Q Plot.

The multiple regression model statistically significantly predicted 18.8% of the variance in students' grit scores, $F(5, 253) = 11.677$, $p < .0005$, $R2 = .188$, adj. $R2 = .17$. The regression equation is the following: student's grit score = 3.104 + (-.107) * openness + (.151) conscientiousness + (.124) extraversion + (.033) agreeableness + (-.138) neuroticism. Four personality traits from the Big-Five personality traits added statistically significance to the prediction, $p < .05$: openness $B = -1.07$, $t(258) = -1.997$, $p = .047$, 95% CI [-.231, -.002]; conscientiousness $B = .151$, $t(258) = 3.91$, $p < .0005$, 95% CI [.075, .228]; extraversion $\beta = .124$, $t(258) = 3.461$, $p = .001$, 95% CI [.053, .194]; and neuroticism $B = -.138$, $t(258) = -3.19$, $p = .002$, 95% CI [-.223, -.053]. Students' personality traits of openness to experience, conscientiousness, and extraversion positively predicted their grit score. Students' personality trait of neuroticism, on the other hand, negatively predicted their grit score. The personality trait of agreeableness had no significant association with students' grit score ($p = 0.498$). Regression coefficients and standard errors can be found in Table AE-14 shown in Appendix E.

Table AE-15, shown in Appendix E, presents another secondary multiple regression analysis for the subdimensions of grit — perseverance of effort and consistency of interest. As shown in table AE-15, the regression model predicting perseverance of effort from personality traits was statistically significant; the regression equation is the following: students' perseverance of effort score = 2.689 + (-.063) * openness + (.226) conscientiousness + (.239) extraversion + (-.043) agreeableness + (-.052) neuroticism. The regression model accounted for 15.4% of the variance in students' perseverance of effort scores $F(5, 258) = 10.414$, $p < .0005$.

Conscientiousness and extraversion were significant positive predictors of students' perseverance of effort. The regression model predicting students' consistency of interest scores from their Big-Five personality traits accounted for 9.6% of the variance in students' consistency of interest scores, $F(5, 258) = 6.498$, $p < .0005$. The regression equation is the following: students' consistency of interest scores = 3.511 + (-.150) * openness + (.077) conscientiousness + (.009) extraversion + (.110) agreeableness + (-.224) neuroticism. Only neuroticism was a significant negative predictor of students' consistency of interest scores.

A one-way analysis of variance (ANOVA) was conducted to determine if students' grit, perseverance of effort, and consistency of interest were different for student groups with different learning goals orientation. Participants were classified into two groups — challenge-oriented ($n = 115$) and performance-oriented ($n = 231$) — based on their answers to the goal-orientation item of the questionnaire, which asked students which concerns were more important to them in choosing courses: performance concerns or challenge-oriented learning concerns. However, for all three dependent variables, the data did not pass the absence of outliers and normal distribution for each group. Hence, I followed up with a Kruskal-Wallis test. Distributions of students' grit scores were similar for all groups, as assessed by visual inspection of a boxplot. Median grit scores were statistically significantly different between students with a challenge-oriented learning goal (3.50) and students with a performance-oriented learning goal (3.38), $\chi 2(1) = 9.452$, $p = .002$. Distributions of perseverance of effort scores were similar for all groups, as assessed by visual inspection of a boxplot. Median perseverance of effort scores were statistically significantly different between students with a challenge-oriented learning goal (3.75) and students with a performance-oriented learning goal (3.25), $\chi 2(1) = 13.370$, $p < .0005$. Distributions of consistency of interest scores were similar for all groups, as assessed by visual inspection of a boxplot. Median consistency of interest scores were not statistically significantly different between students with a challenge-oriented learning goal (3.50) and students with a performance-oriented learning goal (3.25), $\chi 2(1) = 1.301$, $p = .254$.

### 1(b) Can student personality traits, grit, and goal orientation predict students' peer assessment marks and final marks?

To understand the relationship between students' personality traits, grit level, and goal orientation and their peer assessment marks and final marks, I conducted a set of two hierarchical regressions in which the Big-Five personality traits and the two subdimensions of grit were used to predict two dependent variables: students' peer assessment marks and final marks. Hierarchical regression was run to determine if the addition of grit improved the prediction of students' peer assessment marks and final marks over and beyond personality traits alone. These regressions were completed in three steps, with the Big-Five personality traits entered in the first block, followed by the two subdimensions of grit (perseverance of effort and consistency of interest) in the second, and the students' goal orientation in the third. Overall, the Big-Five personality traits alone accounted for about 9.1% of the variance in students' final marks, F(5, 196) = 3.931, p = .002. The regression equation is the following: students' final marks = 68.891 + (-1.478) * openness + (2.206) conscientiousness + (-.312) extraversion + (-1.038) agreeableness + (1.639) neuroticism + (1.723) perseverance of effort + (-1.057) consistency of interest + (.238) students' goal orientation. In this first step, two independent variables were significant predictors of students' final marks, namely conscientiousness, B = 2.585, t(201) = 3.788, p < .0005, 95% CI [1.239, 3.931], and neuroticism B = 1.168, t(207) = 2.471, p = .014, 95% CI [.236, 2.10]. Adding the two subdimensions of grit to the second block significantly increased the amount of variance that could be accounted for in the students' final marks, ΔR2 = .034, F(7, 194) = 3.971, p < .0005. In the second block three variables statistically significantly predicted students' final marks in the course: conscientiousness, B = 2.233, t(201) = 3.229, p = .001, 95% CI [.869, 3.597], neuroticism B = 1.650, t(201) = 2.204, p = .029, 95% CI [.173, 3.127], and perseverance of effort, B = 1.707, t(201) = 2.182, p = .030, 95% CI [.164, .3.250]. In contrast, consistency of interest did not significantly predict students' final marks in the course. In the third step, students' goal orientation did not significantly predict students' final marks; therefore, individual results for predictors of students' final marks and this dependent variable are not presented or discussed further. Results for these analyses are presented in table AE-16 presented in Appendix E.

In the final model, I entered the Big-Five personality traits in the first block, followed by the perseverance of effort and consistency of interest scores in the second block, and students' goal orientation in the third block, in order to determine their predictability of the students' peer assessment marks. Results of evaluations of assumptions led to a transformation of the dependent variable — students' peer assessment marks — to reduce skewness and the number of outliers and to improve normality, linearity, and homoscedasticity of residuals. Results for these analyses are presented in table AE-17 shown in Appendix E.

A reflect and logarithmic transformation was used on peer assessment marks. The first block significantly predicted (the reflection and log of) students' peer assessment marks, F(5, 234) = 2.915, p = .014. In this first step, two independent variables were significant predictors of (the reflection and log of) students' peer assessment marks — conscientiousness, B = .023, t(239) = 2.233, p = .026, 95% CI [.026, .004], and neuroticism B = .039, t(239) = 2.379, p = .018, 95% CI [.007, .071].

However, adding the two subdimensions of the grit construct in the second step and adding students' goal orientation to the regression model in the third step did not significantly predict (the reflection and log of) students' peer assessment marks; therefore, results of step 2 and 3 of the regression analysis are not discussed. The regression equation of the first step model is the following: (the reflection and log of) students' peer assessment marks = .420 + (-.029) * openness + (.032) conscientiousness + (.012) extraversion + (.008) agreeableness + (.039) neuroticism.

## 4.5. Phase 2 of the research

Phase 2 expanded on Phase 1. First, after completing the data collection in Phase 1, I wanted to expand the study to explore another hypothesis linked to the literature on the development of project ownership. Since students' development of project ownership is associated with their persistence in the face of challenges [61], [261], I hypothesized that students who demonstrate higher levels of grit will successfully develop intellectual and emotional ownership of their making projects. To explore the association between the grit construct and the construct of project ownership, I added a scale that measures the construct of project ownership in the study's questionnaire. Second, after an initial analysis of the data collected in the fall semester of 2018 and the winter semester of 2019, I found that students' grit level as measured by the Grit-S [14] did not predict their individual contribution to their team project or their academic success in the course. I decided to add an updated measure of grit that was developed after a review of the Grit-S by Datu et al.: the Triarchic Model of Grit Scale (TMGS). In addition, to examine the construct validity of grit over persistence and to examine if persistence has any predictive ability over students' individual contribution to their team project or their academic success, I introduced another validated measure of persistence. This comparative measure of persistence was extracted from the Value in Action (VIA) Survey of Character Strengths [276] and incorporated into the study to examine the predictive validity of persistence and its association with the study's dependent variables — that is, the learning outcomes: final marks, peer assessments, and project ownership — as measured by the Grit-S and TMGS.

Phase 2 addressed three research questions:

2(a) What is the incremental validity of the TMGS over and beyond the Big-Five personality traits in predicting students' project ownership, peer assessment marks, and final marks, specifically compared with the Grit-S scale and the VIA persistence scale?

I hypothesized that grit scores as calculated by the TMGS would be positively associated with students' final marks, peer assessment marks, and development of intellectual and emotional project ownership. I also hypothesized that grit as measured with TMGS would be a better predictor of academic outcomes in an authentic learning environment than persistence or the Grit-S scale.

2(b) Is there a relationship between students' development of intellectual or emotional project ownership and their individual contribution to their team's project or their final marks in the course?

I hypothesized that students who develop higher intellectual and emotional ownership would have higher final and peer assessment marks.

2(c) Is students' goal orientation associated with their development of intellectual and emotional ownership of their team's project?

I hypothesized that students who have a challenge-oriented learning goal would develop higher intellectual and emotional ownership than students who have a performance-oriented learning goal.

### 4.5.1. Method

#### 4.5.1.1. Participants and data collection

Data collection for Phase 2 was conducted in the fall semester of 2019. A total of 132 students participated in the study; 25 (18.9%) were female students. In terms of year of study, 36 students were first-year students, 74 were second-year students, 15 were third year students, and 7 were fourth-year students. Participants were registered in the first- and second-year introductory engineering design courses that aim to offer students an authentic learning environment.

To answer the questions posed in Phase 2, I modified the questionnaire used in the Phase 1 to include the new constructs of project ownership and persistence, as well as the new elements of the TMGS. The data collection process in Phase 2 was split into two parts.

The first part was a modified version of the questionnaire used in Phase 1 to include elements of the TMGS. The Big-Five personality traits data were obtained from the professors, who had administered a personality assessment exercise at the first week of the semester to facilitate team building.

The second part of the data collection process in Phase 2 was administered at the end of the course to assess students' project ownership. The questionnaire used included demographic questions that asked students their name, the course they were registered in, and elements of the project ownership scale developed by Hanauer et al. [15].

#### 4.5.1.2. Procedure and measures

Phase 2 included three more measures than in Phase 1: the TMGS, and the Values in Action persistence scale, and a project ownership scale.

##### 4.5.1.2.1. Triarchic Model of Grit Scale (TMGS)

In the second week of the semester, I administered a modified version of the Phase 1 questionnaire to students who were taking part in the study. Their grit was also calculated using an 11-item scale developed by Datu et al. [277]. The scale includes three dimensions: perseverance of effort (TMGS-PE), consistency of interest (TMGS-CI), and adaptability to situations TMGS-ATS). Adaptability to situations refers to an individual's ability to adapt to changing circumstances in life [277]. Six of the 11 items are from Duckworth's Grit-S scale [14], and the additional five items measure students' adaptability to situations. Items are rated on 5-point Likert-type scale (1 = Not like me at all; 5 = Very much like me). In their validation study of the Triarchic Model of Grit Scale, Datu et al. [277] the internal reliability of the scale's dimensions were αs = .84, .84, .88 respectively.

