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Enculturation of Diverse Students to the Engineering Practices through First-Year Engineering College Experiences

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Delivering significant results in pivotal roles such as Sr. Consultant to high-profile clients, Sr. Project Manager directing teams, and Executive Leader of initiatives and programs that boost organizational effectiveness and optimize operations have been hallmarks of Dr. Wickliff's career spanning more than 24 years with leaders in the oil & gas and semiconductor industries.

As an expert in the areas of Executive Leadership and Team Development, Strategy Design & Execution, Supply Chain Optimization, Change Management, System Integration and LEAN Process Improvement (technical and business), Dr. Wickliff is passionate about Organizational Wellness and the Holistic Wellness of individuals. She is also a professional Facilitator and Motivational Speaker. Dr. Wickliff earned a PhD in Interdisciplinary Engineering from Texas A&M University where she combined Industrial Engineering and Organizational Development to conduct research in the area of talent management and organizational effectiveness. She also completed an executive MBA from the University of Texas-Dallas and a BS in mechanical engineering from the University of Houston. She is founder of a nationally recognized pre-college initiative program, FreshStart, which has served more than 2000 students since its inception.

Dr. Wickliff is blessed to work daily in the area of her passion – developing young professionals – in her exciting current role at Texas A&M University. She is the Director of the College of Engineering's, Zachry Leadership Program and a Professor of Engineering Practice. At Texas A&M University, she has taught Capstone Senior Design and Foundations of Engineering courses, but now teaches Engineering Leadership Development courses. She has also taught Project Management and Risk Management courses for the University of Phoenix.

Dr. Wickliff has been honored with University of Houston's Distinguished Young Engineering Alumni Award, the Black Engineer of the Year Career Achievement Award for New Emerging Leaders and featured in several publications. She has presented keynote addresses, facilitated workshops and given motivational presentations at numerous civic and corporate forums domestically and internationally. She is a contributing author to Tavis Smiley's book, "Keeping the Faith", with her inspiring life story. She believes that her life's calling and thus career quest is to be a catalyst of significant, positive change and growth for individuals and entities. However, through it all, Dr. Wickliff gives top priority to her relationship with God, her husband Oscar Smith and her three sons – Jamar Dugat, