The Impact of Integrating Making Activities to Cornerstone Design Courses on Students' Implicit Theories of Making Ability

Mr. Mohamed Galaleldin, University of Ottawa

Mohamed Galaleldin is a Professional Engineer and a PhD candidate - at the University of Ottawa, Ontario, CA. He is interested in investigating the impact of integrating a maker curriculum to engineering design education.

Dr. Hanan Anis, University of Ottawa

Hanan Anis holds an NSERC Chair in Entrepreneurial Engineering Design and is a professor in Electrical and Computer Engineering at the University of Ottawa.

Prior to Joining the University in 2004, Hanan was the co-founder and Chief Technology Officer at Ceyba, an optical long-haul networking company that employed 250 people at its peak. Hanan also worked at Nortel Networks in different positions conducting pioneering research in various areas of photonics, ranging from device physics to optical networking. She has numerous journal and conference publications and patents. Hanan's current research interests include Biophotonics, Innovation and engineering education.Her passion is to help students graduate with an entrepreneurial mind set that enable them to play leading roles in existing organizations or create their own jobs.

The Impact of Integrating Making Activities to Cornerstone Design courses on Students' Implicit Theories of Making Ability

Abstract

A person's implicit theories in a certain domain are known to have a direct influence on that person's performance, behaviour, self-esteem, enjoyment and sense of belonging to the domain. This paper explores the role of implicit theory in engineering students' beliefs about the nature of their making abilities and their self-identification as makers. This is done by assessing if a collaborative project-based engineering design course built on making activities can contribute to influencing students to have a growth mindset about their making abilities. Data from full-time engineering undergraduates were collected during the second week of the fall term. As predicted, the majority of engineering students had a growth mindset about their making abilities mindset, with male students more likely to have a fixed mindset than female students. Moreover, engineering design courses that successfully integrate making activities into the curriculum are shown to induce students to develop a growth mindset in relation to their beliefs about the nature of their making abilities.

Keywords: Implicit Theories; Engineering Design Education; Maker Movement; Makerspaces; Growth Mindset

Introduction

The primary purpose of this study is to examine the potential opportunities the maker movement presents to engineering design education. The maker movement is a relatively new trend that has the potential to shift the future of education [1] through (1) digital, physical and logic tools, (2) community infrastructure and (3) the maker mindset, which is characterized as curious, playful, optimistic, persistent, resourceful and willing to take responsibility, take risks and share information [2, p. 5]. These characteristics are similar to the engineering habits of mind [3]: systems thinking, creativity, optimism, collaboration, communication and attention to technical considerations [4, p. 152].

The maker movement also has the potential to respond to the calls for increased exposure in K-12 curriculum to sciences, technology, engineering and math (STEM) and hands-on and design experiences in college level engineering curriculum [4, p. 151], [5] by integrating making activities into the curriculum to expose students to design activities and experiential learning technology [3]. The term "making" today covers a broad set of activities from different disciplines, highlighting the innumerable opportunities for interdisciplinary work [1]. Sheridan et al. [6] defined making activities 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.

Integrating making activities in engineering schools' curriculum engages students in experimental learning opportunities through the creation of physical or digital objects and by providing access to sophisticated tools that engage students in new forms of thinking, support experimentation and advocate for a growth mindset that encourages persistence and the seeking of challenges and learning, all of which represent valuable learning opportunities that align with the learning outcomes aspired to by engineering schools [3].

In this paper, we assessed the impact of integrating making activities into two engineering design courses on one non-cognitive attribute — implicit theories —. The study presented in this paper focuses on the integration of making activities into two collaborative project-based-learning engineering design courses that offer students an authentic learning environment where they work with a real-time client to solve an engineering problem and engage in a series of prototyping activities. The learning environment of both courses is designed to involve students in creating physical or digital prototypes, while thinking about what they are doing to engage in higher-order thinking tasks such as analysis, synthesis and evaluation [7].

The two courses under study are a first-year introduction to engineering design course and a second-year introduction to product development course. In the first-year course, students are presented with three options for team projects: building a zero-net energy greenhouse, creating a hydroponics project or creating a robot for water sampling. Students in the second-year course work in a team environment with clients to solve an accessibility problem, such as creating a hand sanitizer for a client with limited motor control, a skating device to teach children with disabilities how to skate, a snow removal device that can be installed on a wheelchair for a client with cerebral palsy, a portable lightweight ramp, a portable wheelchair curtain, an assistive feeding device, a wheelchair robotic arm, and smart curtains for windows at long-term care residences. Detailed project descriptions are available on request.