#### 4.5.1.2.2. Values in Action persistence scale

A fourth page was added to the modified Phase 1 questionnaire to measure students' persistence. Persistence was measured using the eight-item scale from the International Personality Item Pool (IPIP) Values in Action Inventory of Strengths.

#### 4.5.1.2.3. Project ownership scale

Students' feelings of intellectual and emotional project ownership were measured at the end of the course using a 16-item Likert-style survey that was developed based on a two-year study by Hanauer et al. [15]. The survey consists of two subscales: the cognitive ownership subscale is a 10-item five-point scale that assess the degree to which students feel they have intellectual ownership over their work, assigning them a "project ownership-content" (POC) score; and the emotional ownership subscale is a 6-item scale that asks students to rate on a five-point scale their strength of emotions towards their work assigning them a "project ownership-emotion" (POE) score. The survey has an internal reliability of $\alpha = 0.86$ for the cognitive ownership subscale and $\alpha = 0.85$ for the emotional ownership subscale. I have replaced the word "lab" from the original scale with the word "project" in our study to be more accurate in describing the subject of the assessment in this study which is students' ownership of their design project.

### 4.5.2. Results and discussion

Table 9 presents descriptive statistics and intercorrelations among all study variables. The score for cognitive project ownership — referred to as project ownership-content (POC) — had a significant negative small correlation with agreeableness ($r = -.279$, $p < .05$) and a small positive correlation with neuroticism ($r = .328$, $p < .05$). The score for emotional project ownership — referred to as project ownership-emotions (POE) — had a significant positive strong correlation with POC (r = .637, p < .01). The adaptability to situations (ATS) score (from the TMGS) had a significant positive small correlation with openness (r = .234, p < .01), extraversion (r = .212, p < .05), and consistency of interest (r = .204, p < .05), POC (r = .292, p < .01), POE (r = .259, p < .05); ATS also had a significant positive moderate correlation with grit (r = .378, p < .01) and perseverance of effort (r = .448, p < .01)and a small negative correlation with neuroticism (r = -.259, p < .01). The persistence score as measured with the VIA scale had a significant strong positive correlation with grit (r = .709, p < .005), perseverance of effort (r = .672, p < .005), and consistency of interest (r = .516, p < .005); it also had a significant moderate positive correlation with ATS (rβ = .339, p < .005), a small positive correlations with conscientiousness (r = .260, p < .01) and extraversion (r = .198, p < .05), and a significant small negative correlation with neuroticism (r = -.280, p < .05) and POC (r = -.269, p < .05).

2.A. What is the incremental validity of the TMGS in predicting students' project ownership, peer assessment marks, and final marks, specifically compared with the Grit-S scale and the VIA persistence scale?

Next, I performed a set of four multiple regressions to examine the incremental validity of the TMGS in predicting students' final marks, peer assessment marks, and project ownership-content (POC) and project ownership-emotions (POE) scores. The independent variables included in each of the four models were openness to experience, conscientiousness, extraversion, agreeableness, neuroticism, and TMGS. I entered the Big-Five personality traits in Step 1; the TMGS score was entered in Step 2. Cases with missing data where a student had dropped the course or elected not to complete the initial personality assessment test, the TMGS, or the project ownership questionnaire were excluded from each analysis.

### TABLE 9 - MEANS, STANDARD DEVIATIONS AND BIVARIATE CORRELATIONS FOR PERSONALITY TRAITS, GRIT, PEER ASSESSMENT MARKS, FINAL MARKS, PROJECT OWNERSHIP, ADAPTABILITY TO SITUATIONS, AND PERSISTENCE VARIABLES

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Openness | | | | | | | | | | | | | | | |
| 2 Conscientiousness | -.016 | | | | | | | | | | | | | | |
| 3 Extraversion | .450** | -.181 | | | | | | | | | | | | | |
| 4 Agreeableness | .054 | .337** | -.475** | | | | | | | | | | | | |
| 5 Neuroticism | .301** | -.361** | .398** | -.520** | | | | | | | | | | | |
| 6 Grit-S | .013 | .292** | .236* | -.008 | -.268** | | | | | | | | | | |
| 7 Perseverance of effort | .079 | .223* | .229* | .033 | -.277* | .777** | | | | | | | | | |
| 8 Consistency of interest | -.045 | .263** | .172 | -.039 | -.182 | .866** | .002 | | | | | | | | |
| 9 Peer assessment | .108 | -.066 | .037 | -.032 | .175 | .092 | -.060 | .063 | | | | | | | |
| 10 Final mark | .248* | .058 | .117 | -.049 | .232* | -.112 | -.109 | .105 | .583** | | | | | | |
| 11 POC | .140 | -.230 | -.002 | -.279* | .328** | -.127 | -.179 | -.042 | .014 | -.030 | | | | | |
| 12 POE | .214 | -.041 | .016 | -.116 | .231 | .147 | -.152 | -.096 | .025 | .153 | .637** | | | | |
| 13 TMGS | .103 | .293** | .244* | .078 | -.306** | .841** | .724** | .672** | .118 | -.125 | -.241* | -.225* | | | |
| 14 ATS | .234* | .173 | .212* | .147 | -.259** | .378** | .448** | .204* | .101 | -.084 | -.292** | -259* | .777* | | |
| 15 Persistence | .006 | .260** | .198* | .025 | -.280** | .709** | .672** | .516** | .154 | -.007 | -.269* | -.132 | .625** | .339** | |
| Number | 108 | 108 | 108 | 108 | 108 | 129 | 129 | 129 | 101 | 92 | 81 | 81 | 129 | 129 | 127 |
| Mean | 2.02 | 2.97 | 1.98 | 2.85 | 1.94 | 3.47 | 3.82 | 3.13 | 4.34 | 76.95 | 2.43 | 2.89 | 3.77 | 4.06 | 3.87 |
| Standard deviation | .630 | 1.12 | 1.20 | .744 | .942 | .538 | .576 | .725 | .522 | 11.57 | .589 | .758 | .462 | .595 | .562 |
| Cronbach's Alpha | - | - | - | - | - | .72 | .60 | .72 | - | - | .828 | .853 | .756 | .763 | .776 |

$* p < .05$ , $** p < .005$ ,$*** p < 0.0005$

Results of the evaluation of assumptions led to the transformation of one dependent variable to reduce skewness, reduce the number of outliers, and improve the normality, linearity, and homoscedasticity of residuals. Peer assessment marks were transformed using a reflection and log transformation.

As presented in tables AE-18 and AE-19 in Appendix-E, the set of variables entered in the first block statistically significantly predicted students' POC score, R2 = .213, Adj. R2 = .153, F (5, 65) = 3.528, p = .007, students' final marks R2 = .286, Adj. R2 = .233, F (5, 67) = 5.373, p < .0005. The first block did not statistically predict students' POE, R2 = .105, F (5, 65) = 1.519, p = .196, nor did it predict (reflect and logarithmic) students' peer assessment marks, R2 = .054, F (5, 97) = 1.098, p = .366. In the first block, three personality traits added statistically significantly to predicting students' POC scores: openness, B = .274, t(71) = 2.079, p = .042, 95% CI [.011, .538]; extraversion, B = -.168, t(71) = -2.275, p = .026, 95% CI [-.316, -.021]; and agreeableness B = -.305, t(71) = -2.168, p = .034, 95% CI [-.586, -.024]. As for the model predicting students final marks, three personality traits added significantly to the model: openness B = 4.166, t(72) = 2.717, p = .008, 95% CI [1.105, 7.226]; conscientiousness, B = 2.658, t(72) = 3.637, p = .001, 95% CI [1.199, 4.117]; and neuroticism, B = 2.60, t(72) = 2.605, p = .011, 95% CI [.608, 4.593].

Adding the TMGS variable in the second block significantly increased the amount of variance that could be explained for the POC score, Adj. R2 = .193, ΔR2= .049, F(6, 64) = 3.796, p = .003, and students' POE score — although the regression model wasn't statistically significant, Adj. R2 = .090, ΔR2= .063, F(6, 64) = 2.153, p = 0.059. The amount of variance explained did not increase for students' peer assessment marks, ΔR2= .025, F(6, 97) = 1.364, p = .237, nor for students' final marks, ΔR2= .001 F(6, 66) = 4.437, p = 0.001. In the second step, TMGS was a statistically significant positive predictor of students' POC scores, B = -.030, t(70) = -2.062, p = .043, 95% CI [-.058, -.001], and POE scores, B= 3.569, t(72) = 2.621, p = .011, 95% CI [.849, 6.290].

To compare the predictive ability of the TMGS with the Grit-S scale and the Values in Action persistence scale, I repeated the same multiple regression analyses again while replacing the variable in the second block, TMGS, with the Grit-S score and the VIA persistence score. Adding students' grit scores as measured by Duckworth's Grit-S did not add significantly to predicting students' project ownership-content score, B = -.190, p = .163, their project ownership-emotions score, B = -.319, p = .087, their peer assessment scores, B = -.182, p = .124, or their final marks B = 1.049, p = .521. Similarly, adding the VIA persistence scale in the second block did not add significantly to predicting students' project ownership-content score, B = -.229, p = .071, their project ownership-emotions score, B = -.187, p = .288, their peer assessment scores B = .120, p = .313, or their final marks, B = 1.947, p = .214.

Subsequent linear regression analysis was conducted to examine the incremental validity of the adaptability to situations subdimension of the TMGS to predict students' final marks, per assessment marks, and project ownership-content and project ownership-emotions scores. Regression analysis results are presented in table AE-20 found in Appendix E. The regression established that adaptability to situations statistically significantly predict project ownership-content, R2 = .085, F(1, 78) = 7.260, p = .009, adj. R2 = .073, and project ownership-emotions, R2 = .067, F(1, 78) = 5.631, p = .02, adj. R2 = .055. ATS did not statistically predict peer assessment mark, F(1, 97) = .964, p = .329, nor did it predict students' final marks F(1, 87) = .616, p = .435.

2.B. Is there a relationship between students' development of intellectual or emotional project ownership and their individual contribution to their team's project or their final marks in the course?

To understand if there is a relationship between students' feelings of intellectual or emotional ownership on their peer assessment marks or final marks, a multiple regression analysis was conducted to predict students' peer assessment marks from their project ownership-content and project ownership-emotions scores. The results of the evaluation of assumptions led to the transformation of one dependent variable — peer assessment marks — to reduce skewness, reduce the number of outliers, and improve the normality, linearity, and homoscedasticity of residuals. A reflection and log transformation was used on students' peer assessment marks. Project ownership-content and project ownership-emotions did not statistically significantly predict (reflection and log of) students' peer assessment marks, F (2,55) = .017, p = .984, nor did it statistically significantly predict students' final marks F (2,54) = 1.493, p = .234.

2.C. Is there an association between students' goal orientation and their development of intellectual and emotional ownership of their team's project?

To determine the impact of students' learning goals on their development of intellectual and emotional project ownership, I conducted a one-way ANOVA. Students were classified into two groups: challenge-oriented learning goal (n = 27) and performance-oriented learning goal (n = 54). Data are presented as mean ± standard deviation. Project ownership-content scores were lower for students who had a performance goal (2.39 ± 0.53) than a challenge goal (2.49 ± .70), and project ownership-emotions scores were lower for students who had a performance goal (2.83 ± 0.77) than a challenge goal (2.84 ± .70), but the differences between two students groups for both variables were not statistically significant, POC: F(1, 79) = .477, p = .492; POE: F(1, 79) = .007, p = .932.

### 4.6. Overall summary of results

In this section, I provide a summary of the results of the study in relation to the main research questions presented in section 4.2.1. The first research question explored if between students' personality traits, grit and goal orientation can predict students' peer assessment marks, final marks, and project ownership. Conscientiousness, Neuroticism and perseverance of efforts had a positive relationship with students' final marks and peer assessment marks. Grit's subdimension of perseverance of efforts was positively associated with student's final marks however, it had no statistically significant relationship with students' peer assessment marks. Table 10 presents a summary of the multiple regression analyses between students' characteristics and their final marks and peer assessment marks.

**TABLE 10 - SUMMARY OF REGRESSION ANALYSIS RESULTS EXAMINING THE ASSOCIATION BETWEEN STUDENTS' CHARACTERISTICS & THEIR FINAL MARKS & PEER ASSESSMENT MARKS**

| Students' Characteristics | Predictor | Final Marks | Peer Assessment Marks |
|---|---|---|---|
| Personality traits | Openness | No | No |
| | Conscientiousness | + | + |
| | Extraversion | No | No |
| | Agreeableness | No | No |
| | Neuroticism | + | + |
| Grit | Perseverance of Efforts | + | No |
| | Consistency of Interests | No | No |
| Goal Orientation | Learning Goal Orientation | No | No |
| | Adj. R2 | 8.9% | 3.9% |

* No = Absence of a statistically significant relationship between the variables; + = A positive statistically significant relationship; - = A negative statistically significant relationship

Further analysis was conducted between students' girt level measured with a more up to date scale with their final marks and peer assessment marks to compare it with the previous results obtained using the Grit-S scale. The results remained consistent with perseverance of efforts being the only subdimension of grit that had a positive association with students' final marks. Grit when measured using both scales didn't have any statistically significant relationship with students' peer assessment marks. Table 11 presents a comparison between each grit scale's ability to predict students' final marks or peer assessment marks.

**TABLE 11 - A COMPARISON OF GRIT'S SUBDIMENSIONS' RELATIONSHIP WITH STUDENTS' FINAL MARKS & PEER ASSESSMENT MARKS MEASURED USING TWO DIFFERENT GRIT SCALE**

| Predictor | Final Marks | | Peer Assessment Marks | |
|---|---|---|---|---|
| Phase of Data Collection | Phase 1 | Phase 2 | Phase 1 | Phase 2 |
| Grit Measure | Grit-S | TMGS | Grit-S | TMGS |
| Perseverance of Efforts | + | + | No | No |
| Consistency of Interests | No | No | No | No |
| Adaptability to Situations | N/A | No | N/A | No |
| Adj. R2 | 9.4% | 2.8% | 3.7% | Not significant |

* No = Absence of a statistically significant relationship between the variables; + = A positive statistically significant relationship; - = A negative statistically significant relationship

Conscientiousness, extraversion and perseverance of efforts had a statistically positive relationship with students' development of intellectual ownership with their projects. Openness on the other had had a negative relationship with students' development of intellectual ownership with their projects. Overall, students' personality traits and grit predicted 19.3% of the variance in students' POC scores. There wasn't a statistically significant relationship between students' personality traits or grit and their development of emotional ownership of their projects. Table 12 presents a summary of the results of the regression analysis predicting students' intellectual and emotional project ownership. The third student characteristic considered in the study, students' goal orientation, had no statistically significant association with students' development of intellectual or emotional ownership of their projects. An analysis of variance test revealed that there were no statistically significant differences in POC or POE scores between students' who adopted a learning goal orientation or those who had a performance goal orientation.

### TABLE 12 - SUMMARY OF REGRESSION ANALYSIS RESULTS EXAMINING THE ASSOCIATION BETWEEN STUDENTS' CHARACTERISTICS & THEIR DEVELOPMENT OF INTELLECTUAL AND EMOTIONAL PROJECT OWNERSHIP

| Students' Characteristics | Predictor | POC | POE |
|---|---|---|---|
| Personality traits | Openness | - | No |
| | Conscientiousness | + | No |
| | Extraversion | + | + |
| | Agreeableness | No | + |
| | Neuroticism | No | + |
| Grit | Grit (TMGS) | + (4%) | No |
| | Adj. R2 | 19.3% | Not Significant |

* No = Absence of a statistically significant relationship between the variables; + = A positive statistically significant relationship; - = A negative statistically significant relationship

The second research question considered in this study looked at the relationships between the three students' characteristics considered in this study. First, a multiple regression analysis was conducted to investigate the association between students' Big-Five personality traits and students' grit. Conscientiousness and extraversion had a statistically positive relationship with grit while openness and extraversion had negative relationships with grit. Table 13 presents a summary of the multiple regression analysis assessing the relationship between students' predicting students' grit score from their personality traits.

An analysis of variance test revealed that students' goal orientation was statistically significantly associated with their grit score. Students' who adopt a learning goal orientation were grittier than their peers who adopt a performance goal orientation. Figure-3 presents the means plot for grit scores of each student group.

TABLE 13 - SUMMARY OF REGRESSION ANALYSIS RESULTS EXAMINING THE ASSOCIATION BETWEEN STUDENTS' BIG-FIVE PERSONALITY TRAITS AND GRIT

| Students Characteristics | Predictor | Grit |
|---|---|---|
| Personality Traits | Openness | - |
| | Conscientiousness | + |
| | Extraversion | + |
| | Agreeableness | No |
| | Neuroticism | - |
| | Adj. R2 | 18% |

* No = Absence of a statistically significant relationship between the variables; + = A positive statistically significant relationship; - = A negative statistically significant relationship

The third research question aimed to assess if students' development of intellectual or emotional project ownership impacts their academic success or their individual contribution to their team's project. A multiple regression analysis was conducted to answer the research question. Results of the regression analysis revealed that project ownership was not associated with students' final marks F (2,55) = .017, p = .984; nor with students' peer assessment F (2,54) = 1.493, p = .234.

FIGURE 3 - MEANS PLOT OF STUDENTS' GRIT SCORE BASED ON THEIR GOAL ORIENTATION

## 4.7. General discussion

This research was conducted to test the role of three non-cognitive measures — personality traits, grit, and goal orientation — in explaining academic success in authentic learning environments. I considered three variables to quantify students' learning in the learning environment under study: students' final marks in the course, their peer assessment marks, and their development of intellectual and emotional ownership of their projects. In addition, I explored the association between grit and the students' Big-Five personality traits.

### 4.7.1. Grit's association with personality traits and students' goal orientation

The correlation analyses conducted in the study show that personality traits are significantly related to students' grit scores. The regression analysis further clarified the relationships between the Big-Five personality traits and grit. First, all the Big-Five personality traits except for agreeableness were associated with students' grit. Second, perseverance of effort was positively related to conscientiousness and extraversion. Third, neuroticism was negatively related to consistency of interest. Fourth, openness was a significant predictor of grit only at the higher construct and not for its two subdimensions.

These results suggest there is a strong overlap between conscientiousness and the perseverance of effort dimension of grit and provides more evidence for the critique to the grit construct from Credé et al. [190] that grit might be a repackaging of the conscientiousness trait. The negative relationship between the personality trait of neuroticism and consistency of interest is similar to findings of Grohman et al. [278]. In their study of the relationship between passion and perseverance and creativity, they found that the consistency of interest dimension of grit is not associated with passion as assessed by teachers and, in line with the finding of the study discussed in this chapter, that consistency of interest was negatively associated with neuroticism. They argued that the consistency of interest dimension of grit is akin to the narrower construct of commitment and lacks the emotional component and personal investment in an activity that is included in conceptualizations of passion in the literature. Hence, the negative relationship between consistency of interest and neuroticism and the positive relationship with conscientiousness provide further evidence that the consistency of interest dimension of grit demonstrates an individual’s commitment rather than passion.

The results of the study also indicate that students who have challenge-oriented learning goals — that is, students whose goal is to improve their abilities — are grittier than their peers with performance-oriented learning goals — students whose goal is to gain favourable judgment over their abilities. The reason for this difference in grit scores could be because students with a performance-oriented learning goal persevere less on long-term goals than those who have a challenge-oriented learning goal.

### 4.7.2. Impact of personality traits on academic success in authentic learning courses

I found that students’ personality traits are associated with their academic success and the level of their contribution to their team’s project in an authentic learning environment. Personality traits accounted for 9.1% of the variance in their final marks. Conscientiousness and neuroticism were strong predictors of students’ final marks in the course and their contribution to their team’s projects as assessed by their peer assessment marks. But I did not find any association between students’ academic success and level of contribution to their team’s project with the other three personality traits: openness to experience, extraversion, and agreeableness.

Students’ conscientiousness had a clear positive effect on their final mark in the course. It is only logical that hard-working, organized, diligent, and industrious students perform better academically and receive a higher peer assessment mark from their peers in relation to their contribution to the completion of their project in an authentic learning environment. Also, conscientiousness students are more likely to be motivated to learn [213], which can explain why in a learning environment where the students have more control over their learning, those who are more intrinsically motivated to learn perform better. This result is also similar to previous studies on the predictive ability of personality traits that found conscientiousness is a robust predictor of academic success [199], [210], [200], [279].

Neuroticism also was a predictor of students’ final and peer assessment marks. This finding may indicate that a degree of neuroticism might be useful to students’ success in an authentic learning environment. Although there has been some correlational evidence in the literature that suggests emotionally stable students perform better academically than neurotic students due to the debilitating effects of anxiety [280], empirical research on personality traits points to a different relationship between neuroticism and performance. Prior studies on neuroticism have found that highly neurotic individuals’ levels of worry, anxiety, and sensitivity to potential negative outcomes can lead to them to be more prepared and exert more effort, which in turn might lead to better performance [281], [282]. Findings from Smillie et al. [282] attribute the academic success of neurotic students to them putting more effort towards their project and learning process. In a study exploring the association between personality traits and retention in first- and second-year engineering program at East Carolina University, Hall et al. [191] noted that neuroticism is positively associated with overall effort, intensity, focus, performance, and retention; they also reported an overlap between conscientiousness and neuroticism. Other studies on different groups have also found similar results. In their study of association between personality traits and academic achievement, Rosander et al. [210] found that students who rated higher on neuroticism attained higher grades in language and practice topics. Komarraju et al. [209] also found a positive association between neuroticism and academic achievement and suggested that anxiety about failure might prompt students to prepare compulsively for exams. Although these results suggest that a degree of neuroticism might be associated with a better performance, neuroticism is still associated with conflict, anger, anxiety, and stress [280], [283], and further research is needed to examine exactly how much neuroticism is helpful for students and to explore its relationship with performance in different learning environments. Research is also needed to explore at what point neuroticism becomes a liability to students' learning and academic success.

These findings suggest that the personality traits of conscientiousness and neuroticism play a positive role in students' academic success and students' level of contribution to a team project in engineering design courses. For engineering educators, these results suggest it may be important to promote traits of perseverance, organization, and diligence. These findings also draw attention to the positive relationship between neuroticism and academic performance in authentic learning environments and might direct educators to provide more support to neurotic students so that their stress and efforts lead to learning and academic success in the learning environment.

### 4.7.3. Grit and academic success

The statistical analysis conducted in Phase 1 indicates that the perseverance of effort dimension of grit is positively related to students' final marks in the course. However, the perseverance of effort dimension did not predict students' individual contribution to their team's project as measured by the peer assessment mark. The regression analysis also revealed that the second dimension of grit, consistency of interest, did not predict students' final marks or their peer assessment. Moreover, using a more up-to date-measure of the grit construct, the TMGS, revealed only that students’ adaptability to change in situations predicts their ability to develop intellectual and emotional ownership of their projects.

These results suggest that persisting and maintaining effort in the face of learning challenges contribute positively to students’ learning process and academic success in the course as measured by their final mark in the course. This result also confirms Credé et al.’s [190] meta-analysis findings that the perseverance of effort dimension of the grit construct has more concrete validity than consistency of interest. The results also suggest that the subdimensions of grit cannot predict performance in a team environment since neither predicted students’ individual contribution to their projects as measured by peer assessment. On the other hand, the personality trait of conscientiousness is a positive predictor of academic success and performance in an authentic learning environment where students work collectively towards completing a project.

These results also confirm the finding from Credé et al. [190] that the positive correlation between conscientiousness and grit — in this research, a Pearson coefficient of $r = .320$ — limits the incremental value of grit scores for the prediction of performance over and above conscientiousness. In my study, the subdimensions of grit increased the variance in students’ final marks explained by the Big-Five personality traits by only 3.4%. This incremental increase in the variance explained in students’ final marks was explained only by the subdimension of perseverance of effort. Although the percentage of variance explained by perseverance of effort in students’ final marks is described as small by Cohen’s [275] guidelines, a 3.4% effect size in the education domain can have a significant improvement on students’ learning [284]. Taken all together, the Big-Five personality traits and perseverance of effort explain 12.5% of the variance, which is a considerable amount that can guide engineering educators to factors that contribute to students' academic success in an authentic learning environment. Moreover, Coe [284] suggests that most educational interventions have an effect size that is described as small by Cohen's [275] guidelines; Coe argues this small effect size is due either to the wide variation found in the population as a whole against which the measure of effect size is calculated or to the fact that academic achievement is complex and harder to influence than other outcomes. It should also be noted that the size of the relationship between perseverance of effort and students' final marks can be explained by the association of a student's efforts to study and prepare for the individual assessment components of the final marks of the course — the midterm and final exam. This hypothesis is supported by fact that both perseverance of effort and consistency of interest were not associated with peer assessment marks, which is a more authentic assessment method of students' performance and involvement in the authentic learning activities of their team's project.

That said, the results of the study suggest that grit as currently conceptualized in the literature has a weak relationship with academic success in an authentic learning environment that aims to help students construct engineering design knowledge in a makerspace environment. Since making activities are characterized as activities that stimulate innovation, creativity, and team-oriented problem-solving [46], this result suggests that grit might be a poor predicter of performance in tasks that require creativity and innovation, involve teamwork, and have goals that might constantly change throughout the project life. Moreover, Credé et. al [190] argue that although grit might be an excellent predictor of performance in well-defined tasks, it is less well related to performance in ill-defined tasks. This result provides empirical evidence for Credé's argument and suggests that grit might not be suitable to predict performance and success in ill-defined, socially situated, collaborative tasks, and projects.

Grohman et al. [278] also reached a similar finding in their study examining the predictive power of perseverance of effort and consistency of interest in relation to creativity: they conclude that both facets of grit as measured by Duckworth's Grit-S [14] do not predict creativity. They argue that the consistency of interest dimension of the grit construct fails to capture the emotional and personal investment components of definitions of passion in the literature; rather, it focuses only on the narrower construct of commitment [278]. Similar criticism has been directed towards the consistency of interest dimension by Muenks et al. [221] and Jordan et al. [285] for its failure to capture the individual's purpose, desire, and interest in the context and its failure to place significant emphasis on measuring the goal-orientation element of the grit construct. The use of the TMGS in Phase 2 of the study did not improve grit's predictive power of students' academic performance in the course; however, the adaptability to situations dimension of the grit construct that was introduced by Datu et al. [277] was able to predict students' feelings of intellectual and emotional ownership of their project.

Taken as a whole, my regression analysis suggests that grit might be a poor predictor of students' achievement and performance in authentic learning environments. It also provides more empirical evidence to the grit literature suggesting a limited and weak relationship between grit and academic performance [190], [201], [216], [218], [221], [286].

Another hypothesis that can be drawn from these results is pertinent to the authenticity of the assessment tools used to measure students' learning. The courses under study use several methods to assess students' learning, including peer assessment to gauge students' engagement with and contribution to their team's project, project marks to assess students' performance in their project, and midterms, assignments, and final exams to assess students' learning of the design process and knowledge of problem-solving methods and tools that can be used in engineering design problems. Although these assessments try to assess students authentically, the lack of association between students' grit level and their marks draws attention to the need to examine these assessment tools and whether they are best suited to capture students' learning in a making environment. Blikstein et al. [52] observe that with the spread of making activities in schools, there is a growing need to develop assessment measures of students' learning in making settings; they note that the use of existing traditional measures of learning in technological settings poses a threat to the incorporation of making activities in education because it encourages instructors to align their practices with inadequate standards. Similarly, and despite the criticism pointed at the grit construct in its growing literature, my results highlight the need to develop authentic assessment tools of students' learning at the higher education level.

### 4.8. Conclusion

The quantitative study presented in this chapter has examined the relationship between several personal characteristics and academic performance in authentic learning environments. The study has also provided valuable empirical contributions to the literature on the construct of grit. The study's findings indicate that engineering students' grit level is positively associated with openness, conscientiousness, extraversion, and challenge-oriented learning goals, and negatively associated with neuroticism. Also, the findings indicate that grit's subdimension of perseverance of effort is associated with students' academic success in the course. Overall, the results indicate a weak to a non-existing association between students' grit and their performance in learning environments that require creativity and collaboration between students. The study also explored two measures of grit, the Grit Scale from Duckworth et al. [14] and the Triarchic Model of Grit Scale from Datu et al. [277]; neither measure was able to predict students' academic performance. The TMGS did introduce a new subdimension of grit, adaptability to situations, which was positively associated with project ownership. This might indicate that more research is required to reconceptualize the grit construct and design a measure that is more accurate in capturing the grit construct.

The Big-Five personality traits were a stronger predictor of students' learning outcomes in an authentic learning environment than grit. The study found that conscientiousness and neuroticism positively predicted students' success in the learning environment as measured by students' final marks. Also, extraversion, agreeableness, and adaptability to situations were positively associated with students' development of intellectual project ownership, while openness was negatively associated with it.

The study also provides more insight into the construct of project ownership in an academic makerspace setting. The findings indicate that students' development of emotional ownership of their project is not related to any of the study's independent variables, namely the personality traits of openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism, along with grit and goal orientation. However, an unexpected result that emerged from the comparison between the different grit scales was that adaptability to situations is positively associated with students' development of intellectual ownership of their projects. The findings also indicate that project ownership is not related to students' academic performance in the course. Finally, the study's findings suggest that students' goal orientation has no association with their development of ownership over their projects.

## 4.9.Limitations

The research conducted in this chapter has two limitations. First, the study design relied on self-report questionnaires, which can be susceptible to faking or social desirability bias, especially when students are asked to assess their own competence [287]. Second, the design I followed in Phase 2 prevented me from investigating the impact of students' development of project ownership, whether emotional or intellectual, on the level of grit they employed during their project. In designing the data collection tool in Phase 2 of the research, I had to administer the grit measure at the beginning of the semester and assess students' feelings of project ownership at the end of the semester, so I could not assess whether the development of project ownership in turn affected their grit. Administering the data collection tools in two steps was necessary to ensure that the questionnaire was short enough to motivate students to complete it, as a questionnaire's length has a significant effect on the dropout rate [288]. As well, because the Grit Scale originally developed by Duckworth [219], from which the TMGS is developed, is not suitable to be used for pre-test and post-test assessment research, I wasn't able to re-administer the scale to measure students' grit level at the end of the study.

# Chapter 5 Conclusion

As presented in Chapters 3 and 4, I conducted two research studies on the impact and integration of making projects into engineering school curriculum, specifically cornerstone engineering design courses. The first study provides evidence for the authenticity of the learning environment of cornerstone engineering design courses based on making projects and activities. The second assesses the impact of certain non-cognitive attributes on students' learning in these courses. This chapter provides a synopsis of the studies conducted in this dissertation and connects their findings to implications for engineering educators and future research. Accordingly, this chapter will present a proposed framework for the integration of making projects and activities to engineering design courses; recommendations for engineering professors who are interested in designing learning environments centered around on making activities; and discusses topics and questions suggested for future research efforts.

## 5.1. A framework for integrating making projects to design courses

In this section I outline a proposed conceptual framework for the integration of making projects and activities to engineering design courses. This framework aims to place the learner at the center of the learning environment. The framework is based on four main pillars: the pedagogical approach, the learning environment, the context of the course and the learning activities that students engage in during the course. In this learning environment where making projects play as a central role in providing an authentic learning experience for engineering students, students set their own learning goals, chose topics and technologies they wanted to explore, and reflected on their progress.

### 5.1.1. The pedagogical approach

Engineering educators interested in integrating making projects and activities to their courses should adopt a pedagogical approach that is project-based, aims to offer authentic learning opportunities, and situates students in an environment that simulates participation in a community of practice. First, by situating students in a project-based learning environment, engineering educators empower students to pursue questions and topics that are intriguing to them [289]. The role of the instructor in a project-based pedagogical approach becomes that of a coordinator and designer of the learning environment [289].

Also, a project-based learning approach prepares the necessary learning environment that resembles professional learning communities where students “develop the skills and dispositions necessary in the "real world;' including communication, problem solving, project management. motivation, and persistence” [287, p. 32].

Second, situating students in a learning environment that offers authentic learning opportunities allows students to “cultivate necessary skills that newcomers to any discipline have the most difficulty acquiring on their own” such as identifying reliable information, recognizing relevant patters in unfamiliar contexts, and working across disciplinary and cultural boundaries to generate innovative solutions [70]. Also, the integration of making projects to design courses offers instructors an opportunity to engage students in authentic engineering design activities. These activities can be both technical and organizational. Technical activities can be such as, but not limited to, developing concepts through sketching, research, communication with clients and users of the designs, prototyping, and technical problem solving. Organizational activities are activities related to time and project management, and communication among team members and with the instruction team for the course.

Third, by designing a learning environment that enables students to participate in a community of practice, engineering educators can promote self-learning, peer-learning, and experiential learning [290]. The integration of making projects and activities to design courses facilitated this effort by situating students within a community of makers. Members of makers’ communities of practice share a passion for hands-on technical activities, and provide resources and support for students to develop their skills and knowledge [291]. Learning within a community of practice is a process of participation and belonging that has three modes: engagement, imagination, alignment [292]. Students engage in design and fabrication activities with their peers; they construct images of design practice and of themselves as engineering designers; and as they engage in these activities within this community of makers they gain and understanding of the practice’s rules and norms.

### 5.1.2. Learning Environment

The integration of making projects to the design courses understudy situated students in an authentic learning environment of engineering design. The authenticity of the students' learning experience emerged from their interactions with their team members', their project manager, their relationship with the course's instruction team and their work in their design project. The learning environment that instructors should aim to construct to ensure students authentic learning is one that is multidisciplinary and collaborative, provides access to students with different levels of expertise, and allows students to play or assume multiple roles. The integration of making projects and activities into design courses facilitated students' exposure to a multidisciplinary set of topics. The topics that students exposed themselves to were not limited to their engineering discipline. Since students were situated in a making environment, the making project and the solution path that students were following shaped the topics they were exposed to. Also, the multidisciplinary nature of teams also allowed students to discuss and teach each other topics across disciplines.

Moreover, making projects allow for collaborative learning as students work together to fabricate their prototypes. Essential to this collaborative learning environment was the role of project managers who are students' who had completed the course in earlier semesters. Their role was to guide students' in their design process. Their presence in the learning environment ensured peer learning opportunities and students' access to experts. Although project managers might not be experts in engineering design or professional engineers yet, their presence guarantees that students have access to mentorship throughout their project. The presence of project managers also contributes to the efforts of constructing a learning environment that is based on principles of situated learning and communities of practice.

Furthermore, as students were designing and building their prototypes they were exposed to various roles as they have to design, problem-solve, procure resources, negotiate with suppliers, communicate with their client, peers, and the instruction team. The making projects also helped construct a learning environment that provided entry points to accommodate students at different skill levels. Students who were new to a particular topic or technology explored topics and technologies for the first time and practised them, while more experienced students explored topics and technologies they were interested in and practised theories they had learned in school but never practised.

#### 5.1.3. Context

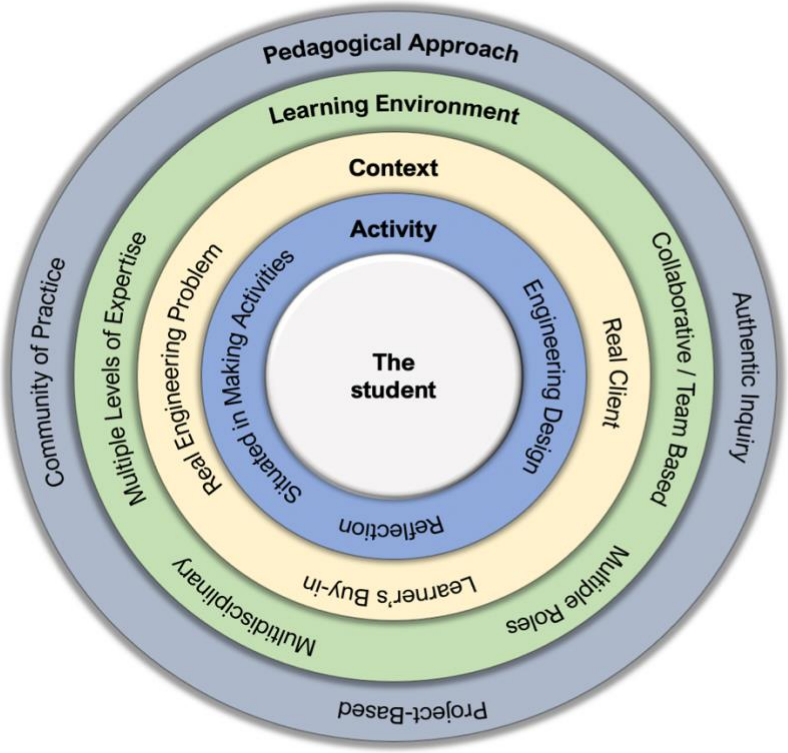
The authenticity of the learning environment depended on the presence of real problems that real clients faced, which motivated students to solve these problems and gave them a sense of responsibility towards their client. Students strove for in-depth understanding and learning of technical and organizational topics and skills they were passionate about, whether independently or collaboratively, and they assigned value to the learning environment and activities. Students' buy-in and interest in the project was necessary to ensure their authentic learning and achievement. When students' find a connection and interest in their project, they have special interest in the topics they are exploring and the solution they are developing, spend more time working on the project, feel a sense of accountability to their client, and indicate that they are interested to continue working on the project even after finishing the course.

#### 5.1.4. Activity

Making and engineering design activities represent the main learning activities that students engage with in this learning environment. Making projects offered a learning environment that facilitated students' learning and practice of engineering design skills. Students learned to empathize with their client to define their problem. They worked collaboratively on developing ideas, designs, and prototypes to solve an ill-defined design problem for a real client. Students also learned to deal with the uncertainty inherent in engineering design. They learned how to transform their ideas into prototypes while meeting human, technical, and financial constraints. Students also learned how to design and ideate while considering the manufacturability of their designs and used prototyping to visualize their concepts and how elements of their designs fit together. Making projects also allowed for a learning environment that facilitated the students' exposure to the multidisciplinary nature of engineering design, engaged students in authentic design and problem-solving tasks, helped them realize the importance of the conceptual design phase, encouraged them to assume responsibility for their design process and learning, and gave them a sense of the impact engineering has on society.

Moreover, the making projects challenged students with real and ill-defined problems where they developed and practised design and problem-solving skills. Students learned about defining their client's needs and solved problems related to machine elements, electrical motors, programming, selecting and sourcing materials, learning about and choosing between different fabrication techniques for their prototype parts, and making their prototype appealing to their client. Students also learned to simplify problems and break them down into smaller ones; they also learned the importance of brainstorming and evaluating several ideas and approaches.

**FIGURE 4 - CONCEPTUAL FRAMEWORK FOR INTEGRATING MAKING PROJECTS TO ENGINEERING DESIGN COURSES**



Another activity that is a by-product of making projects is reflection. As students were going through their design process reflection, they received feedback on their work and progress. This feedback was a result of the design of the learning environment or a by-product of the making activities. The feedback that students received as a result of the learning environment's design includes feedback received form each team's project manager, teaching assistant, course's instructor or their client. The other type of feedback that students receive arises from their making and prototyping activates as they test and validate their assumptions when they construct their prototypes. Students' constantly reflect on their progress and work and make constant adjustments and iterations to their performance.

## 5.2. Factors' Influencing students' learning in a maker-based learning environment

The quantitative part of the dissertation assessed the impact of three measures of non-cognitive attributes on students' academic success in this authentic learning environment. The results point to the positive relationship between the personality traits of conscientiousness, neuroticism, and perseverance of effort (a subdimension of grit) and students' academic success, as well as the positive relationship between the personality traits of extraversion and agreeableness and students' ability to adapt to changes and develop intellectual ownership of their project. The results also point to a positive relationship between students' adoption of a challenge-oriented learning goal and their academic success. However, the results reveal a negative relationship between the personality trait of openness to experience and students' development of intellectual ownership of their project.

The study provides more insight into the construct of grit, which was not found to be a relevant indicator of students' academic success in a collaborative learning environment that required creativity and innovation. The research also revealed that the perseverance of effort dimension of grit is positively associated with conscientiousness and that the consistency of interest dimension of grit is negatively associated with the personality trait of neuroticism, providing more evidence that items in the Grit Scale might not reflect passion the way grit is conceptualized by Duckworth et al. [219] and instead that these items measure commitment rather than passion or desire for a topic or domain [278]. These results have two main implications: the first is that although the results indicate that grit is not associated with students' academic success or level of contribution to their project, it is necessary to remember that grit is conceptualized at the individual level of analysis and that authentic learning environments are collaborative, so there is a need for a better conceptualization of grit, not only at the individual level but also in a collaborative team environment; the second is that there still isn't an available grit scale that captures how grit is conceptualized by Duckworth et al. [219] to include the passion component of the grit definition [219]. Indeed, although the research pertaining to the grit construct is growing, there is still more work being done to define it [285].

Considering the results of the quantitative study of this dissertation with the qualitative study reveal that students' individual characteristics (personality traits, grit, and goal orientation) all account for less than 20% of students' academic performance in the course. The results of both studies also point to the impact of the social environment on students' learning experience. Factors such as students' interest in the project, team dynamics, work distribution strategies among team members, project and time management approaches, and the presence of mentorship and scaffolding strategies have a much larger impact on students' performance than individual students' differences. These results point instructors to pay more attention to the situated, social nature of learning when designing features of a learning environment.

## 5.2. Implications for engineering instructors

The findings of my qualitative study in Chapter 3 suggest several recommendations for engineering instructors who are interested in incorporating making projects into their curriculum. First, instructors should offer students proper scaffolding in time and project management to ensure that they capitalize on the learning opportunities of the making activities and to support an authentic engineering design experience. Students' ability to manage their time and properly prioritize learning activities and requirements — in both the course with an integrated making project and other academic courses — is vital to their achievement and learning in a course based on a making project. In comparing the performance of the two teams studied in Chapter 3, I observed that Team Mystique's ability to outline an aggressive schedule that accounted for each student's unique academic requirements, their ability to prioritize academic requirements, and their excellent team skills, such as helping each other achieve personal learning goals or collaborating together to complete their project, facilitated their learning and ability to overcome challenges throughout the semester. This recommendation is also aligned with the literature on the impact of time management on students' academic performance. In their study of the relationship between time management and performance, Macan et al. [293] find that students who practise time management behaviours perceive that they perform better than those who do not and report lower levels of stress. Providing time management training to students not only helps them during a project-based learning course based on a making project but also provides them with valuable professional work skills that can facilitate their transition from students to engineers [294].

Second, instructors should encourage and allow students to pursue making projects that have personal value and a connection to them. Students' interest in a topic can motivate them to strive for deeper understanding of the topic and ensures their enjoyment, engagement, and concentration [295]. Members of Team Mystique showed higher levels of excitement and motivation in the project and the topics they explored as they were completing their project than Team Sunday Funday showed. Students in Team Mystique also expressed interest and intent to continue working on the project after the end of the course on their personal time. On the other hand, the members of Team Sunday Funday did not show similar interest in working on their project after the end of the semester and did not feel that their product could provide real help to their client. One noticeable difference between the two teams was how they selected their projects: Team Mystique's project was suggested by one of the members of the team, while Team Sunday Funday's project was selected by the instructor after each student submitted a list of three project preferences from a list of projects provided to all students in the course. Two out of the three members of the team noted that the project selected for them by the professor was the last one in their list of preferences, which could partly explain the difference in students' motivation and interest in the project.

Third, instructors should encourage students to assign or elect a leader for their teams from the early weeks of the semester. The presence of a leader early on helped Team Mystique start and engage in the design process from the early stages of the semester. The leader distributed work among team members, kept the team on track, ensured completion of assigned tasks on time, helped team members understand each other's perspectives, and helped team members when they were struggling with a technical challenge or managing their time. All of these factors helped students complete their project on time and achieve their personal learning goals. Although a leader did emerge eventually for Team Sunday Funday, the presence of a leader from the start of Team Mystique's design process helped them to achieve their learning goals and better manage their time and project. The presence of an obvious leader in Team Mystique can be attributed to many factors, including the team's diversity in terms of its members' year of study and engineering discipline and the familiarity of the team members with each other. Therefore, ensuring a diverse team in terms of both disciplinary knowledge and level of expertise would ensure peer learning and mentorship and a better distribution of roles among team members.

Fourth, in a multidisciplinary learning environment with participants from different engineering disciplines and years of study, instructors should consider the students' workload and emphasize the importance of their learning over delivering a final functional prototype. Even though the product in design courses is important, so too is learning the various skills, such as teamwork, communications, problem-solving, and the ability to follow a design methodology [296]. In students' discussions of the challenges they were facing, they emphasized their sense of accountability to the client pressure to complete their product in the short time frame of the semester as a source of stress. While this accountability can be seen as an advantage of incorporating making projects into engineering design courses — because it situates students in a more authentic environment compared to other design courses where students still recognize the instructor as the ultimate final authority in the learning environment [297] — instructors should communicate and emphasize the importance of the students learning critical skills over delivering a functional final prototype, as this would help regulate students' stress and help them focus and reflect on their learning.

Fifth, during my discussions with the students about recommended improvements for the course, they indicated they were interested in and enjoyed learning practical skills. I recommend that instructors expose students to as many making technologies as possible and that this exposure be situated in an authentic context. This would motivate student to learn and train them to use different tools to create their prototypes, thus reducing the demand for 3D printers.

Sixth, instructors should encourage and design the course so that students start their design process as early in the semester as possible, since four months is a very limited time for students to go through a product or an artifact design process that includes prototyping, gathering feedback from a real client, and producing several iterations. Moreover, instructors should emphasize the important role of the empathy, problem definition, and ideation phases, as these phases will affect the number of design pivots and iterations students will have to make once they start the prototyping phase. Another alternative would be for instructors and curriculum designers to explore extending making projects through two terms to give students enough time to go through each step of the design process.

