International Journal of Engineering Education Vol. 36, No. 1(B), pp. 420–435, 2020
Printed in Great Britain
0949-149X/91 $3.00+0.00

Effect of Personality Traits in Team Dynamics and Project Outcomes in Engineering Design*

JUSTINE BOUDREAU and HANAN ANIS
Center for Entrepreneurship and Engineering Design, University of Ottawa, Ottawa, ON K1N 9A7, Canada.
E-mail: jboud030@uottawa.ca, hanis@uottawa.ca

The University of Ottawa's Faculty of Engineering is home to multiple rapid prototyping facilities and entrepreneurship spaces. These include a makerspace, a machine shop and a design space for any student to use free of charge. In the Makerlab, students take courses that introduce them to collaborative project-based learning, engineering problem-solving and prototyping. The goal of the first- and second-year engineering design courses is to introduce engineering design processes, time and project management, and analysis, prototyping and testing. In each course, students work in groups on a semester-long project to meet the needs of a real client whom they meet with three times over the course of the project. The objective of this paper is to understand the impact of each team member's personality, more specifically the Big Five personality traits (openness, conscientiousness, extraversion, agreeableness and neuroticism), on team dynamics and team performance with regards to their project throughout the semester in a project-based learning environment. Factors considered are gender, GPA, the Big Five personality scores, final peer evaluations and team dynamics, project manager evaluations and project grades. Multiple regression analysis is conducted to determine if any of the factors listed influence team performance and dynamics as well as individual project grades.

Keywords: engineering design; personality; team dynamics; project-based learning

1. Introduction

Teamwork is a skill that employers search for when hiring new people. In engineering design, diverse people come together to work on a project and must collaborate efficiently to get the job done. It is important to understand personality differences within a team so that a team can be built for best effectiveness. The skills of each member should complement the skills of others, and each member should push the team to innovate and produce better outputs. In engineering design in particular, where people are asked to come up with the best solution to a problem, often under pressure of a deadline (or a course grade) it is important to know how different people will work together to give that optimal end product. As project managers or teachers, it is useful to know which people will work best together to give them the best experience possible and at the same time obtaining better results. This paper explores the relationship between personality traits and individual/team performance in an engineering design course.

1.1 Collaborative Learning and Teamwork

Institutions want to graduate engineers who can design and who have complex design thinking skills, including the ability to think and communicate as part of a team [1]. Project-based learning is known to enhance student motivation and retention by providing hands-on experience solving practical problems while working in a team [1]. It is a common educational method to apply knowledge to solving an open-ended problem [2]. Gomez Puente, van Eijck & Jochems [3], in their literature review of design-based learning approaches, identify key characteristics of design-based learning. They explain that often design tasks are done collaboratively in a community of practice in contextualized situations where peers work together, communicate ideas and use engineering terminology. Teamwork and collaborative learning are also shown to be the basis for project-based learning. The authors outline projects that are the most relevant to project-based learning as open-ended, authentic, hands-on, real-life and multidisciplinary design projects. Authentic and open-ended design projects offer the opportunity to develop reasoning and domain-specific knowledge and to enhance the inquiry process. Another characteristic of design-based learning is that students are supervised and coached during their design process and project implementation to scaffold their learning and enhance their understanding.

Project-based learning work is a prime example of an out-of-class collaborative learning activity that has been confirmed to work particularly well for engineering design courses and presents benefits like developing alternative methods of approaching problems and improving social and communication skills and self-confidence [3, 4]. Collaborative learning can be broadly defined as "a situation in which particular forms of interaction among people are expected to occur, which would trigger learning

* Accepted 19 November 2019.

mechanisms" [5, p. 5]. Collaborative learning is where students work in teams to accomplish a common goal while the following elements are present: positive interdependence, individual accountability, face-to-face promotive interaction, appropriate use of collaborative skills and group processing [4]. In comparison with traditional lecture-centred learning, students participating in cooperative approaches demonstrate higher academic achievement, greater persistence and critical thinking skills, deeper understanding of material, more positive and supportive relationship with peers, and much more [6, 7].

Engineers will always be faced with working in a team, most likely a diverse one, to accomplish their work [8]. Teamwork skills are a top priority for employers, which is another reason they should be taught explicitly [1, 3, 7, 9]. Students in high school who are interested in engineering are even being trained in teamwork as early as grade 12 [10]. Teams enable multiple perspectives, experiences and a broad skill set for projects [11, 12]. However, simply putting students into groups does not generate collaborative learning; structuring them to be cooperative is necessary for this learning to happen [4, 6]. This structure must include parameters for the form of instructions to students, the physical setting and other institutional circumstances where a type of social contract can specify the types of interactions that can occur [5]. Ideally, in collaborative learning, people with a high degree of interdependence work together to complete a common goal [11]. Collaborative learning can greatly enhance a student's experience; however, if a team is dysfunctional, it can lead to a negative experience. For example, members who do not participate, causing an extra burden on the rest of the members, will trigger low team morale and reduced cooperation [7]. Therefore, teamwork skills such as project and time management, conflict resolution and communication skills should be taught to student groups to help them have the best experience possible [3, 9]. In a statement that encapsulates much of this research, Oakley et al. write, "With a group, the whole is often equal to or less than the sum of its parts; with a team, the whole is always greater." [9, p. 13]

Team performance models include individual, group and environmental factors. Organizations often do team training to address individual factors, like experiences and skills, and improve interpersonal relationships with conflict management [11, 13]. A few methods have been outlined for how and when to teach teamwork skills. Although there are differing theories, many agree that teams should be allowed to try, fail and learn from their experience as well as be offered guidance and training when problems come up [3, 4, 9].

1.2 Personality and Diversity

Many studies have been conducted on personality types and the advantages that diversity in teams has for functionality and performance. Individual differences have an effect on team effectiveness and group processes [7], and diverse teams are also seen as an important way to encourage innovation and creativity, as well as diversity more generally [1, 13, 14].

One of the personality indicators is the Big Five factor model, which can "represent diverse systems of personality description in a common framework" [15, p. 103]. The five factors in the Revised NEO Personality Inventory (NEO PI-R), or OCEAN, are openness, conscientiousness, extraversion, agreeableness and neuroticism. [7, 15] This variable-centred approach focuses on dimensions (or traits) in a population [16]. Each factor is characterized by various dimensions of personalities. Openness refers to curiosity, active imagination, aesthetic sensitivity and independent-mindedness; conscientiousness is self-discipline, determination, a will to achieve, being orderly and being responsible; extraversion refers to being talkative, sociable, assertive and energetic; agreeableness is the tendency to be cooperative and altruistic and trustful; and neuroticism is the tendency to experience negative affect, to not be calm and to be neurotic [7, 12, 15]. A person can range from high to low in each factor which will make up their personality. George and Jones [17] argue that no personality profile is necessarily better then another as different factors are suited to different kinds of tasks, and point out positive aspects of low and high degrees of a factor. Some factors have been hypothesized to have specific effects on team performance. For example, high conscientiousness is believed to have a relationship to good performance, high neuroticism may lead to proficiency in critical thinking, and low agreeableness may be a sign of a good drill sergeant [17]. Since this theory has been proved multiple times in academia, numerous studies have used it to determine the influence of personality on team effectiveness [16, 18, 19].

Clinebell and Stecher [7] explain that these different combination of factors and personalities put together may enhance or detract group performance but that group performance should ultimately be facilitated by diverse personality types since they can provide a balanced approach overall. But although diverse personalities are needed, they can also lead to conflict and different expectations of the team process. This idea is supported by Hua [13] and Chiang [16] in their dissertations. Cronin & Weingart [20] present the view that diversity will increase the likelihood of the miscommunication and misinterpretations of needs and tasks to be accomplished by the team and therefore is likely to create conflict. When team members are not aware of personality type information and its use in a team setting, there also tends to be more role conflict in the group [7]. Conversely, Clinebell and Stecher [7, p. 378] state that ''awareness of differences was actively used by students to promote team functioning.'' In this case, it is important to know how different personality traits can influence the outcome of a team project. However, an opposite view holds that conflict will generate creativity, spark innovation and force team processes to improve [13]. Finally, diversity is also seen as a business necessity: having employees who are comfortable with diverse cultures provides a broad range of perspectives and experiences [21, 22].

1.3 Team Formation and Peer Evaluation

There are many ways design teams can be formed, and the literature varies on which one gives better results. The main difference is between teams that are self-selected and instructor-assigned and, if they are assigned, the factors that the decisions are based upon. For collaborative learning groups, research supports the formation of teams that are generally instructor-assigned and have three to four members [4, 7, 9]. Felder and Brent [4] and Oakley et al. [9] argue that the teams must also be formed with people of different ability levels and not have people who are in minority groups outnumbered. The reason for these choices is that strong students can better understand the material by teaching it to weaker students, and weaker students can observe how strong students approach problems and solve them. Teams can also be formed with more explicit attention paid to different personalities and roles within teams [14]. The methods of doing this include MBTI and the five-factor personality type indicators. For example, Shen, Prior, White and Karamanoglu [14] use the Keirsey Temperament Sorter, where the sixteen MBTI personality types are distributed into four temperament groupings, which are then compared against their proficiency in engineering design. Stronger students, in particular, may be unhappy about instructor-assigned teams; however, understanding that they will not be able to choose their co-workers in their careers helps them accept this kind of team formation [9]. It is also suggested that team roles be rotated so that everyone in a group has a chance to experience all the roles and practise them, as well as to understand task interdependence [4, 7]. The results here could point to a specific way of organizing teams for better performance.

Peer evaluations are an important tool in teamwork. They allow team members to know how they are doing and give feedback to their peers, which they can use to reflect on their own progress if the evaluation is done early enough [3, 9]. They also provide a way to increase accountability and control behaviour [7, 23]. Peer evaluation is assumed to be objective and valid since it is based on real contributions from members and is not a subjective perception affected in part by personality types [22]; it is a useful supplement to the other grades in the course and can be an accurate measure for the instructor to establish the contribution from each member and adjust grades accordingly [9].

Team dynamics have a critical effect on results. Positive team dynamics and interactions will lead to higher-quality performance and team output [24]. Collaboration is also a key factor in team interactions [24, 25]. How team members interact and exchange information will have an effect on the outcomes of their efforts [25]. Next, factors that can influence individual as well as group performance will be discussed.

1.4 Influential Factors on Individual Performance

Openness is defined as being imaginative, curious, broad-minded and intellectual; consciousness is being orderly, responsible, dependable and achievement striving; extraversion is being talkative, energetic, sociable and assertive; and neuroticism is being neurotic, worried, anxious and angry [15, 26]. In their review of empirical literature on the Big Five as predictors of post-secondary academic achievement and meta-analysis, O'Connor and Panunonen [27] identify conscientiousness as most consistently linked to different indicators of academic success, including GPA. It is often interpreted in terms of motivation and assumed to have a logical relation between behaviors of some facets of conscientiousness and performance. They also found that that measures of openness have been predictors of GPA and performance however it was a less prominent correlation in the literature. The authors found very few correlations with the other Big Five factors. In another meta-analysis of job performance and personality dimensions, Barrick and Mount [26] also found that conscientiousness was a consistent predictor of job performance. Their results also show that openness and extraversion are predictors for training proficiency and ability to learn, which could lead to good performance. Individual job performance across multiple occupations and cultures has also been shown to have a significant relationship with conscientiousness [28, 29]. In their examination of academic performance predicted by personality traits, Chamorro-Premuzic and Furnham [30, p. 245] concluded that ''conscientious, stable and introverted individuals would be more likely to succeed in university-based academic settings''. They found that there is a significant positive correlation between conscientiousness and academic performance and extraversion and neuroticism both significantly correlate negatively.

1.5 Influential Factors on Team Performance

The interaction of different people and personalities in teams may cause circumstances of low productivity and poor experiences [7]. Past research shows that personality traits and their composition in teams are closely related to team performance [16, 18, 28]. Many studies have proven that Big Five traits are able to predict team performance [16]. Out of the five Big Five traits, consciousness seems to be the most prone to influencing teamwork in a project-based learning environment. It determines how each member will carry out their tasks for their project, thus affecting the outcome of the entire team. O'Neill & Allen [28] found it to be one of the most consistent Big Five trait predictors of job and team performance, and Hua [13] showed that it is significantly correlated with team performance. Bradley, Klotz, Postlethwaite, and Brown [31] demonstrate that teams with a high level of openness have been shown to perform better because open-minded people tend to have more positive attitudes, are more adaptive and promote open discussion in teams. They explain that collaborative teams tackle conflict and enable constructive debate. Teams with lower neuroticism (high emotional stability) also tend to use good conflict-resolution strategies because they are level-headed and view themselves and others positively. In a meta-analysis of the Big Five effect on team performance, Peeters, Van Tuijl, Rutte and Reymen [12] also show positive correlation of agreeableness and conscientiousness with team performance. In addition, O'Neill & Allen [28] argue that a high level of conscientiousness, agreeableness and openness leads a team to perform better. They also state that lower neuroticism and a mix of extraversion is good on a team.

Social loafing, defined as individuals who exert less effort when working in a team, leading to less productive groups, has been demonstrated by Sherif [18] with a qualitative case study to be linked to low scores on each of the five factors, openness, conscientiousness, extraversion, agreeableness and neuroticism. The loafer is described as uncreative/not open to new ideas, unorganized, introverted, selfish and emotionally stable [18]. The morale of a group, and therefore its productivity, will suffer as the more conscientious students carry the burden of those who do not participate [7].

Various other relevant factors also influence team performance. Grade point average (GPA), which can represent motivation and capability, has also been proven to be a significant factor for team performance [11]. Gender and racial diversity have reported mixed results, having found either to be beneficial to performance (by including diversity) or to have no significant impact (team members don't notice or push past the differences) [13]. Personality traits have been linked to cultural factors, which in turn influence social behaviours and team performance [16, 19]. According to Vaz et al. [2], the impacts of project-based learning differ by gender, and gender affects how students approach project work. They argue project-based learning approaches might be more interesting for women and cause them to do better. Women have also been found to be more motivated by a social context and collaboration [21]. These factors are also useful for understanding team relationships and improving efficiency.

1.6 Courses

Engineering students at the University of Ottawa are exposed to engineering design in first- and second-year courses. The first-year engineering design course, called Engineering Design, is currently mandatory for first-year mechanical, biomedical mechanical, electrical and civil engineering students. The second-year engineering design course, called Introduction to Product Development and Management for Engineers and Computer Scientists, is open to all departments of engineering as well as computer scientists from different years. The focus of both courses is on client-centred design, where groups of students work on a specific client's problem or needs during one semester and deliver a final physical prototype. Groups are formed from multidisciplinary and multi-year engineering or computer science students within the first two weeks of class. In the first week of class, students are required to do a Big Five personality test (from ITP Metrics) [23], which gives them a rating for each of the Big Five parameters [15]. With reflection on their personality, students pick their own teams in the first two weeks of the semester from students in the same lab section. They are encouraged to seek diverse types of people with complementary personalities and skills sets to form a team of four to six members. Their first deliverable then consists of creating and signing a team contract.