Students participate in a weekly lab session at the University of Ottawa's Makerspace that aims to integrate making activities into the engineering curriculum, familiarize students with the Makerspace environment and facilitate their entry into the students' maker community of practice (CoP) that has formed within the Makerspace since its opening. The labs scaffold students' learning of several making technologies. For example, in the second-year engineering course, students build a chariot during their lab time using those technologies. The chariot is entirely made of the parts they manufacture, program and assemble. Figure I shows a picture of a chariot built by students.

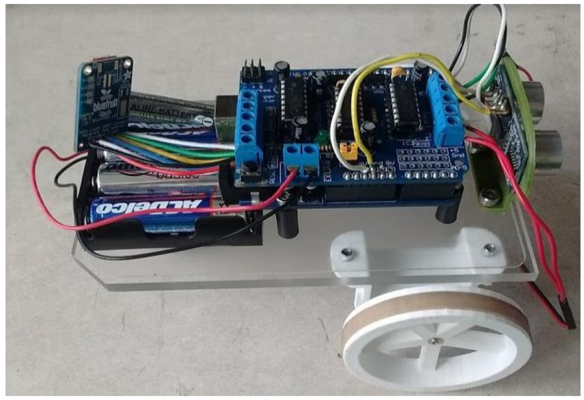

FIGURE I – PICTURE OF THE CHARIOT PROJECT BUILT BY STUDENTS IN THE SECOND-YEAR INTRODUCTION TO ENGINEERING DESIGN COURSE

The making activities that students engage in during the course aim to train them on how they can easily develop their ideas from concept to prototype. Labs are divided into two portions. In the first, students are introduced to various rapid prototyping and engineering tools. Labs are held in the Makerspace, where students are introduced to technologies such as sheet metal processing, SolidWorks, 3D printing, Arduino, PCB design, soldering and mobile app development. In the second portion of the labs, students work on their project's prototypes.

This article explores the potential effects of integrating making activities into an engineering school's curriculum by focusing on students' implicit theories about their making abilities. Two research questions are discussed in this article: the first explores the relationship between students' making abilities mindset and students' characteristics; the second question aims to understand if integrating making activities into introductory engineering design courses affects students' implicit theories of making abilities. To be able to experimentally investigate the impact of integrating maker curriculum into introductory engineering design courses, we compared two groups of engineering students registered in a fourth-year mechanical engineering capstone course: students who had taken an introductory engineering design course with making activities integrated into it, and students who had not in their first or second year of study. For the purpose of this article, traditional engineering design courses are defined as cornerstone or capstone engineering design courses that don't engage students in a hands-on, experiential learning experience of engineering design.

Background

Implicit personality theories are beliefs about the nature of human attributes and an individual's control over his or her abilities or the world [8]. Those who hold an entity theory, for example, believe that human attributes cannot be enhanced and that individuals do not have control over an attribute in a specific domain. On the other hand, incremental theorists believe individuals have the ability to grow, provided they have the proper motivation, opportunity and instruction [9]. Implicit personality theories are related to essentialist beliefs [9], which refer to the view that social categories are discovered rather than invented and natural rather than artificial, and that they predict other properties [10]. Implicit personality theories in a certain domain have a direct influence on self-esteem, enjoyment and performance [11], [12], [13], [14]. They also contribute to an individual's sense of belonging to a domain. Their greatest impact can be felt when people face complex and novel tasks [15], [9].

Implicit theories orient individuals towards different goals [16], [17], [9]. Individuals who hold an incremental theory tend to adopt learning goals when faced with challenges, regardless if they think they will succeed or not when tackling a task or a challenge, and they are found to be more motivated and persistent when faced with a challenge or an obstacle than are entity theorists [16], [14], [18]. Entity theorists on the other hand, are found to be more confident that behaviours in a domain are consistent across situations, knowing a person's trait in a specific domain in a particular situation allows them to predict their behaviour in a new setting [19]. Entity theorists are willing to put more effort into a challenge if they expect to succeed and appear competent. When faced with an overwhelming challenge, their performance tends to worsen, and they tend to adopt a helpless response as their goal of appearing competent appears more out of reach. Effort exerted in a particular task is an indicator of a lack of inherent ability [20].

Research has found that a person's implicit theory of intelligence can change as a result of contextual influences [21]. An environment's implicit theories also have an impact on the goals pursued by individuals within them [22]. Organizations that endorse an entity theory encourage individuals to pursue performance goals [16], which can cause people to disregard valuable learning opportunities [23]. Incremental organizations, on the other hand, encourage individuals to pursue learning goals, helping them to face challenges and setbacks and adopt mastery-oriented behaviours [23].

Implicit personality theories are measured by asking people to agree with several statements that represent entity and incremental theories [9]. Dweck's model of theories about the self is domain-specific and focuses on people's beliefs about themselves and the type of goals they pursue [24]. Dweck, Chiu & Hong [25] developed a three-item questionnaire to assess an individual's entity versus incremental personality theory in the domains of intelligence and morality. The three items in the implicit personality theories of intelligence domain measure are the following:

a) You have a certain amount of intelligence and you really can't do much to change it;
b) Your intelligence is something about you that you can't change very much; and
c) You can learn new things, but you can't really change your basic intelligence.

Respondents indicated their agreement with these statements on a 6-point scale from 1 (strongly agree) to 6 (strongly disagree) [25, p. 269]. Respondents with a score of 3.0 or below are classified as entity theorists, and those with a 4.0 score or higher are classified as incremental theorists. Dweck et al. [25] reported that typically about 85% of respondents are evenly distributed between the two implicit theories, while 15% of the participants are excluded. The morality measure is similar to the intelligence measure.

Since implicit personality theories are domain-specific [25], many researchers have developed implicit personality theories measures for specific domains, such as a scale that measures the sense of belonging to math [26], a scale of implicit negotiations beliefs [14] developed after the measure of implicit person theory developed by Dweck et al. [25], measures of implicit theories of managerial ability [13], and a measure of the implicit theories of emotions [27].

Researchers have also successfully manipulated implicit personality theories by introducing participants to instructions that demonstrated an attribute as fixed or malleable, providing them with a “scientific” article that compelled them to think that the attribute under study is either inherent or malleable, or by offering a workshop that taught the incremental theory [9].

Previous researchers in the field of self-theories have defined implicit personality theories in their studies as a dichotomous variable [25] consisting of two levels — entity and incremental theories — based on an individual’s score on a single dimension. In this study, implicit theories of making abilities are treated as a categorical variable with three levels: students who have a fixed mindset, students who have a growth mindset, and students who hold a mindset between fixed and growth mindsets. Also, for the purpose of this study, making activities have been defined as those that are focused on designing, building, modifying and/or repurposing material objects, for playful or useful ends to create a “product” of some sort that can be used, interacted with or demonstrated [28].

The results of this study contribute to the body of knowledge about the implications of integrating making activities into an engineering school’s curriculum. The study also contributes to understanding the extent to which students’ participation in making activities helps them adopt a growth mindset in relation to their making skills. This study investigates whether female engineering students are more likely than male engineering students to hold an entity theory of making abilities. Similar studies that have investigated implicit theories in the domain of intelligence and mathematical abilities have found that when female students view their abilities as fixed, they tend to lose their confidence when faced with challenges [29].

Research Questions

RQ1: Are students’ implicit theories of making abilities associated with their gender, year of study or whether they had participated in a design competition in the past?

RQ2: Do engineering design courses that are built around making activities influence students to have a growth mindset?

Methods

Participants

Participants in this study (n = 198) were undergraduate engineering students at the Faculty of Engineering at the University of Ottawa, Ontario. Students were from different engineering disciplines: mechanical engineering, civil engineering, software engineering, computer engineering and chemical engineering. There were 157 (79.3%) men and 41 (20.7%) women. Most of the respondents were fourth-year students (55.1%; n = 109), followed by second-year students (21.7%; n = 43), first-year students (19.7%; n = 39), and third-year students (3.5%; n = 7). (See Table II.)

TABLE I. SAMPLE DESCRIPTION

		Year of Study				
		1st Year	**2nd Year**	**3rd Year**	**4th Year**	**Total**
Gender	**Male**	25	37	5	90	157
	Female	14	6	2	19	41
Total		**39**	**43**	**7**	**109**	**198**

Measures

The variables in this study included students' making abilities, goals, year of study, experience in a design competition team, peer assessment score, course grade and cumulative GPA. Students' cumulative GPA and grades were on a 10.0 scale.

The questionnaire presented students with the definition of making activities provided by Martin [28] twice, the first time before asking them whether they self-identify as makers or not, and the second before presenting them with the making abilities mindset scale. Students' implicit theories about their making abilities were measured using a modified version of the implicit personality theories of intelligence scale [25]. The modified scale was composed of three items:

a) You are either a maker or you are not — even trying very hard you cannot change much.
b) You have to be born a maker — without innate talent, you cannot be a maker.
c) Some people are makers, others aren't — and no practice can change it.

Since implicit personality theories are "conceptually domain specific" [25], and we are focusing on how students' implicit theories about their making abilities are related to students' skills and academic achievement in engineering design courses, it was preferable to use a domain-specific measure [19, p. 22], [24, p. 175].

Student responses to the domain-general measure of implicit personality theories developed by [19] were also measured to see if there was any association between their implicit personality theories about the nature of their making abilities and their implicit personality theories about personality. The measure consists of three items:

- The kind of person someone is, is something very basic about them and it can't be changed very much.
- People can do things differently, but the important parts of who they are can't really be changed.
- Everyone is a certain kind of person and there is not much that can be done to really change that.

Both measures were composed of entity theory items because incremental theory items are found to be too compelling — that is, when incremental theory questions are presented to students, they will most likely respond positively [25], [24]. For both measures, students indicate their extent of agreement with each item on a 6-point scale with responses ranging from 1 (strongly agree), 2 (agree), 3 (mostly agree), to 6 (strongly disagree). A higher score indicated a strong incremental theory, and low score indicated a fixed theory.

To ensure that only students with clear theories were included, implicit theories of making abilities were treated as a categorical variable, and participants were classified as entity theorists if their implicit theories of making abilities score was 3.0 or below and classified as incremental theorists if their implicit theories of making abilities score was 4.0 or above. Following this criterion, 62 (31.3%) students out of the 198 participants were excluded because they had a score between 3.0 and 4.0.

After completing the measures of implicit theories of making abilities and of implicit personality theories, students were presented with a four-item scale that assessed their learning and performance goals [24]. The scale aims to assess students' concerns in learning environments, whether these are performance concerns or challenge-oriented concerns. The scale consists of the following statements:

a) If I knew I wasn't going to do well at a task, I probably wouldn't do it even if I might learn a lot from it.
b) Although I hate to admit it, I sometimes would rather do well in a class than learn a lot.
c) It's much more important for me to learn things in my classes than it is to get the best grades.
d) If I had to choose between getting a good grade and being challenged in class, I would choose ... (Circle one: "good grade" or "being challenged").

The first three items were scored on a 6-point scale with responses ranging from 1 (strongly agree), 2 (agree), 3 (mostly agree), to 6 (strongly disagree); a high score indicated the respondent's preference for learning goals. The last item converts to a dichotomous variable that indicated the respondent's goal choice.

Procedure

The study was administered in three engineering design courses at different levels of study. The first course is an introduction to engineering design course for first-year engineering and computer sciences students; the second is an introduction to product development for second-year engineering and computer sciences students; and the third is a computer-aided design (CAD) capstone course for fourth-year mechanical engineering students.

Fourth-year mechanical engineering students had to respond to a pre-course questionnaire that asked them about the design courses they had taken in previous years, whether they had participated in an engineering design competition, and whether they had used any of the design spaces at the Faculty of Engineering: the Richard L'Abbé Makerspace or the Brunsfield Centre machine shop.

The study's main questionnaire — refer to Appendix B — was administered during the second week of the fall semester of the 2018–2019 academic year. Students responded to the questionnaire through an online link.

Results & Discussion

Students' implicit theories of making abilities were treated as a categorical variable to ensure that only students with a clear mindset were included in the study. As a result, students who scored between 3.0 and 4.0 in the implicit theories of making abilities scale were excluded from the analysis. The resulting sample were 136 students, of which 106 (77.9%) were men and 30 (22.1%) were women. Table II presents a detailed description of the resulting sample with students with a fixed or growth mindset only.

TABLE II. STUDENTS WITH A CLEAR MINDSET SAMPLE DESCRIPTION

		Year of Study				
		1st Year	**2nd Year**	**3rd Year**	**4th Year**	**Total**
Gender	**Male**	18	27	5	56	106
	Female	12	5	2	11	30
Total		**30**	**32**	**7**	**67**	**136**

As expected, a majority of the sample had a growth mindset about their making abilities (84.6%; n = 115), and only (15.4%; n = 21) of the study sample had a fixed mindset about their making abilities. Table III presents the number of students who held a fixed or growth making abilities mindset for each gender group.

A Spearman's rank-order correlation was run to assess the relationship between students' maker identity and their implicit theories of making abilities. Preliminary analysis showed the relationship to be monotonic, as assessed by visual inspection of a scatterplot. There was no statistically significant correlation between the two variables, $r_s(136) = .091$, $p = .292$.