Seventh, instructors should ensure that student teams have a project manager who can provide proper guidance throughout the semester. Instructors should also try to ensure that students are in constant communication with their project manager as soon as they start working on the project. Students' interactions with their project manager provided peer learning opportunities and helped students in both teams tackle technical challenges, solve problems, find alternative fabrication techniques for parts and elements of their designs, and source materials for their projects, whether from the makerspace or from stores outside campus. The project managers in the course under study were second-, third- or fourth-year engineering students who were patrons of the makerspace or members of the makers community of practice in the university's makerspace.

Eighth, instructors should take into account the logistical delays that students might encounter during prototyping phases. These delays can be caused by three factors: the search for sources for the parts they want to order for their prototypes; the time it takes to ship parts from overseas; and the reduced access to makerspace equipment due to the high demand on rapid prototyping equipment and tools, especially 3D printers, close to the final deadline. To provide students with more time, instructors should recommend they source materials locally as much as possible, offer parts that are commonly order by most teams through the makerspace, and provide students with training on multiple rapid prototyping technologies to reduce the demand on one particular type of equipment.

Ninth, instructors should design the learning environment to offer students' opportunities to reflect on their learning and their progress in their project. Engaging students in reflective activities and practices throughout the course leads them to bring their ideas, designs, and creative and technical solutions to their consciousness and then to think about them and evaluate them [122]. Although making projects engage students in prototyping activities that facilitate reflection on their work, and the presence of weekly deadlines encourages students to reflect on their performance and behaviour throughout the course, instructors should not leave reflection to chance. Rather, they should design activities that facilitate students' reflection throughout the course to ensure that students develop in-depth understanding of the concepts and topics they are exploring.

The results of the research in Chapter 4 guide engineering educators to promote traits of perseverance, organization, and diligence. They also call attention to the positive relationship between neuroticism and academic success in authentic learning environments and encourage educators to provide more support to neurotic students and dedicate more resources to their projects and learning. Another implication of the study is that engineering educators should motivate and encourage students to adopt a challenge-oriented learning goal instead of a performance-oriented learning goal. Finally, educators should encourage traits of extraversion, agreeableness, and adaptability to situations in order to promote students' development of intellectual project ownership.

### 5.3. Future research

The findings of this research highlight the need for further empirical research on the integration of making projects into engineering school curricula and its implications on students' learning. The research points to several research gaps related to students' performance in a collaborative learning environment based on making projects. The first is the need for research to examine the impact of the presence of a leader on the quality of the learning experience and on the completion and quality of students' projects. Second, empirical research is needed to investigate the relationship between creativity and students' learning outcomes such as academic success and the development of project ownership in similar learning environments based on making projects; moreover, more research is needed to understand which part of the design processes — divergent or convergent — different types of students enjoy. Third, the findings of the research described in Chapter 3 reveal the important role that project managers — students who are members of the makerspace's community of practice and who have taken the course in the past — play in scaffolding students' learning and facilitating a project's success; however, there isn't a lot of research on the necessary skills or the required training for these students who form part of the instruction team. Investigating the role of project managers in more detail and shedding light on the necessary training and skills they need will help engineering educators set up learning environments where students enjoy learning and achieve their objectives. Fourth, although the findings provide insight into the authenticity of the learning environment in a cornerstone design course, more research is required to guide engineering educators to implement making projects and activities, whether as interventions limited to a few lectures or as activities throughout the semester.

The research discussed in Chapter 4 only scratches the surface to understand the impact of certain non-cognitive skills on students' performance in an authentic learning environment. First, further empirical research is required to better define, conceptualize, and measure grit at a team level, given that it is conceptualized and measured as an individual trait in the literature. Second, more research is required to understand the role of project ownership in fostering students' grit and whether students' grit level is affected by their feelings of intellectual and emotional ownership of their project. A study of a similar design was conducted by Verdin et al. [240] to investigate if students' identification with engineering and feelings of belonging affected their grit level. Their findings reveal that both subdimensions of grit are affected by students' engineering identity and feelings of belonging to engineering. Third, although findings from Chamorro et al. [298] do not provide an explanation for the negative relationship observed in this research between openness to experience and students' intellectual project ownership in the course under study (as they did not find any relationship between openness to experience and convergent thinking), they do highlight the need for future research to investigate the interaction between students' personality traits and the different phases of creative design projects. Finally, this research also highlights the need to develop authentic assessment tools to measure students’ learning in learning environments based on making projects and activities.

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# Chapter 7 Appendices

## Appendix A

1- What is your name?

2- Would you self-identify as a maker?

3- On a scale of 1 to 5, 5 being an expert maker, how would you rate yourself?

4- Have you taken any engineering design course at the university level?

5- What is your year of study?

6- What is your engineering discipline?

## Appendix B: Interview protocol

Week 1

- Can you please introduce yourself?
- What is the name of your group?
- How did you guys form your group?
- What project are you working on?
- What did you know about the project before you started?
- Which phase of the design process are you at now?
- Who defines the scope of work?
- What do you think you have to do?
- Do you guys have a leader in the group?
- Do you have a weekly plan?
- Are you following a long-term plan?
- Do you guys feel any uncertainty?
- How are you dealing with these uncertainties?
- How are you collecting criteria for your product?
- Does the client get involved in that?
- How do you guys distribute the work between you guys?
- Why did you guys choose this course?

Week 2

- How are you doing with your design project so far?
- How do you feel about your progress?
- What did everyone contribute to the work?
- What have you learned this week?
- What engineering concepts have you used from the past three years at the school?
- What are you doing this week?
- Did you meet your client last week?
- What step of the design process do you think you are at now?
- What are the challenges that you are facing?
- What’s the plan?
- What information are you missing up to now?

Week 3

- How are you feeling about your progress?
- How did the last deliverable go?
- Which step of the design process are you in?
- So what’s your plan moving forward?
- What would you say that you have learned so far?
- Is there any system for task distribution that you are following?
- How many times do you guys meet?
- What challenges are you facing this week?

Week 4

- What have you guys done so far?
- How did the meeting with your client go?
- What are you doing this week?
- How are you going to split the work?
- Are you facing any challenges?
- Which step of the design process are you in?
- How do you guys feel about your progress now?
- What would you say are the lessons that you have learned in the last two or three weeks?
- Are you feeling any stress this week?

- If yes, what are your sources of stress?
- If you remember in the first interview I had with you, I asked you what were your learning objectives in this course. Are they still consistent or are they changing?

Week 5

- How are you guys doing with the project?
- Are you feeling any stress this week?
- What are the challenges that you are facing?
- What are you doing this week?
- Are you learning anything new this week?

Week 6

- What have you guys been doing in the past week?
- Are you guys stressed this week?
- Are you learning anything new this week?
- What are the things that you need to do to complete your project?
- Do you want to add anything?
- Are you excited to present your work on Design Day?

Week 7:

- What was the final feedback you had received from your client? And Design Day judges?
- Are you going to continue working on your project?
- What are the lessons learned from the course?
- How much do you like the project?
- Have you learned anything new in the past three weeks?
- Did you struggle with time management?
- If you were to go back and teach this course, what would you do to make it better?
- Did this course help you understand what it means to be a designer?
- After this course, do you think you want to work as a designer?

## Appendix C: Code book

| Research question | Conceptual framework element | | | Definition | First cycle code: structural and initial coding | |
|---|---|---|---|---|---|---|
| | | | | | Code | Acronym |
| Do makerspaces help create authentic learning environments? | Criteria for higher intellectual achievement | Construction of new knowledge | / | Evidence of students engaged in manipulating information and ideas by synthesizing, generalizing, explaining, hypothesizing or arriving at conclusions that produce new meaning and understanding for them | First cycle: intellectual achievement: construction of new knowledge | 11CN |
| | | | Failure to construct new knowledge | When students indicate that they have failed to construct new knowledge | Construction of new knowledge – failure to construct new knowledge | 11CN-FCNK |
| | | | Lessons learned – empathy | Students indicating they have learned to empathize with users of their products and designs | Construction of new knowledge –empathy | 11CN-LL-Empathy |
| | | | Lessons learned – time management | Any expression where students indicate that they have learned how to manage their time | Construction of new knowledge –time management | 11CN-LL-TM |
| | | | Lessons Learned – Teamwork skills | Expressions indicating that students' teamwork skills have been improving | Construction of new knowledge – teamwork skills | 11CN-LL-TW |
| | | | Lessons learned – project management skills | Expressions indicating that students' project management skills have improved | Construction of new knowledge – project management skills | 11CN-LL-PM |
| | | Disciplined inquiry | Use of existing knowledge | Evidence of student exposure to existing knowledge | First cycle: intellectual achievement: disciplined inquiry: use of existing knowledge | 11UEK |
| | | | Striving for in-depth under-standing | Are students being exposed to a topic thoroughly to explore connections and relationships to produce relatively complex understanding | First cycle: intellectual achievement: disciplined inquiry: striving for in-depth understanding | 11IDU |
| | | | Expressing ideas | Is there enough conversation and expression of ideas with various stakeholders in the learning | First cycle: intellectual achievement: | 11EI |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | process (instruction staff, peers, clients) | disciplined inquiry: expressing ideas | |
| | | Value beyond school | Helping others | Students find value in helping others | First cycle: intellectual achievement: assigned value | 11AVH |
| | | | Experiential learning | Students found value in hands-on activities and learning | | 11AVExL |
| | | | Personal value | Students drive personal value from the course | | |
| | | | Career | Students thought that the course can help them with their career | | |
| | Features of the learning environment | Authentic context | | How the makerspace provided for how design work can happen in real life:<br>purpose and motivation for learning,<br>sustained and complex learning environment | Authentic context | 12AC |
| | | | Meeting with the client | Interactions with a real client and expressions indicating that the project or problem that students were working to solve was ill-defined, complex, and real | | 12AC-meeting with the client |
| | | | Scope | Expressions that explain how students developed their project's scope of work | | 12AC-Scope |
| | | | Use of engineering tools | Use of engineering tools as an indication of the authenticity of the learning environment | | 12AC-UET |
| | | Authentic task | | Are the tasks ill-defined?<br>Do they have real-world relevance? | Authentic | 12AT |
| | | Scaffolding | | Does the makerspace provide for scaffolding opportunities? | | 12S |
| | | Articulation | | How do students articulate their work in the makerspace? | | 12AR |
| | | Collaborative learning | | Do students have the opportunity to work collectively? | | 12CL |
| | | Access to multiple roles | | Are students exploring their projects from multiple perspectives? | | 12MR |
| | | Access to expert performance | | Does the makerspace provide students with interactions with people with various levels of expertise and expert performance?<br>Access to a community of learning? | | 12EP |
| | | | Project manager | Help received from project manager to learn new concepts | | 12EP-PM-LC |
| | | | | Project managers helping students with selecting materials for their prototypes and navigate technologies that can help them manufacture their prototypes | | 12EP-PM-MP |
| | | | More experienced peers | Help received from peers to learn new concepts | | 12EP-MEP-LC |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Help received from peers to learn new concepts | | 12EP-MEP-TET |
| | | Reflection | | | | Do students reflect and what is the nature of this reflection? | | 12R |
| | | Authentic assessment | | | | Do students demonstrate their effective performance with acquired knowledge?<br>Was the assessment integrated with the activity? | | 12AA |
| | Skills | Design | Ideation | | | Evidence of students engaging in ideation strategies to create new ideas to solve their project problem | | 13DId |
| | | | Iterative process | | | Evidence of students engaging in the iterative cycle of design where they create ideas, prototypes, and concepts and they test/evaluate them against their design criteria and requirements and adjust accordingly | | 13DIt |
| | | | Prototyping | | | Prototyping activities | Prototyping | 13DProto |
| | | | Uncertainty | Source | | What's the source of uncertainties that students encounter throughout the design process? | Uncertainty – sources | 13DUs |
| | | | | Dealing with it | Adapt | When students adjust their ideas and prototypes to accommodate the uncertain nature of the design process | Uncertainty – dealing with it through adaptability | 13DUd-adapt |
| | | | | | Research | When students conduct research to find solutions and ideas instead of making assumptions to deal with lack of information | Uncertainty – dealing with it through conducting research | 13Dud-resea |
| | | Problem-solving | Problem definition | | | Students' articulation of their design project's problem | Problem-solving definition | 13PSD |
| | | Creativity | | | | | | 13C |
| | | Teamwork | Leadership | | | What kind of leadership model did the team follow — was there any leader assigned at the beginning of the project | Teamwork leadership | 13TWL |
| | | | Meeting frequency | | | Number of times the team meet and for how many hours on a weekly basis | Teamwork meeting frequency | 13TWMF |
| | | | Work distribution | | | Work distribution strategy | Team work distribution strategy | 13TWWDS |
| | | Project management | Planning | | | Planning strategy used by the students to execute weekly tasks and design process to complete their project | Project management planning | 13PMP |
| What are the challenges that students | Challenges | Dealing with the client | Communication | | | When students indicate they faced challenges communicating their ideas to their client | Challenge of communicating with the client | 21CCC |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| encounter when participating in a making design course? | | Working in the makerspace | | | Students' challenges of working in the makerspace | Challenge of working in the makerspace | 21CWinM |
| | | Busy schedule | | | Students' challenges with finding the time in their schedule to juggle course work and their project tasks with other courses they have | Challenge of balancing schedule | 21CBS |
| | | Exposure to new knowledge | | | Instances when students frame learning new concepts as a struggle or a challenge | Challenge of learning new concepts | 21CLNC |
| | | Stress | Source of stress | | | | 21CStress |
| | | | | Heavy workload | Students indicating they were stressed due to heavy workload from other courses and the project | | 21CStress-WL |
| | | | | Deadlines | Students indicating they were stressed due deadlines | | 21CStress-DL |
| | | | | Progress | Students feeling stressed because they thought they were late on their progress on the design process | | 21CStress-P |
| | | | | Delivering on expectations | Students feeling stressed due to meeting client's expectations or having a functional prototype by the end of the course | | 21Csstress-E |
| | | | | Uncertainty | Students feeling stressed when they are experiencing ambiguity because of lack of either know-how to execute a task or information | | 21CStress-U |
| | | | | | | | |
| | | WorkLoad | | | Expressions of students describing that they are overwhelmed by the amount of work they have to do. | Challenge of heavy workload | 21CWS |