The lectures and the labs are the two main components of the courses. In the lectures, the students learn design methodologies, processes for product development, and time and project management. Students in the second-year course also learn about business models, economics and marketing. Students put these skills to use in their own semester-long project to meet the needs of a specific client. Each section of the first-year course works for the same client on the same project, which is usually different from the other sections. In the second-year course, the students are given a list of projects for various clients and asked to choose their top three. The professors then distribute projects so as not to have more than two teams working on the same one. The theme for the first-year course changes almost every semester and is different between sections. The theme for the second-year course is always accessibility. This means students work on projects like wheelchair skis, portable wheelchair ramps and foot-controlled guitars. Clients are diverse, ranging from individuals to organizations like hospitals, and have different needs.

Each team meets their client a minimum of three times during the semester. The first-year course meetings are either in the classroom or lab, and the students in the second-year course meet their client wherever is most convenient for the client. The first meeting with the client, in the third week of the semester, is used to determine specific needs for the project. The teams then develop metrics and concepts before meeting the client a second time to get feedback. Next is the start of prototype iteration cycle where the students use facilities like a makerspace and a machine shop to make three or more prototypes to get to their final product. The makerspace and machine shop are two of seven student spaces hosted by the Centre for Entrepreneurship and Engineering Design (CEED) that are available for students to use for prototype designing and building. After the first prototype is completed, a third client meeting is held to receive more feedback on the product features and functionality. The client is then presented with the final product at the end of the semester at Design Day, a showcase featuring all the cornerstone engineering design teams.

The work is done mostly at home, with some lab time dedicated to working on the project. The rest of the labs are designed to teach students the necessary skills to be able to do their projects or to give them enough of an introduction that they can learn more by themselves if needed. Skills in first year include Solidworks, Matlab, laser cutting and one lab that varies to teach something project-specific. In second year, they learn 3D printing, PCB design, mobile app development, lathe and mill. In addition, common to both is Arduino, soldering and sheet metal work. The labs for the second-year course are done with the specific goal of making parts for a small smartphone-controlled car that is assembled in one of the last labs. All labs take place in the Makerlab, which is a sister facility to the Makerspace and one of the CEED spaces.

Each lab has a teaching assistant (TA) and a project manager (PM) who are present every week. The TA is typically a graduate student, and the PM is typically an undergraduate student who has taken the course before. Both the TA and the PM act as guides and mentors to the groups as they go through their design process and learn the skills necessary to do so. Both sit together at the end of the semester and evaluate each student in their lab based on their contribution to the project over the semester. The students also evaluate their TA and PM at the end of the semester.

Each group does a peer and team assessment twice in the semester using a tool also developed by the Individual and Team Performance (ITP) Lab at the University of Calgary, one of the ITP Metrics assessment tools [23]. The first individual and team evaluation happens in the sixth week of the term, so the groups are able to receive feedback from their teammates and improve on their work before most of the heavy project work and prototyping happens. The first evaluation is also used by the professor, TA and PM to catch the groups that need extra help or an intervention to resolve group problems. The second evaluation happens at the end of the term and is used to weigh the final project grades based on contribution from each member.

2. Objective

The literature outlines multiple contradictory views on how personality traits influence teamwork and task performance and which specific traits do this. In the context of engineering design, we are interested to understand the various factors that have an impact on performance in a team. We have conducted classical action research where this study has the objective of studying the impact of team members' personalities, more specifically their Big Five personality traits, on team dynamics and team performance with regards to a semester-long project in fall 2018 and winter 2019 in a project-based learning environment. Both individual and group performance are considered by collecting quantitative data. The research question answered is the following: Are personality traits a predictor of team or individual success in a project-based design course?

This question is important because team-based projects are being used more and more in engineering, and so it is crucial to understand if personalities have the same effect in this context as in other reported ones. The results were expected to support the hypothesis that a person with higher openness, agreeableness and conscientiousness will perform better in the project. This would mean that these three traits would correlate with team and individual success in the course. A team with higher scores of the same three traits was also expected to perform better in the engineering design course, as will a team with more diverse members.

3. Method

Data were collected through the courses' regular operation for the personality test, peer evaluation, team dynamics, year of study, PM evaluation and project mark. The students were asked to share their GPA, gender and team role voluntarily. Multiple regression analysis was conducted to determine if any of the factors listed could be shown to influence team performance and dynamics. Two sets of data were used to evaluate the students individually and as a group to answer the research question. Individual characteristics include personality scores, peer evaluation, adjusted project mark, PM evaluation, GPA and gender. Group characteristics are team dynamics, project mark and average team personality scores. The individual dataset includes 191 people, 152 males and 39 females. 102 students were in the first-year class and 89 in the second-year class. The group dataset includes 57 teams, 26 of them are first-year teams and 31 are second-year teams.

3.1 Personality Test

ITP Metrics is a free assessment-based system with many different tools, including the Big Five personality test [23]. The test is used to determine the scores of the five different personality factors, reported with their six specific facets. Participants answer 120 questions on a 5-point Likert scale relating to each of the traits: openness, conscientiousness, extraversion, agreeableness and neuroticism (emotionality). Each of the factors is rated on a positive scale, where 0 is low and 1 is the maximum. All scores in a team for a factor were averaged to be able to compare teams.

3.2 Peer Evaluation and Team Dynamics

Another tool ITP Metrics offers is the peer feedback system, which provides "round-robin ratings of each member's effectiveness in the team on five dimensions (communication; commitment; foundation of knowledge; skill and abilities; emphasising high standards; and focus)" [23, p. 1]. The students evaluate themselves, each of their team members and the team itself and receive anonymous feedback to supplement their scores. Many software applications exist for peer feedback to facilitate data collection and analysis; CATME (Comprehensive Assessment for Team Member Effectiveness) is the most popular [23]. Following a comparative study between CATME and ITP Metrics, Jaimeson and Shaw [32] confirmed that ITP Metrics is the preferred assessment platform based on time effectiveness for students and instructors, support for individual and team development, actionable feedback and effective integration into learning activities.

ITP Metrics uses a five-dimensional framework that is identical to CATME, with a few adapted terms [23]. The effectiveness of using these five dimensions, as listed above, has been shown to be reliable and have valid evidence [33]. The purpose of the tool is to advance research into how peer feedback works, what influences the ratings and how to make successful teams, all of which make the tool perfect for application for this study. It is applicable and meaningful since the teams here are working with task interdependence [23].

3.3 Project Mark and PM Mark

Project grade is the indicator of team performance. Over the course of the semester, students work on developing their prototypes and submit a deliverable almost weekly with their team to help guide them through the design process. Table 1 outlines all the deliverables, which add up to be 35% of the final grade for both courses.

The project mark that each team received in the fall 2018 and winter 2019 semesters was used in the group analysis as an indicator of how well the team performed together. However, since some analysis was done for individuals, an adjusted project grade was used to determine the individual contribution by the student. This was calculated using a personal factor applied to each person, which was taken from the peer evaluation results and ranged between 0.6 and 1.1. This method was used for consistency in this study because the actual adjusted project grade used at the end of both courses to weigh the grade given to students for their final mark is calculated slightly differently depending on the professor.