Intriguingly, we found that students' identification as makers was not correlated with their making abilities mindset. Most of the students who had a fixed mindset in relation to their making abilities mindset (n = 21) also self-identified as makers (n = 19). Dale Doughetry [30] argued for the similarity between a maker mindset and a growth mindset that "encourages students to believe they can learn to do anything." Although this finding does not contradict Doughetry's observation on the similarity between the maker mindset and characteristics of a growth mindset, it does raise several questions on the relationship between self-identifying as maker and holding a maker mindset or a growth making abilities mindset for engineering students. What this result indicates is that an engineering student might self-identify as a maker without having a maker mindset and/or not necessarily hold an incremental theory in relation to their making abilities. Another hypothesis is that an engineering student might hold a maker mindset yet hold an entity theory in relation to their making abilities. Another hypothesis that can provide an explanation for the absence of a relationship between students' maker identity and implicit theories of making abilities is the broad nature of what the community of practice around making classifies as making activities [31].

TABLE III. STUDENTS MAKING ABILITIES MINDSET PER GENDER GROUP

		Making Abilities Mindset		
		Fixed Mindset	**Growth Mindset**	**Total**
Gender	**Male**	20	86	106
	Female	1	29	30
Total		**21**	**115**	**136**

Research Question 1:

Are students' implicit theories of making abilities associated with their gender, year of study or whether they had participated in a design competition in the past?

A Fisher's exact test was conducted between gender and the students' making abilities mindset. There was a statistically significant association between gender and the students' making abilities mindset, $p = 0.044$, with the odds ratio for male students having a fixed mindset = 6.744, 95% CI [0.866 to 52.493]. (See Figure I.) This result indicates that engineering female students are more likely to hold an incremental theory in relation to their making abilities than male engineering students.

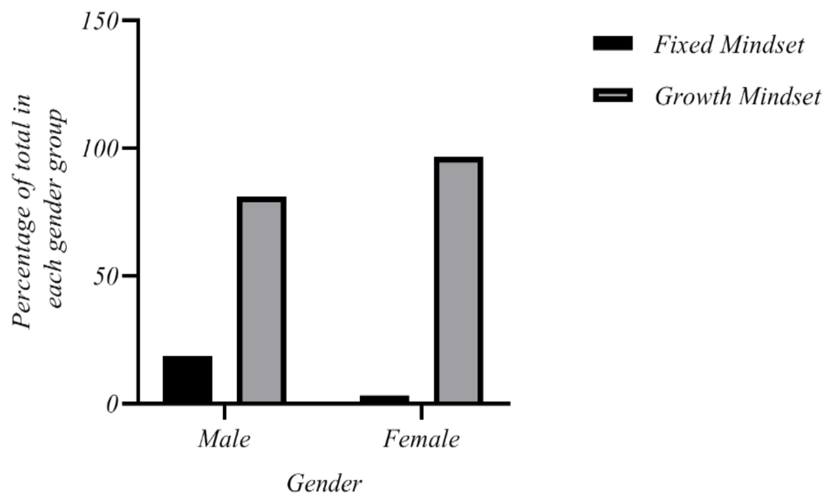

FIGURE II - STUDENTS' MAKING ABILITIES MINDSET BASED ON GENDER GROUP

Studies on the impact of mindset in mathematics skills on students' math performance and STEM career aspirations find that female students are more vulnerable than male students to the detrimental effects of holding an entity theory mindset [32], [29], [33], [34]. Van Alderen-Smeets and Walma van der Molen [35] analyzed the findings of studies on the impact of implicit theories on STEM career choice and aspirations and noted that improving students' implicit theories, especially for female students with entity beliefs, can increase their STEM self-efficacy and the probability that they will choose a career in a related STEM field.

This result confirms that female engineering students have a growth mindset in relationship to their making abilities. Also, it emphasizes the importance of the role that altering female students' mindsets from a fixed mindset to a growth mindset can play in motiving female students to choose an engineering career.

To understand the association between students' year of study and their participation in design competition teams and their implicit theories of making abilities, a Fisher's exact test (2-sided) was conducted. The test revealed that there was no statistically significant association between students' year of study ($p = 0.217$) and their previous experience in design competition teams ($p = 1.0$).

Research Question 2:

Do engineering design courses that are built around making activities influence students to have a growth mindset?

To answer this research question, the participants considered were fourth-year mechanical engineering students in the remaining sample of students with a clear mindset (either growth or fixed making abilities mindset). Fifty-three fourth-year mechanical engineering students with a clear making abilities mindset (either growth or fixed) responded to the pre-course survey. Of the 30 students (56%) who had taken a traditional introduction to engineering design course, 10 students (33.3%) had a fixed making abilities mindset. By comparison, of the 23 students who had taken one of the design courses under study that had integrated making activities into the course, 2 students (9%) had a fixed mindset.