## Appendix D: Chapter 4 questionnaires

This survey is about your beliefs on the nature of your abilities.

The data from this survey will be used to understand how to better teach engineering design and implement a Maker curriculum in engineering schools. This survey should take you about 10 minutes to complete.

### Consent Form

You are invited to participate in the above-mentioned research study conducted by Mohamed Galaleldin under the supervision of Professor Hanan Anis. The purpose of the study is to understand the impact of students' persistence on their performance in collaborative engineering design courses. The study is part of a doctoral thesis project.

Your participation will consist of replying to a survey that will take approximately 10 minutes to complete. Your participation entails that you allow us to collect information regarding your beliefs about your abilities, as well as your performance in this course.

We assure you that the information you will share with us will remain strictly confidential. The contents of the survey will be only be used for this research study. Your identity will remain confidential and will not be disclosed in any publications or conference nor will it be shared with any organization.

The survey responses will be held in a secure location, as the data will be stored in the principal investigator's office. The survey document will collect your name, student no., year of study, engineering discipline, and GPA, none of which will be shared publicly. You are free to omit any part of the survey if you wish to do so. Your personal information is only collected to connect your academic performance in this course to your responses to this questionnaire.

You are under no obligation to participate in this study and if you choose to participate, you can withdraw from the study at any time and/or refuse to answer any questions, without suffering any negative consequences. If you choose to withdraw, all data gathered up to the point of withdrawal will be erased. By signing this form, you acknowledge that you have been presented with the information and that you agree to participate in this study.

If you have any questions about the study, you may contact the principal investigator or the supervisor.

Part-1

* 1. Do you agree to the above terms? By clicking Yes, you consent that you are willing to answer the questions in this survey.

○ Yes
○ No

* 2. What is your full name?

* 3. What is your gender?

○ Male
○ Female
○ I'd rather not say
○ Other

* 4. What is your year of study?

○ First Year
○ Second Year
○ Third Year
○ Fourth Year

* 5. What is your engineering discipline?

| | |
|---|---|
| Computer Engineering | Software Engineering |
| Chemical Engineering | Computer Science |
| Mechanical Engineering | Civil Engineering |
| Electrical Engineering | |

Other (please specify)

* 6. Are you a local or an international student?
○ Local student
○ International student
○ Other (please specify)

* 7. Which engineering course are you currently registered in?

On the following pages you will find many phrases that are intended to describe people's behavior. The questions were designed to be answered rapidly, so please assign ratings to items based on your initial thoughts and feelings about the statements. Please rate each statement in accordance with the way you honestly see yourself.
Please use the rating scale below to describe how accurately each statement describes **you**.

* 8. If I had to choose between getting a good grade and being challenged in class, I would choose ... (Circle one)
Good grade
Being challenged

9. I Don't quit a task before it is finished.
Very Inaccurate
Moderately Inaccurate
Neither Inaccurate nor Accurate
Moderately Accurate
Very Accurate

10. I am a goal-oriented person.
Very Inaccurate
Moderately Inaccurate
Neither Inaccurate nor Accurate
Moderately Accurate
Very Accurate

11. I Finish things despite obstacles in the way.
Very Inaccurate
Moderately Inaccurate
Neither Inaccurate nor Accurate
Moderately Accurate
Very Accurate

12. I am a hard worker.
Very Inaccurate

Moderately Inaccurate
Neither Inaccurate nor Accurate
Moderately Accurate
Very Accurate

13. I don't get sidetracked when I work.
Very Inaccurate
Moderately Inaccurate
Neither Inaccurate nor Accurate
Moderately Accurate
Very Accurate

14. I give up easily.
Very Inaccurate
Moderately Inaccurate
Neither Inaccurate nor Accurate
Moderately Accurate
Very Accurate

15. I do not tend to stick with what I decide to do.
Very Inaccurate
Moderately Inaccurate
Neither Inaccurate nor Accurate
Moderately Accurate
Very Accurate

**Here are several statements that may or may not apply you. For the most accurate score, when responding, think of how you compare to most people—not just the people you know well, but most people in the world. There are no right or wrong answers, so just answer honestly!**

* 16. New ideas and projects sometimes distract me from previous ones.
○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 17. Setbacks don’t discourage me.
○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 18. I have been obsessed with a certain idea or project for a short time but later lost interest.
○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 19. I am a hard worker.
○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 20. I often set a goal but later choose to pursue a different one.

○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 21. I have difficulty maintaining my focus on projects that take more than a few months to complete.

○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 22. I finish whatever I begin.

○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 23. I am diligent.

○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 24. I appreciate new opportunities that come into my life.

○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 23. Changing plans or strategies is important to achieve my long-term goals in life.

○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 26. Changes in life motivate me to work harder.

○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 27. I am able to cope with the changing circumstances in life.

○ - Very much like me

○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

* 28. I am always motivated to improve my skills or abilities .

○ - Very much like me
○ - Mostly like me
○ - Somewhat like me
○ - Not much like me
○ - Not like me at all

End of Survey!
Thank you!

**Part-2**

* 1. Do you agree to the above terms? By clicking Yes, you consent that you are willing to answer the questions in this survey.

Yes
No

* 2. What is your full name?

* 3. What is your gender?

○ Male
○ Female
○ I'd rather not say
○ Other

* 4. What is your year of Study?

○ First Year
○ Second Year
○ Third Year
○ Fourth Year

* 5. What is your engineering discipline?

Computer Engineering

Chemical Engineering

Mechanical Engineering

Electrical Engineering

Software Engineering

Computer Science

Civil Engineering

Other (please specify)

* 6. Are you a local or an international student?

○ Local student
○ International student
○ Other (please specify)

* 7. Which engineering course are you currently registered in

8. My design project will help to solve a problem in the world.

- Strongly Agree

- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

9. My project was important to the engineering community.
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

10. I faced challenges that I managed to overcome in completing my design project.
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

11. I was responsible for the outcomes of my design project.
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

12. The findings of my design project gave me a sense of personal achievement.
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

13. I had a personal reason for choosing the design project I worked on.
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

14. The design problem I worked on was important to me.
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

15. In conducting my design project, I actively sought advice and assistance.
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree

- Strongly disagree

16. My design project was interesting.
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

17. My design project was exciting.
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

18. To what extent does the word delighted describe your experience of this engineering design course?
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

19. To what extent does the word happy describe your experience of this engineering design course?
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

20. To what extent does the word joyful describe your experience of this engineering design course?
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

21. To what extent does the word astonished describe your experience of this engineering design course?
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

22. To what extent does the word surprised describe your experience of this engineering design course?
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

23. To what extent does the word amazed describe your experience of this engineering design course?
- Strongly Agree
- Agree
- Neither Agree or Disagree
- Disagree
- Strongly disagree

End of Survey!

Thank You!

## Appendix E: Chapter-4 Regression Analysis Tables

**TABLE AE-14 - MULTIPLE REGRESSION COEFFICIENTS FOR BIG-FIVE PERSONALITY TRAITS PREDICTING STUDENTS' GRIT IN PHASE 1 OF THE STUDY**

| Predictor | Value | | |
|---|---|---|---|
| | B | S $E_B$ | β |
| Intercept | 3.104 | .232 | |
| Openness | -.107* | .054 | -.128 |
| Conscientiousness | .151*** | .039 | .247 |
| Extraversion | .124** | .036 | .163 |
| Agreeableness | .033 | .049 | .025 |
| Neuroticism | -.138*** | .043 | -.261 |
| $R^2$ | .188*** | | |
| Adj. $R^2$ | .171 | | |

Note: N = 269, * $p < .05$ , ** $p < .005$ ,*** $p < 0.0005$

**TABLE AE-15 - MULTIPLE REGRESSION COEFFICIENTS FOR BIG-FIVE PERSONALITY TRAITS PREDICTING STUDENTS' PERSEVERANCE OF EFFORT AND CONSISTENCY OF INTERESTS**

| Predictor | Dependent variable | | | | | |
|---|---|---|---|---|---|---|
| | Perseverance of effort | | | Consistency of interest | | |
| | B | SEB | β | B | SEB | β |
| Intercept | 2.689 | .309 | | 3.511 | .369 | |
| Openness | -.063 | .072 | -.057 | -.150 | .086 | -.118 |
| Conscientiousness | .226*** | .052 | .279 | .077 | .062 | .082 |
| Extraversion | .239*** | .048 | .321 | .009 | .057 | .010 |
| Agreeableness | -.043 | .065 | -.044 | .110 | .078 | .098 |
| Neuroticism | -.052 | .058 | -.059 | -.224** | .069 | -.222 |
| $R^2$ | | .171*** | | | .114*** | |
| Adj. $R^2$ | | .154 | | | .096 | |