The project manager's evaluation is done by the TA and PM at the end of the semester and used as a supplement to the peer evaluation to ensure the groups are evaluating each other accurately. The students are graded individually using a five-item rubric with 5 points each for a total of 25 points, based on the work that the TA and PM see in the lab periods. The five items are teamwork, professionalism, communication, organization and discipline, and technical contribution. (See the table in Appendix A for the rubric.) This evaluation could also be used to determine individual effort and contribution by the students.

3.4 Other Metrics

Demographic information like gender was used to identify trends in the population of students. GPA has also been used in other studies as an indicator of

Table 1. Design course deliverables

	First-year course		Second-year course	
	Name	Weight	Name	Weight
Deliverable A	Team formation and contract	0.7%	Team formation and contract	0.7%
Deliverable B	Need identification	1.75%	Need identification and product specifications	1.75%
Deliverable C	Design criteria	2.8%	Conceptual design, project plan and feasibility study	3.5%
Deliverable D	Conceptual design	1.75%	Detailed design and prototype I	2.8%
Deliverable E	Project schedule and cost	2.8%	Project progress presentation	1.75%
Deliverable F	Prototype I and client feedback	3.5%	Business model	1.75%
Deliverable G	Prototype II and client feedback	4.2%	Prototype II and client feedback	3.5%
Deliverable H	Prototype III and client feedback	5.25%	Economics report	5.25%
Deliverable I	Design day presentation	5.25%	Design day presentation	5.25%
Deliverable J	Final presentation	3.5%	Intellectual property	1.75%
Deliverable K	Final report	3.5%	Final presentation	3.5%
Deliverable L	–	–	Final report	3.5%

individual performance, which is why it was included here as well.

4. Results

4.1 Individuals

To start, a Spearman's rank-order correlation was run to assess the relationship between the individual performance variables. The results are shown in Table 2. This table demonstrates how each of the individual performance variables are related. They all show a significant relationship except for the adjusted project mark and GPA.

A multiple regression was run with 191 cases to predict the adjusted project grade from the Big Five traits. It demonstrates a relationship between the Big Five traits and the adjusted project mark since the model is significant.

Next, gender was added to the regression model, and the regression was run again. This second multiple regression was run to predict the adjusted project grade from the Big Five traits and gender.

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 1.384. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values. There was no evidence of multicollinearity, as assessed by tolerance values greater than 0.1. There were no studentized deleted residuals greater than ± 3 standard deviations, there were no leverage values greater than 0.2, and values for Cook's distance were above 1. The assumption of normality was met, as assessed by a P-P Plot. The first multiple regression model statistically significantly predicted adjusted project grade, $F(5, 185) = 2.502$, $p < 0.05$, $R^2 = 0.063$. The addition of gender led to a statistically significant increase in R^2 of 0.021, $F(6, 184) = 2.810$, $p < 0.05$. See Table 3 for full details on each regression model.

Tables 4 and 5 show correlations between the Big Five traits, separated by gender. By graphing the adjusted project grade versus the personality traits by gender as well, the contrast between both can be observed. Extraversion is shown here in Fig. 1.

The mean of the Big Five traits are shown in the Table 6. The distribution of data was similar for all traits and for both genders (similar standard deviations). A one-way analysis of variance (ANOVA) test was conducted for each trait and showed no significance between the means of each gender, with the lowest for neuroticism of $p = 0.131$.

4.1.1 Males

Since gender had a significant effect in the previous regression model, another model was con-

Table 2. Individual performance correlation

	Adjusted project mark	Peer evaluation	PM evaluation
Peer evaluation	0.191**	–	
PM evaluation	0.283**	0.297**	–
GPA	0.046	0.251*	0.431**

* Statistically significant at p < 0.05 level; ** Statistically significant at p < 0.01 level.

Table 3. Summary of multiple regression analysis – individual

	Model 1 (Big Five)		Model 2 (Big Five & gender)	
Variable	**B**	β	**B**	β
Constant	30.603		29.427	
Openness	0.677	0.021	0.634	0.020
Conscientiousness	2.959	0.095	2.898	0.093
Extraversion	–6.435	–0.203*	–6.893	–0.217*
Agreeableness	4.084	0.138	3.806	0.128
Neuroticism (Emotionality)	–1.759	–0.060	–2.493	–0.085
Gender			1.608	0.146*
R^2	0.063		0.084	
F	2.502*		2.810*	
ΔR^2	0.063		0.021	
ΔF	2.502*		4.134*	

* Statistically significant at p < 0.05; B = unstandardized regression coefficient; β = standardized coefficient.

Table 4. Big Five trait correlations – males

	Openness	Conscientiousness	Extraversion	Agreeableness
Conscientiousness	0.155	–		
Extraversion	0.333**	0.186*	–	
Agreeableness	0.469*	0.349**	0.260**	–
Neuroticism	–0.131	–0.432**	–0.313**	–0.172*

* Statistically significant at p < 0.05 level; ** Statistically significant at p < 0.01 level.

Table 5. Big Five trait correlations – females

	Openness	Conscientiousness	Extraversion	Agreeableness
Conscientiousness	–0.103	–		
Extraversion	0.357*	0.078	–	
Agreeableness	0.173	0.380*	0.185	–
Neuroticism	–0.123	–0.372*	–0.423**	–0.353*

* Statistically significant at p < 0.05 level; ** Statistically significant at p < 0.01 level.

structed to evaluate the relationship between the Big Five traits and the adjusted project grade for each gender separately. With 152 males, 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 1,445. There was homoscedasticity, as assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values. There was no evidence of multicollinearity, as assessed by tolerance values greater than 0.1. There were no studentized deleted residuals greater than ±3 standard deviations, there were no leverage values greater than 0.2, and values for Cook's distance were above 1. The assumption of normality was met, as assessed by a P-P Plot. The full multiple regression model statistically significantly predicted adjusted project grade, $F(5, 146) = 4{,}108$, $p < 0.05$, $R^2 = 0.123$. Extraversion added statistically significantly to the prediction, and all added Big Five factors led to an increase in R^2 of 0.013. Regression coefficients and standardized coefficients can be found in Table 7.

Given that openness is found to be poor predictor, having low coefficients and significance, it was taken out of the model, leaving the Big Five CEAN traits. The new model is statistically significant, $R^2 = 0.119$, $F(4, 147) = 4.986$, $p < 0.01$; adjusted $R^2 = 0.096$. In this model, extraversion and agreeableness were statistically significant predictors, –9.556, $p < 0.0005$ and 6,258, $p < 0.05$ respectively.

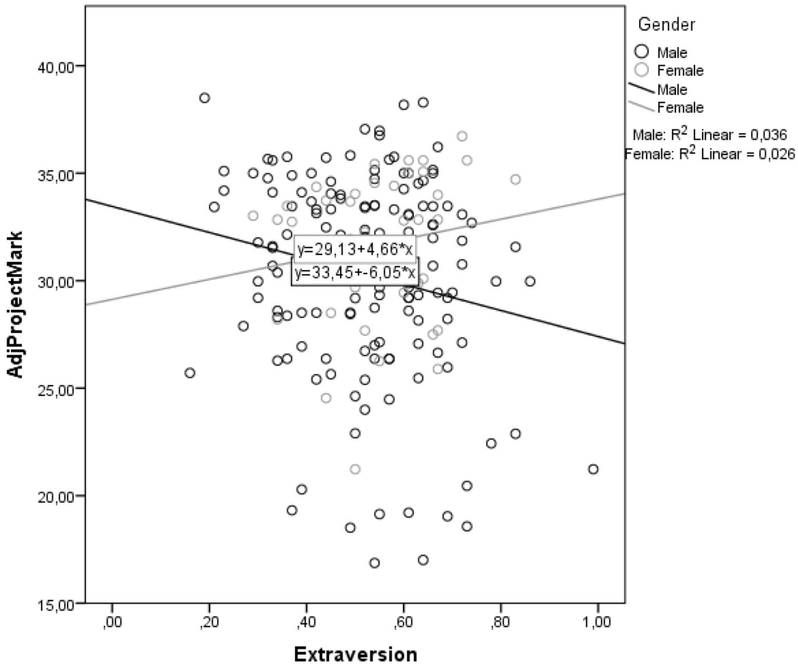

Fig. 1. Adjusted project mark vs extraversion (by gender).