A chi-squared test of association between the type of introductory engineering design courses that students had taken in their first two years of study and their making abilities mindset was conducted. All expected cell frequencies were greater than five. There was a statistically significant association between the type of introductory design course students had taken in their first or second year at the faculty and their making abilities mindset $X^2(1) = 4.512$, $p = .034$. There was a moderately strong association between the type of introductory design course and students' making abilities mindset $\varphi = 0.292$, $p = 0.034$. The odds ratio for students who had taken a design course with making activities integrated into it and had a fixed mindset was 0.190, 95% CI [0.037 to 0.979].

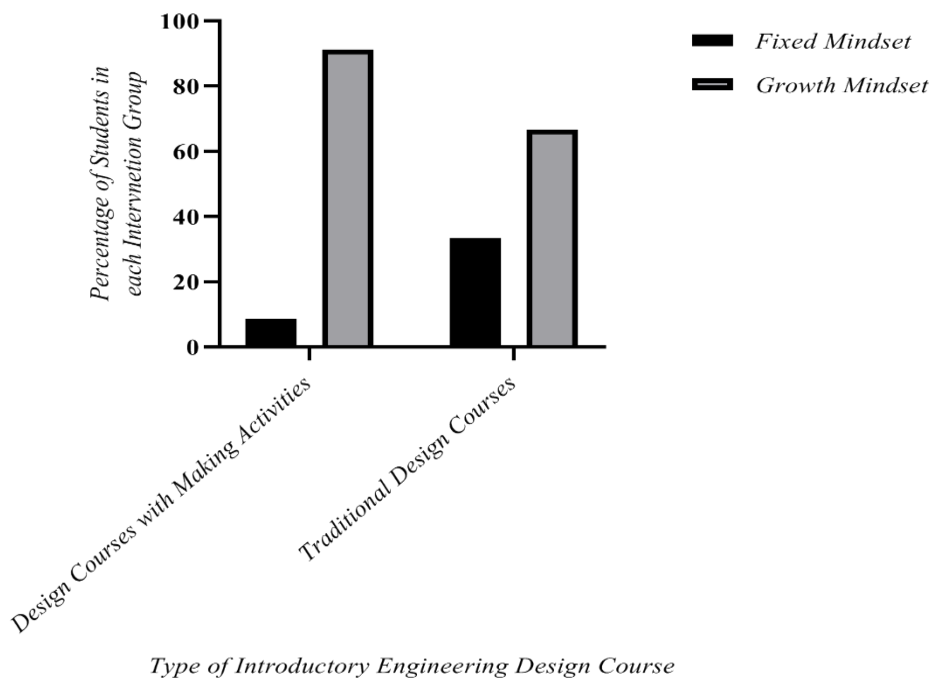

FIGURE III - STUDENTS' MAKING ABILITIES MINDSET BASED ON TYPE OF INTRODUCTORY ENGINEERING DESIGN COURSE

This result indicates that introducing students to making activities in their early years at engineering schools can ensure that students move forward to their careers with a growth making abilities mindset. The two interventions assessed here provided students with an opportunity to alter their mindset through an experiential learning environment. This observation was also made by Rikke Lindekilde [36], who noted that implicit theories can be altered from an entity theory to an incremental one by engaging students in the iterative process of learning. Lindekilde uses the Kolb [37] model of the learning cycle to explain how experiential learning affects students' implicit theories. In her transformation model of experiential learning experiences, students go through four stages:

1) Reflective observation: students identify barriers that represented an entity theory they held;
2) Abstract conceptualization: participants in an experiential learning environment identify alternative incremental implicit theories;
3) Active experimentation: students' engagement in embodied experiences helps them discuss future work and provides them with concrete enacted experiences;
4) Concrete experiences: students engage in exercises that represent "aha experiences" that help them recognize new incremental implicit theories. [35, p.67].

In the context of our study, first and second-year engineering students are introduced to a learning environment that challenges their implicit theories of their making abilities by introducing them to technologies that are new to them, facilitating their engagement with a makers community of practice that has formed in the Makerspace, and tasking them with creating several prototypes for an engineering project that engages them in authentic engineering practice experience where they interact with a real-time client.

Students are also introduced to design thinking methodology in both first- and second-year courses that encourages to empathize with their clients/users of their product. Students register for the courses with limited or no experience with the use of the technologies they learn about in the course, something that also helps them to reflect on the nature of their ability to use digital and physical technologies to learn new skills and bring their ideas to reality and helps them to realize that it can be developed and nurtured through effort and experience.