Note: N = 262, * < .05 , $p < 0.0005$

**Table AE-16 - Multiple regression coefficients for personality traits, perseverance of effort, and consistency of interest in predicting students' final marks**

|  | Final marks |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | Step 1 |  |  | Step 2 |  |  | Step 3 |  |  |
| Predictor | B | SE B | β | B | SE B | β | B | SE B | β |
| Intercept | 70.214 | 4.154 |  | 69.330 | 5.323 |  | 68.891 | 5.755 |  |
| Openness | 1.446 | .893 | .123 | 1.442 | .888 | .123 | 1.478 | .908 | .126 |
| Conscientiousness | 2.585** | .683 | .299 | 2.233** | .692 | .259 | 2.206* | .706 | .256 |
| Extraversion | .101 | .635 | .012 | -.307 | .653 | -.037 | -.312 | .655 | -.037 |
| Agreeableness | -1.270 | .807 | -.124 | -1.049 | .801 | -.102 | -1.038 | .804 | -.101 |
| Neuroticism | 1.824* | .742 | .195 | 1.650* | .749 | .176 | 1.639* | .753 | .175 |
| Perseverance of effort | - | - | - | 1.707* | .782 | .158 | 1.723* | .788 | .159 |
| Consistency of interest | - | - | - | -1.055 | .671 | -.111 | -1.057 | .672 | -.111 |
| Students' goal orientation | - | - | - | - | - | - | .238 | 1.168 | .014 |
| $R^2$ | .091** |  |  | .125** |  |  | .126 |  |  |
| Adjusted $R^2$ | .068 |  |  | .094 |  |  | .089 |  |  |
| $\Delta R^2$ | - |  |  | .034* |  |  | .000 |  |  |

* $p < .05$ , ** $p < .005$ ,*** $p < 0.0005$

TABLE AE-17 - MULTIPLE REGRESSION COEFFICIENTS FOR PERSONALITY TRAITS, PERSEVERANCE OF EFFORT AND CONSISTENCY OF INTEREST PREDICTING STUDENTS' PEER ASSESSMENT MARKS

| | Peer assessment (reflection and log of) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Step 1 | | | Step 2 | | | Step 3 | | |
| Predictor | B | SE B | β | B | SE B | β | B | SE B | β |
| Intercept | .420 | .087 | | .359 | .116 | | .433 | .111 | |
| Openness | .029 | .020 | .104 | .031 | .020 | .109 | .025 | .021 | .089 |
| Conscientiousness | .032* | .015 | .156 | .027 | .015 | .129 | .029 | .015 | .141 |
| Extraversion | .012 | .013 | .066 | .009 | .014 | .038 | .007 | .014 | .038 |
| Agreeableness | .008 | .019 | .031 | .040 | .019 | .038 | .008 | .019 | .032 |
| Neuroticism | .039* | .016 | .173 | .023 | .017 | .179 | .041* | .017 | .181 |
| Perseverance of effort | - | - | - | .023 | .018 | .091 | .020 | .018 | .080 |
| Consistency of interest | - | - | - | -.001 | .015 | -.003 | -.002 | .015 | -.008 |
| Students' goal orientation | - | - | - | - | - | - | -.032 | .026 | -.082 |
| $R^2$ | .059* | | | .066* | | | .072* | | |
| Adjusted $R^2$ | .039 | | | .037 | | | .039 | | |
| $\Delta R^2$ | - | | | .007 | | | .006 | | |

* $p < .05$ , ** $p < .005$ ,*** $p < 0.0005$

TABLE AE-18 - MULTIPLE REGRESSION COEFFICIENTS FOR BIG FIVE PERSONALITY TRAITS & TMGS PREDICTING STUDENTS' POC & POE SCORES

| | POC | | | | | | | POE | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Step 1 | | | Step 2 | | | | Step 1 | | | Step 2 | | |
| Predictor | B | SE B | β | B | SE B | β | Predictor | B | SE B | β | B | SE B | β |
| Intercept | 3.143 | .531 | | 4.254 | .747 | | Intercept | 2.848 | .730 | | 4.476 | 1.023 | |
| Openness | .274* | .132 | .285 | .280 | .129 | .291 | Openness | .292 | .181 | .235 | .300 | .176 | .242 |
| Conscientiousness | -.074 | .062 | -.137 | -.063 | .061 | -.118 | Conscientiousness | .002 | .085 | .004 | .018 | .083 | .026 |
| Extraversion | -.168* | .074 | -.334 | -.009 | .080 | -.197 | Extraversion | -.149* | .102 | -.230 | -.048 | .109 | -.073 |
| Agreeableness | -.305* | .141 | -.349 | -.289 | .137 | -.331 | Agreeableness | -.198* | .193 | -.176 | -.174 | .188 | -.155 |
| Neuroticism | .073 | .084 | .124 | .018 | .086 | .031 | Neuroticism | .120 | .116 | .158 | .040 | .118 | .052 |
| TMGS | - | - | - | -.056* | .014 | -.265 | TMGS | - | - | - | -.043 | .020 | -.301 |
| $R^2$ | .213* | | | .262* | | | $R^2$ | .105 | | | .168 | | |
| Adjusted $R^2$ | .153 | | | .193 | | | Adjusted $R^2$ | .036 | | | .090 | | |
| $\Delta R^2$ | - | | | .049* | | | $\Delta R^2$ | - | | | .063* | | |

TABLE AE-19 - MULTIPLE REGRESSION COEFFICIENTS FOR BIG FIVE PERSONALITY TRAITS & TMGS PREDICTING STUDENTS' PEER ASSESSMENT & FINAL MARKS

| | (reflection and logarithmic) Peer assessment | | | | | | | Final marks | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Step 1 | | | Step 2 | | | | Step 1 | | | Step 2 | | |
| Predictor | B | SE B | β | B | SE B | β | Predictor | B | SE B | β | B | SE B | β |
| Intercept | .288 | .096 | | .493 | .155 | | Intercept | 61.483 | 5.439 | | 59.139 | 8.805 | |
| Openness | -.033 | .027 | -.171 | -.032 | .027 | -.167 | Openness | 4.166** | 1.533 | .350 | 4.17* | 1.543 | .350 |
| Conscientiousness | -.077 | .013 | -.064 | -.004 | .013 | -.035 | Conscientiousness | 2.658** | .731 | .428 | 2.61* | .751 | .420 |
| Extraversion | .015 | .015 | .158 | .024 | .016 | .250 | Extraversion | -1.281 | .841 | -.214 | -1.40 | .913 | -.234 |
| Agreeableness | .002 | .024 | .010 | .002 | .023 | .012 | Agreeableness | -.774 | 1.273 | -.085 | -.77 | 1.282 | -.084 |
| Neuroticism | -.024 | .017 | -.196 | -.035 | .018 | -.285 | Neuroticism | 2.600* | .998 | .341 | 2.72* | 1.064 | .356 |
| TMGS | - | - | - | -.056 | .034 | -.216 | TMGS | - | - | - | .060 | .176 | .041 |
| $R^2$ | .064 | | | .099 | | | $R^2$ | .286* | | | .287* | | |
| Adjusted $R^2$ | .000 | | | .024 | | | Adjusted $R^2$ | .233 | | | .223 | | |
| $\Delta R^2$ | - | | | .035 | | | $\Delta R^2$ | | | - | .001 | | |

**Table AE-20 - Multiple regression coefficients for Big-Five personality traits, tmgs-pe, tmgs-ci & ats predicting students’ final marks**

| | Final marks | | | | | |
|---|---|---|---|---|---|---|
| | Step 1 | | | Step 2 | | |
| Predictor | B | SE B | β | B | SE B | β |
| Intercept | 61.483 | 5.439 | | 57.526 | .8.547 | |
| Openness | 4.166* | 1.533 | .350 | 4.965* | 1.546 | .417 |
| Conscientiousness | 2.658* | .731 | .428 | 2.735* | .728 | -.440 |
| Extraversion | -1.281 | .841 | -.214 | -1.574 | .881 | -.263 |
| Agreeableness | -.744 | 1.273 | -.085 | -.718 | 1.244 | -.079 |
| Neuroticism | 2.60* | .998 | .341 | 2.549* | 1.026 | .334 |
| TMGS-PE | - | - | - | 3.569* | 1.362 | .306 |
| TMGS-CI | - | - | - | -.941 | 1.051 | -.100 |
| TMGS-ATS | - | - | - | -2.311 | 1.577 | -.163 |
| $R^2$ | .286* | | | .360* | | |
| Adjusted $R^2$ | .233 | | | .280 | | |
| $\Delta R^2$ | - | | | .073* | | |

* $p < .05$ , ** $p < .005$ ,*** $p < 0.000$

## Appendix F: Author's Publications

1. Jalal, M., & Anis, H. (2020). The Integration of a Maker Program into Engineering Design Courses. *International Journal of Engineering Education*, *36*(4).

2. Jalal, M., & Anis, H. (2020a). The Impact of Students' Grit & Project Ownership on Students' Learning Outcomes in Maker-based Cornerstone Engineering Design Courses. Manuscript Submitted for publication.
3. Jalal, M., & Anis, H. (2020b). The role of students' grit & goal orientation in predicting their academic success in authentic learning environments. Manuscript Submitted for publication.

4. 1. Galaleldin, Mohamed; & Anis, H. (2019). *The Impact of Integrating Making Activities to Cornerstone Design courses on Students' Implicit Theories of Making Abilities*. *American Society of Engineering Education Annual Conference and Exposition*.

5. 2. Galaleldin, Mohamed;,Anis, H., & Dumond, P. (2019). *The Impact of Integrating Making Activities Into Cornerstone Design Courses*. *American Society of Engineering Education Annual Conference and Exposition - 2019*.

6. 3. Galaleldin, Mohamed; Boudreau, J., & Anis, H. (2019). *Integrating Makerspaces in Engineering Design*. *Proceedings 2019 Canadian Engineering Education Association (CEEA-ACEG19) Conference*.

7. 4. Galaleldin, Mohamed; Boudreau, J., & Anis, H. (2019). Team Formation in Engineering Design Courses. In *Conference: Proceedings 2019 Canadian Engineering Education Association*. Ottawa, ON.

8. 5. Rodier, C., Galaleldin, M., Boudreau, J., & Anis, H. (2019). *FROM STEM TO STEAM IN ENGINEERING DESIGN*. *Canadian Engineering Education Association (CEEA - ACEG19) Conference*.

9. Galaleldin, Mohamed, & Anis, H. (2019). *Students' Grit Level as a Predictor of Their Academic Achievement in Engineering Design Courses*. *Canadian Engineering Education Association (CEEA - ACEG19) Conference*.

10. Galaleldin, M. A. A., & Anis, H. (2017). Impact of makerspaces on cultivating students' communities of practice. In *ASEE Annual Conference and Exposition, Conference Proceedings* (Vol. 2017-June).

11. Galaleldin, Mohamed, Boudreau, J., & Anis, H. (2018). The Impact of Students' Academic Locus of Control and Perception of Problem-Solving Ability on Their Performance In Design Projects. *Proceedings of the Canadian Engineering Education Association (CEEA)*.

12. Galaleldin, Mohamed, Anis, H., Dumond, P., & Knox, D. (2018). Scaffolding Strategies For Teaching Engineering Design in a Collaborative Project-Based Learning Environment. *Proceedings of the Canadian Engineering Education Association (CEEA)*.

13. Galaleldin, Mohamed, Bouchard, F., Anis, H., & Lague, C. (2017). The Impact of Makerspaces on Engineering Education. *Proceedings of the Canadian Engineering Education Association (CEEA)*.