Table 6. Mean and standard deviation of Big Five traits by gender

		Openness	Conscientiousness	Extraversion	Agreeableness	Neuroticism
Male	Mean	0.426	0.580	0.526	0.517	0.425
	Std. dev.	0.136	0.148	0.145	0.149	0.154
Female	Mean	0.443	0.573	0.549	0.542	0.470
	Std. dev.	0.157	0.127	0.123	0.157	0.137

Table 7. Summary of multiple regression analysis – males

	Model 1 (O)		Model 2 (OC)		Model 3 (OCE)		Model 4 (OCEA)		Model 5 (OCEAN)	
Variable	**B**	*β*	**B**	*β*	**B**	*β*	**B**	*β*	**B**	*β*
Constant	29.101		26.757		29.420		28.741		31.830	
Openness	2.751	0.081	1.949	0.057	4.826	0.142	2.562	0.076	2.471	0.073
Conscientiousness			4.634	0.148	5.778	0.184*	4.394	0.140	2.786	0.089
Extraversion					–8.664	–0.27*	–9.051	–0.28*	–10.08	–0.32*
Agreeable-ness							5.122	0.164	5.294	0.170
Neuroticism (Emotionality)									–3.924	–0.13
R^2	0.007		0.028		0.092		0.110		0.123	
F	0.993		2.135		4.977*		4.563*		4.108*	
ΔR^2	0.007		0.021		0.064		0.019		0.013	
ΔF	0.993		3.261		10.391*		3.110		2.144	

* Statistically significant at $p < 0.05$; B = Unstandardized regression coefficient; β = Standardized coefficient.

4.1.2 Females

The same analysis that was done with males is also done with females (N= 39). However, none of the models were statistically significant, and none of the individual coefficients were significant either in any model.

4.2 Groups

A Pearson's product-moment correlation was run to assess the relationship between the team factors (project mark and team dynamics) and the average team personality traits. The correlations are shown in Table 8. Based on the significant correlation

Table 8. Average group factor correlations

	Project mark	Team dynamics	Avg O	Avg C	Avg E	Avg A
Team dynamics	0.086	–				
Average O	–0.053	0.106	–			
Average C	0.320*	0.111	0.312*	–		
Average E	0.027	0.021	0.336*	0.348**	–	
Average A	0.058	0.247	0.302*	0.405**	0.375**	–
Average N	–0.191	–0.006	–0.081	–0.557**	–0.424**	–0.254

* Statistically significant at p < 0.05 level; ** Statistically significant at p < 0.01 level.

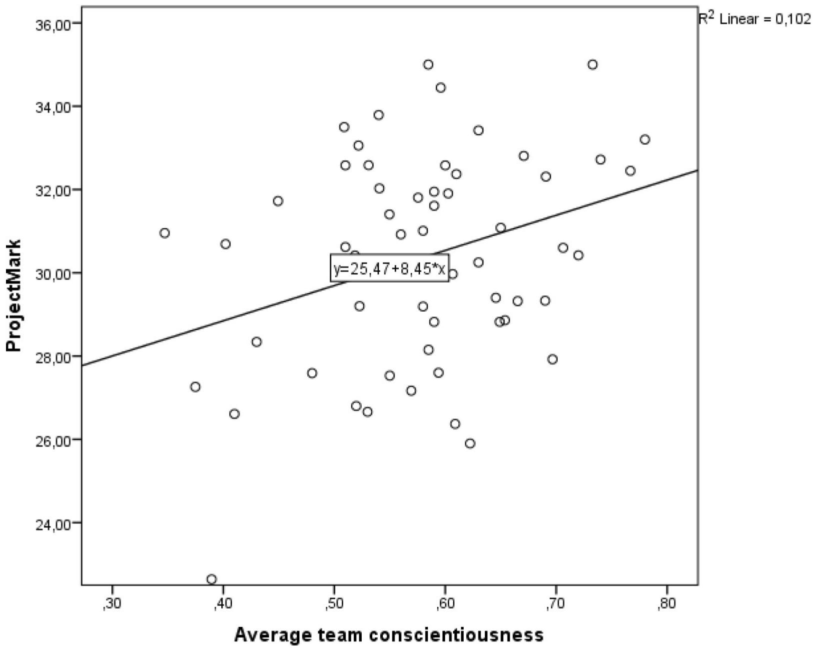

Fig. 2. Project mark vs average team conscientiousness.

between project mark and conscientiousness, a linear regression model was run.

The linear regression was run with 57 observations to understand the effect of the average team conscientiousness on the project mark. To assess linearity, a scatterplot of project mark against average conscientiousness was created with a superimposed regression line. Visual inspection of these two plots indicated a linear relationship between the variables. There was homoscedasticity and normality of the residuals.

The prediction equation was the following: project mark = 25.47 + 8.45*AvgC. Average team conscientiousness statistically significantly predicted project mark, $F(1, 55) = 6.262$, $p < 0.05$, accounting for 10.2% of the variation in project mark with adjusted $R2 = 8.6\%$.

A Spearman's rank-order correlation was run to

Table 9. Variance of group factor correlations

	Project mark	Team dynamics	Var O	Var C	Var E	Var A
Team dynamics	0.159	–				
Variance O	0.272	0.269	–			
Variance C	–0.076	–0.011	0.008	–		
Variance E	0.002	–0.019	0.064	–0.110	–	
Variance A	–0.047	0.050	0.462**	0.158	0.022	–
Variance N	–0.148	–0.185	–0.022	0.201	0.007	–0.025

* Statistically significant at p < 0.05 level; ** Statistically significant at p < 0.01 level.

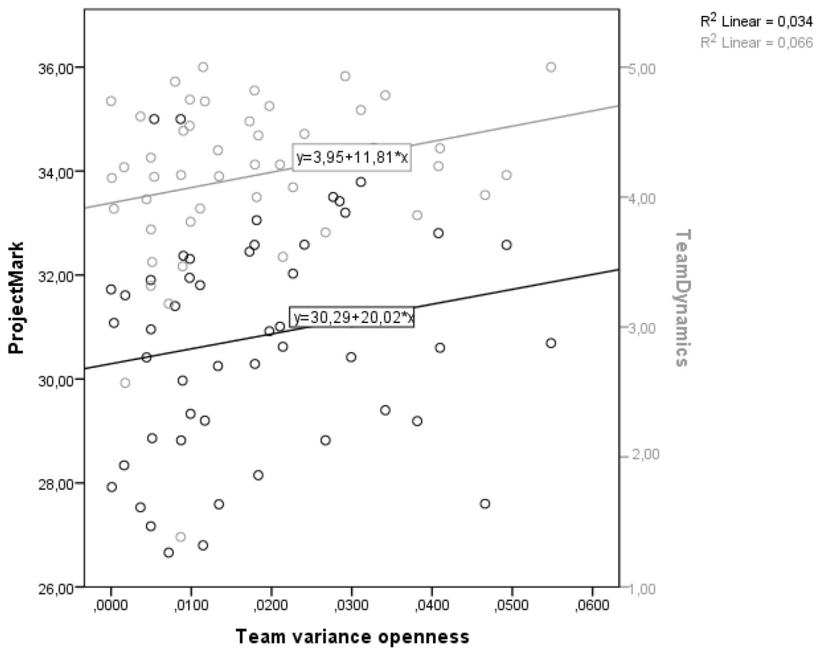

Fig. 3. Project mark and team dynamics vs variance of team openness.