This learning environment is also supported by several scaffolding techniques, such as assigning a project manager to each student-team who is a member of the Makerspace Makers-CoP, training on teamwork and conflict management skills, and using peer learning as a pedagogical tool in the courses. These techniques help ensure that students who hold an entity theory reflect on the nature of their ability and engage in a series of active experiences that reinforce an incremental implicit theory of their making abilities. Our results support the idea that the inclusion of making activities in engineering schools' curriculum works to ensure that students hold an incremental implicit theory about the nature of their making abilities.

Conclusion

The aim of this study was to investigate the impact of collaborative project-based-learning engineering design courses that have successfully integrated making activities into the curriculum on enforcing growth mindsets in students in relation to their making abilities. We found that most students in the sample had a growth making abilities mindset. However, a larger percentage (31%) than what Dweck et al. [25] had reported for their original study (15%) had a mindset that was between growth and fixed mindsets — a result that warrants further research on why those students didn't have a growth mindset and what interventions can be used to encourage those students to hold a growth making abilities mindset.

Another interesting result was the fact that female engineering students were found more likely to have a growth making abilities mindset than male students, a result that can be explained by the fact that those female students had already made a career choice in engineering and most likely that a growth mindset was developed in their earlier years of education.

Moreover, students who have taken an introductory engineering design course that had integrated making activities into its curriculum were more likely to have a growth making abilities mindset than those who had taken a traditional introduction to engineering design course. We think these interventions enforce a growth making abilities mindset by exposing students to open-ended problems and making activities that allow them to realize that their ability can be developed through exposure to and efforts in engineering projects and activities.

There are a number of limitations to this study. The data were collected at one point in time. Also, the sample had a limited number of third-year engineering students.

Future research should focus on exploring the impact implicit theories of making abilities have on engineering students' career choices. Moreover, the interaction between students' implicit theories of making abilities and their learning goal choices in engineering school could also be examined.

References

[1] L. Martin, “The Promise of the Maker Movement for Education,” *J. Pre-College Eng. Educ. Res.*, vol. 5, no. 1, Apr. 2015.

[2] T. Kalil, “Have Fun—Learn Something, Do Something, Make Something,” pp. 30–34, Mar. 2013.

[3] A. M. Thomas and D. Besser, “The Maker Movement and Engineering,” *Bridg.*, vol. Volume 47, no. 3, pp. 32–36, 2017.

[4] National Academy of Engineering National Research Council, “Engineering in K-12 Education: Understanding the Status and Improving the Prospects,” The National Academies Press, Washington, D.C., 2009.

[5] M. Prince, “Does Active Learning Work? A Review of the Research,” *J. Eng. Educ.*, vol. 93, no. 3, pp. 223–231, Jul. 2004.

[6] K. Sheridan, E. R. Halverson, B. Litts, L. Brahms, L. Jacobs-Priebe, and T. Owens, “Learning in the Making: A Comparative Case Study of Three Makerspaces,” *Harv. Educ. Rev.*, vol. 84, no. 4, pp. 505–531, Dec. 2014.

[7] C. C. Bonwell and J. A. Eison, *Active learning : creating excitement in the classroom*. School of Education and Human Development, George Washington University, 1991.

[8] Y. Y. Hong, C. S. Dweck, C. Y. Chiu, D. M. S. Lin, and W. Wan, “Implicit theories, attributions, and coping: A meaning system approach,” *J. Pers. Soc. Psychol.*, 1999.

[9] C. S. Dweck, “Implicit Theories,” in *Handbook of theories of social psychology*, V. 2., P. A. M. van. Lange, A. W. Kruglanski, and E. T. (Edward T. Higgins, Eds. Los Angeles, CA: SAGE, 2012, pp. 43–61.

[10] S. A. Gelman, *The essential child origins of essentialism in everyday thought*. Oxford University Press, 2003.

[11] F. J. Jourden, A. Bandura, and J. T. Banfield, “The Impact of Conceptions of Ability on Self-Regulatory Factors and Motor Skill Acquisition,” *J. Sport Exerc. Psychol.*, vol. 13, no. 3, pp. 213–226, 1991.

[12] J. J. Martocchio, “Effects of Conceptions of Ability on Anxiety, Self-Efficacy, and Learning in Training,” *J. Appl. Psychol.*, 1994.

[13] C. Tabernero and R. E. Wood, “Implicit Theories versus the Social Construal of Ability in Self-Regulation and Performance on a Complex Task,” *Organ. Behav. Hum. Decis. Process.*, vol. 78, no. 2, pp. 104–127, May 1999.

[14] L. J. Kray and M. P. Haselhuhn, “Implicit negotiation beliefs and performance: Experimental and longitudinal evidence.,” *J. Pers. Soc. Psychol.*, vol. 93, no. 1, pp. 49–64, 2007.