Table 10. Average and variance of group factor correlations

	Avg O	Avg C	Avg E	Avg A	Avg N
Variance O	0.110	0.041	0.082	–0.022	0.027
Variance C	0.067	–0.309*	0.140	0.058	0.057
Variance E	–0.017	0.076	0.011	–0.110	0.066
Variance A	–0.080	–0.034	–0.117	–0.293*	0.156
Variance N	–0.095	–0.160	–0.092	–0.077	0.085

assess the relationship between the project mark, team dynamics and variance of the group personality factors. It was done with 53 groups since the personality variance of a few of the groups were outliers. The results are shown in Table 9. None of the factors are significant with project mark or team dynamics however the significance level of openness variance is 0.051 and 0.058 respectively. They are graphed in Fig. 3 and openness variance accounts for 3.4% and 6.6% of project mark and team dynamics respectively.

A Spearman's rank-order correlation was run to assess the relationship between the averages and variances of the group personality factors. The results are shown in Table 10.

5. Discussion

5.1 Individuals

Peer evaluation is widely used by researchers to understand interaction between members in a group [9]. Since the adjusted project mark, PM evaluation and GPA are all related, seen in Table 2, it can be assumed that any of these other variables could be used to determine individual contributions to the project/team.

An important finding here is that GPA correlates to the peer and PM evaluations, indicating that people who perform generally well in school do just as well in a design class. This is supported by studies that have found GPA to be an indicator of team performance [11]. The reason GPA does not have a significant relationship with the adjusted project mark might stem from the fact that much of the adjusted project grade reflects the contributions of other teammates for the project deliverables, and these teammates might have brought down a grade that would normally be higher from an individual with a high GPA. Students with lower GPAs may also be influencing this result by being more engaged in a project-based course and getting a higher grade. The peer and PM evaluation are slightly skewed by perfect grades given to many students therefore we would expect a stronger relationship between all these factors if it was not the case. Another reason for the weaker relationship is that peer and PM evaluation is a measure between group members which is relative to each member.

However, the adjusted project grade is relative to the entire class, so it has a different scale then these evaluations.

One variable, extraversion, was significant within the regression model of predicting the adjusted project grade against all 5 Big Five factors of individuals. The coefficients indicate that extraversion has a large negative relationship (–6.435) to the project grade, indicated in Table 3. This result indicates that a more introverted person would have a significantly higher adjusted project grade and therefore have better team performance. Contrary to the hypothesis that higher conscientiousness and openness would yield better performance, here the coefficients are not significant. It is possible that these two factors have no significant effect on teamwork in this engineering design course. Ostafichuck & Taylor [22] come to a similar conclusion when analyzing peer evaluation and MBTI domains, that only judging/perceiving has a 1% significance on peer scores. Another possible reason for this result is that the adjusted project mark is not an accurate representation of personal effort or contribution by an individual in the team. This mark comes mainly from written reports and is scaled to take into consideration effort in the project, where the main design and prototyping progress and performance of the team may not be accurately captured. Most personality traits were not significant in the model, which could be a result of too much diversity in the sample for a relationship to be noticed. Again, another reason that could influence the project grades is the support offered by the teaching assistants and project managers who offer guidance and help to all the teams to make sure that none are in a critical state.

The second regression model in Table 3 shows the relationship between the Big Five personality traits and gender and the adjusted project grade. In this second model, extraversion and gender are significant and therefore have a significant effect on the adjusted project grade. As with the first model, extraversion is negatively correlated (–6.893). Gender is positively correlated (1.608). Therefore, people who are more introverted and women have better project grades and contribute more. Openness, conscientiousness, agreeableness and emotionality are all positively correlated and were not significant but still add value to the model and increase the R^2 (0.084). Again, this is contrary to our original hypothesis that high openness, agreeableness and conscientiousness scores would lead to a better performance. This second global model, which includes gender, has a higher proportion of variance (R^2) because gender does have an influence on the adjusted project grade, as observed in the regression models in Table 3. Women have been found to be "more ready" than men in first year to do engineering in context [34] and are more motivated by opportunities for social context (such as in this project-based learning environment) [2]. This could be the reason women are more likely than men to have a higher adjusted project grade in this case.

For men, extraversion correlates positively to openness, conscientiousness and agreeableness, and it correlates negatively to neuroticism, as seen in Table 4. This correlation was expected, but the negative relationship between extraversion and the adjusted project grade in the regression models was surprising. Further work needs to be done to properly understand the population and the results found here. It could be possible that the extraversion trait does not have the same effect on team performance as it does on individual performance. The male only regression model shows that openness has a low coefficient and low significance level. A reason for this factor may be that this sample of engineers doesn't have a very high score for openness (maximum is 0.76 out of 1) as shown in Fig.4. Therefore, openness would not have a significant relationship with the project mark, since the data is skewed, and the openness trait is not indicative of the grade.

The regression model containing only male data also had the odd negative extraversion. However, the positive agreeableness coefficient was expected for teamwork, since positive interactions, sympathy and trust leads to a higher-performing team. Once openness was removed from the model, two Big Five factors, extraversion and agreeableness, were found to be significant, which is closer to what is expected.

The results from the female regression model were also unexpected. The females in this sample may have a higher diversity or there might simply not be enough data to be able to find a statistically significant relationship. Even though the means of the Big Five traits are similar and not significantly different between men and women, seen in Table 6, there is the opposite relationship between the personality traits and the adjusted project grade (like Fig. 1 demonstrates). By comparing the Big Five factor correlations of each gender in Table 4 and Table 5, it is evident that the relationships are different between genders. There are 8 significant correlations between factors for males however only 5 for females. This result is surprising and may lead to the conclusion that female behaviour within engineering teams is different from male behaviour, but more research needs to be conducted in this area.

5.2 Groups

The group conscientiousness result demonstrates that the grade for the design project can be

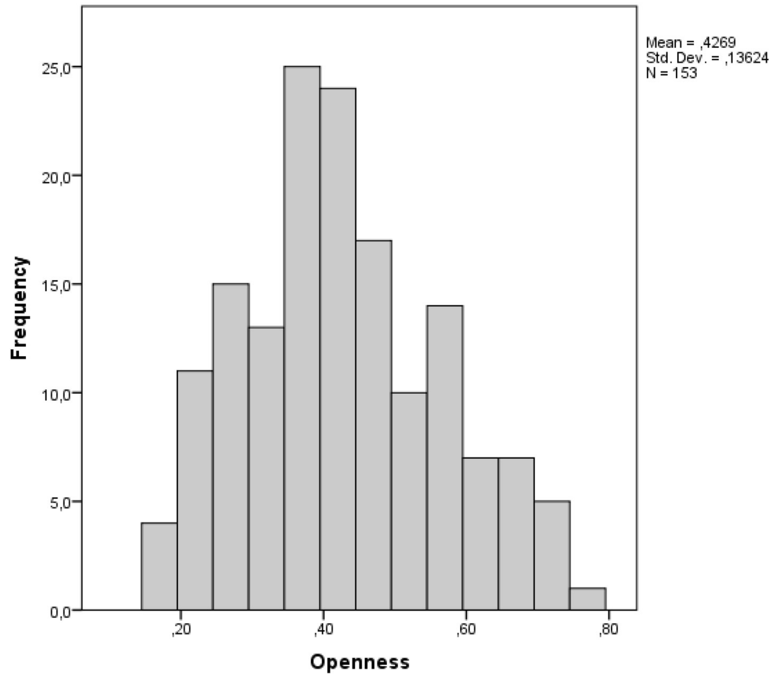

Fig. 4. Openness histogram (males).

explained in part by the average conscientiousness of the team, a finding that supports the hypothesis that higher openness, agreeableness and conscientiousness would lead to better performance. O'Neill & Allen [28] came to the same conclusion that team-level conscientiousness predicts team performance. It can be reasoned that people who are more achievement-striving, organized and task focused will have a better team performance [13, 28]. This relationship can be seen in Fig. 2. The significant negative correlation between the average and the variance of the conscientiousness of a group, seen in Table 10, also indicates that teams with a low conscientiousness variation have a higher total conscientiousness in this sample. Therefore, higher project marks are achieved by teams which have members who are all relatively conscientious. This homogeneous trait leads to all members taking a similar level of responsibility and performing effectively together [29].

Bivariate correlations and regression models have been calculated with the variance between a personality factor for team members in a group. Diversity of the different personality traits shows no significant effect on project mark and team dynamics in Table 9. The graph in Fig. 3 however, represents a variance of openness in a team has some effect on the project grade and team dynamics. This result is again surprising since the hypothesis was that a more diverse team would perform better. However the results agree with Neuman, Wagner and Christiansen [29, p. 32] ideas that "certain traits may enhance performance when the team is homogenous, whereas other traits may enhance performance when the team is diverse". Since this sample of students has already been shown to have low openness, teams that have a member with higher openness would have the high variance in this trait. This team would seem to do better on the project and get along better. The reason we are not seeing any results with diversity in personality might be a result of not having groups that are very different (in other factors then personality), as people tend to pick team members who they know or are like themselves demographically. The demographics of undergraduate student population in engineering is also not terribly diverse [21]. This might be the key to different perspectives and experiences where personality differences may not have the same effect. Other racial, cultural or socio-economic factors may have a larger impact on teamwork then different personality traits. More research in this area needs to be conducted to better understand the effects of personality diversity vs demographic diversity in an engineering design team.

5.3 Limitations

This study has the limitation that the results could only be applied to the particular job of engineering design or something that requires similar skills. Since jobs or tasks have different task structures and organizational environments, they would favour different personality profiles. Results may also differ in other universities since the student population of engineers in different geographic locations or students who have chosen a particular university have similar (or different) personality profiles.

6. Conclusion

Since design is at the core of engineering, and teams are generally needed to accomplish design tasks and teamwork is an important skill to learn. A project-based learning environment is a great place for that exposure. Understanding the effect of the different aspects of personality enables better prediction of team success and better team formation procedures for instructor-assigned teams. The selection can be based on many factors however it is often unclear which ones are best. This study shows the relationship between the Big Five personality traits as well as gender and project grades in project-based engineering design courses. In terms of personality traits, openness is shown to be lower in this sample which can influence relationships with performance factors. This study found that there is a difference in personality trends by gender because 9.6% of the adjusted project grade for males can be explained by their conscientiousness, extraversion, agreeableness and neuroticism (CEAN) personality traits, but that none of the grade for females can be explained by these traits. Overall, however, 8.6% of the project grades can also be explained by average team conscientiousness scores. Finally, personality diversity had no significant relationship in this sample to team or project outcomes.

This study also found a positive significant relationship between peer evaluation, PM evaluation and the adjusted project mark, indicating that any of these other variables could be used to determine individual contributions to the project/team. It also found that GPA correlates to the peer and PM evaluations, indicating that people who perform generally well in school do just as well in a design class.

Further work is suggested to explore the effect of personality traits on design project success to understand how results may vary depending on gender. It would also be interesting to know if a low openness score is common across many departments or many institutions. Lastly, team demographic diversity should be studied in addition to personality diversity to provide a more global understanding of the effect of diverse groups in engineering design.

Acknowledgments—The authors acknowledge funding from the National Sciences and Engineering Research Council of Canada through the Center for Entrepreneurship and Engineering Design (CEED) that made it possible for the Faculty of Engineering to design and develop the courses discussed in this article.

References

1. C. Dym, A. Agogino, O. Eris, D. Frey and L. Leifer, Engineering Design Thinking , Teaching , and Learning, *J. Eng. Educ.*, **34**(1), pp. 103–120, 2005.
2. R. F. Vaz, P. Quinn, A. C. Heinricher and K. J. Rissmiller, Gender differences in the long-term impacts of project-based learning, in *Procedings of the American Society for Engineering Education*, pp. 1–18, 2013.
3. S. M. Gomez Puente, M. van Eijck and W. Jochems, A sampled literature review of design-based learning approaches: a search for key characteristics, *Int. J. Technol. Des. Educ.*, **23**, pp. 717–732, 2013.
4. R. Felder and R. Brent, *Cooperative Learning in Technical Courses: Procedures, Pitfalls, and Payoffs*, Oct. 1994.
5. [5]
   P. Dillenbourg, What do you mean by collaborative learning?, in *Collaborative-learning: Cognitive and Computational Approaches*, P. Dillenbourg, Ed. Oxford: Elsevier, 1999, pp. 1–19.
6. R. T. Johnson and D. W. Johnson, Cooperative Learning in the Science Classroom, *Physical Science Magazine*, pp. 19–20, 2006.
7. S. Clinebell and M. Stecher, Teaching teams to be teams: An exercise using the Myers-Briggs Type Indicator and the Five-Factor personality traits, *J. Manag. Educ.*, **3**(27), pp. 362–383, 2003.
8. W. Brewer and M. I. Mendelson, Methodology and Metrics for Assessing Team Effectiveness, *Int. J. Eng. Educ.*, **19**(6), pp. 777–787, 2003.
9. B. Oakley, R. Brent, R. M. Felder and I. Elhajj, Turning student groups into effective teams, *J. Student Centered Learn.*, **2**(1), pp. 9–34, 2004.
10. A. Gero and O. Danino, High-school course on engineering design: Enhancement of students' motivation and development of systems thinking skills, *Int. J. Eng. Educ.*, **32**(1), pp. 100–110, 2016.
11. M. Hacker, The impact of top performers on project teams, *Team Perform. Manag.*, **6**(5/6), pp. 1–6, 2000.
12. M. A. G. Peeters, H. F. J. M. Van Tuijl, C. G. Rutte and I. M. M. J. Reymen, Personality and Team Performance: A Meta-Analysis, *Eur. J. Pers.*, **20**(5), pp. 377–396, 2006.
13. L. A. Hua, *Diversity in Conscientiousness and Team Composition: Their Relationships with Team Conflict, Performance, and Satisfaction*, Alliant International University, 2013.
14. S.-T. Shen, S. D. Prior, A. S. White and M. Karamanoglu, Using personality type differences to form engineering design teams, *Eng. Educ.*, **2**(2), pp. 54–66, 2007.
15. O. P. John and S. Srivastava, The Big Five Trait Taxonomy: History, Measurement, and Theoretical Perspectives, in *Handbook of personality: Theory and research*, L. A. Pervin and O. P. John, Eds. New York, New York, USA: Guilford Press, pp. 102–138, 1999.
16. C.-M. Chiang, *A Study of the Relationship Between Team Members' Personalities and Cultural Dimensions and Their Effects on Team Performance*, PhD dissertation, Organization Development, Benedictine University, Illinois, USA, 2011.
17. J. M. George and G. R. Jones, *Understanding and Managing Organizational Behaviour*, 6th ed., **111**(479), Pearson, 2012.