[15] C. H. Utman, “Performance Effects of Motivational State: A Meta-Analysis,” *Personal. Soc. Psychol. Rev.*, vol. 1, no. 2, pp. 170–182, May 1997.

[16] C. S. Dweck and E. L. Leggett, “A Social-Cognitive Approach to Motivation and Personality,” *Psychol. Rev.*, 1988.

[17] J. S. Beer, “Implicit self-theories of shyness,” *J. Pers. Soc. Psychol.*, 2002.

[18] R. S. Bergen, “Beliefs about intelligence and achievement-related behaviors,” 1991.

[19] C. Chiu, Y. Hong, and C. S. Dweck, “Lay dispositionism and implicit theories of personality.,” *J. Pers. Soc. Psychol.*, vol. 73, no. 1, pp. 19–30, 1997.

[20] E. S. Elliott and C. S. Dweck, “Goals: An Approach to Motivation and Achievement,” *J. Pers. Soc. Psychol.*, 1988.

[21] C. S. Dweck and L. A. Sorich, “Mastery-Oriented Thinking,” in *Coping: The Psychology of What Works*, vol. 1, Oxford University Press, 1999.

[22] M. C. Murphy and C. S. Dweck, “A culture of genius: How an organization’s lay theory shapes people’s cognition, affect, and behavior,” *Personality and Social Psychology Bulletin*. 2010.

[23] A. D. Nussbaum and C. S. Dweck, “Defensiveness versus remediation: Self-theories and modes of self-esteem maintenance,” *Personal. Soc. Psychol. Bull.*, 2008.

[24] C. Dweck, “Self-theories: Their role in motivation, personality, and development.,” *Essays Soc. Psychol.*, 1999.

[25] C. S. Dweck, C. Chiu, and Y. Hong, “Implicit Theories and Their Role in Judgments and Reactions: A Word From Two Perspectives,” *Psychol. Inq.*, vol. 6, no. 4, pp. 267–285, Oct. 1995.

[26] C. Good, A. Rattan, and C. S. Dweck, “Why do women opt out? Sense of belonging and women’s representation in mathematics.,” *J. Pers. Soc. Psychol.*, vol. 102, no. 4, pp. 700–717, 2012.

[27] M. Tamir, O. P. John, S. Srivastava, and J. J. Gross, “Implicit theories of emotion: Affective and social outcomes across a major life transition.,” *J. Pers. Soc. Psychol.*, vol. 92, no. 4, pp. 731–744, Apr. 2007.

[28] L. Martin, “The Promise of the Maker Movement for Education,” *J. Pre-College Eng. Educ. Res.*, vol. 5, no. 1, Apr. 2015.

[29] C. S. Dweck, “Is Math a Gift? Beliefs That Put Females at Risk.,” in *Why aren’t more women in science?: Top researchers debate the evidence.*, Washington: American Psychological Association, 2007, pp. 47–55.

[30] D. Dougherty, “The Maker Mindset,” in *Design, Make, Play : Growing the Next Generation of STEM Innovators*, M. Honey and D. (David E. . Kanter, Eds. Routledge, 2013.

[31] G. N. Svarovsky, D. M. B. Bequette, and L. Causey, “Making Connections: Challenging the Perceived Homogeneity of Making: American Society for Engineering Education,” in *American Society of Engineering Education*, 2017.

[32] C. S. Dweck, *Mindset: The New Psychology of Success*. New York, NY: Random House, 2006.

[33] S. Nix, L. Perez-Felkner, and K. Thomas, “Perceived mathematical ability under challenge: a longitudinal perspective on sex segregation among STEM degree fields,” *Front. Psychol.*, 2015.

[34] J. L. Degol, M. Te Wang, Y. Zhang, and J. Allerton, “Do Growth Mindsets in Math Benefit Females? Identifying Pathways between Gender, Mindset, and Motivation,” *J. Youth Adolesc.*, vol. 47, no. 5, pp. 976–990, 2017.

[35] S. I. van Aalderen-Smeets and J. H. Walma van der Molen, “Modeling the relation between students’ implicit beliefs about their abilities and their educational STEM choices,” *Int. J. Technol. Des. Educ.*, vol. 28, no. 1, pp. 1–27, Mar. 2018.

[36] Rikke Lindekilde, “Improving geographically distributed collaboration by transforming people’s implicit theories on distributed collaboration through experiential learning activities,” Aarhus University, 2016.

[37] D. Kolb, “Experiential learning: Experience as the source of learning and development, David A. Kolb, Prentice-Hall International, Hemel Hempstead, Herts., 1984. No. of pages: xiii + 256,” *J. Organ. Behav.*, 1984.