18. D. M. Sherif, *How Students' Big Five Personality Traits Manifest in Social Loafing Behavior: A Case Study of Group Assignments at a Southwestern U.S. University*, Grand Canyon University, 2018.
19. R. R. McCrae and J. Costa, P. T., *Personality in adulthood: A five-factor theory perspective*, 2nd ed. New York, New York, USA: Guildford, 2003.
20. M. A. Cronin and L. R. Weingart, Representational Gaps, Information Processing, and conflict in Functionallly Diverse Teams, *Academy of Management Review*, **32**(3), pp. 761–773, 2007.
21. I. J. Busch-Vishniac and J. P. Jarosz, Can Diversity in the Undergraduate Engineering Population Be Enhanced Through Curricular Change?, *J. Women Minor. Sci. Eng.*, **10**(3), pp. 255–282, 2004.
22. P. M. Ostafichuck and C. Naylor, The Influence of Personality Type on Teamwork in Engineering Education, *Proc. Can. Eng. Educ. Assoc.*, pp. 1–7, 2017.
23. Thomas O'Neill, Nicole Larson, Julia Smith, Magda Donia, Connie Deng, William Rosehart and Robert Brennan, Introducing a scalable peer feedback system for learning teams, *Assessment & Evaluation in Higher Education*, **44**(6), pp. 848–862, 2019.
24. S. Streiner, C. Deibler, M. Besterfield-sacre and L. Shuman, Design Process Maps: A Look at Team Dynamics, in *Procedings of the 2010 Industrial Engineering Research Conference*, pp. 1–6, 2010.
25. S. W. J. Kozlowski and G. T. Chao, Unpacking Team Process Dynamics and Emergent Phenomena: Challenges, Conceptual Advances, and Innovative Methods, *Am. Psychol.*, **73**(4), pp. 576–592, 2018.
26. M. R. Barrick and M. K. Mount, The Big Five Personality Dimensions and Job Performance: A Meta-Analysis, *Pers. Psychol.*, **44**, pp. 1–26, 1991.
27. M. C. O'Connor and S. V Paunonen, Big Five personality predictors of post-secondary academic performance, *Pers. Individ. Dif.*, **43**, pp. 971–990, 2007.
28. T. A. O'Neill and N. J. Allen, Personality and the Prediction of Team Performance, *Eur. J. Pers.*, **25**, pp. 31–42, 2011.
29. G. A. Neuman, S. H. Wagner and N. D. Christiansen, The Relationship between Work-Team Personality Composition and the Job Performance of Teams, *Gr. Organ. Manag.*, **24**(1), pp. 28–45, 1999.
30. T. Chamorro-Premuzic and A. Furnham, Personality Traits and Academic Examination Performance, *Eur. J. Pers.*, **17**(3), pp. 237–250, 2003.
31. B. H. Bradley, A. C. Klotz, B. E. Postlethwaite and K. G. Brown, Ready to Rumble: How Team Personality Composition and Task Conflict Interact to Improve Performance, *J. Appl. Psychol.*, **98**(2), pp. 385–392, 2013.
32. M. V Jamieson and J. M. Shaw, CATME or ITP Metrics? Which One Should I Use for Design Team Development and Assessment?, in *Procedings of the American Society for Engineering Education*, pp. 1–16, 2018.
33. M. W. Ohland, N. Carolina, L. G. Bullard, R. M. Felder and R. A. Layton, Assessment of Team Member Effectiveness: Development of a Behaviorally Anchored Rating Scale for Self- and Peer-Evaluation, *Acad. Manag.*, **11**(4), pp. 609–630, 2012.
34. D. Kilgore, C. J. Atman, K. Yasuhara, T. J. Barker and A. Morozov, Considering Context: A Study of First-Year, *J. Eng. Educ.*, **96**(4), pp. 321–334, 2007.

Justine Boudreau completed her mechanical engineering degree at uOttawa and is now working on an Electronic Business Technologies Masters with a focus in engineering education. During the last four years she has spent her time playing with new tech and diversifying her knowledge. She spent almost 2 years working with the Maker Mobile delivering workshops and integrating new curriculum for robotics and women in science and engineering. She then moved on to work for the uOttawa Richard L'Abbé Makerspace while teaching and running the first – and second-year engineering design courses run through the MakerLab.

Hanan Anis is a professor in Electrical and Computer Engineering at the University of Ottawa. She is the NSERC Chair of entrepreneurial engineering design. Her research interests include Engineering Education and photonics.

Appendix A

TA and PM evaluation rubric

Criteria	Level 5 (5 pts)	Level 4 (3.75 pts)	Level 3 (2.5 pts)	Level 2 (1.25 pts)	Level 1 (0 pts)
Teamwork	Is essential to the team, always ensures good cohesion and cooperation.	Helps the team progress and usually cares about team dynamics.	Helps the team progress but does not always care about team dynamics.	Sometimes contributes but is not reliable.	Does not help the team, is not generally noticed.
Professionalism	Early to labs, is fully dedicated and drives things to closure, effective participation style, excellent focus. Owns responsibility for the project, is extremely reliable.	On time, dedicated to the work, participates effectively and good focus. Owns responsibility for their parts, is reliable.	Mostly on time, average dedication, participates regularly and ok focus. Usually responsible and reliable	Mostly late, does not care much about the project, participates occasionally, rarely focused. Not responsible or reliable.	Does not show up, rarely participates, is a detriment to the team.

Criteria	**Level 5 (5 pts)**	**Level 4 (3.75 pts)**	**Level 3 (2.5 pts)**	**Level 2 (1.25 pts)**	**Level 1 (0 pts)**
Communication	Demonstrates excellent communication with teammates as well as PMs. Proactive to inform others of changes or modifications that concerned them. Asks questions when appropriate.	Good communication with teammates and PMs. Mostly proactive to inform others. Asks questions that are usually relevant.	Average communication with teammates and PMs. Sometimes proactive to inform others. Asks some questions but that are not always relevant.	Minimal communication with others. Does not ask questions when unsure.	Does not communicate or ask questions.
Organization and Discipline	Work is done extremely seriously and with precision. Ensures work is relevant and completed early.	Work is done seriously and is relevant, completed on time.	Some effort to make sure work is relevant and done properly. Sometimes completed late.	Minimal effort is put into the work completed. It is never done on time.	No effort to do any work.
Technical contribution	Does most of the work for the project. Has demonstrated excellent ability to learn and use technical skills.	Contributes more of work to the project than others. Has demonstrated ability to learn and use technical skills appropriately most of the time.	Contributes an equal amount to the project. Learns appropriate technical skills but doesn't always use them correctly.	Minimally contributes to the project. Attempts to learn some technical skills but does not use them or uses them incorrectly.	Does not contribute to the project. Does not learn any skills.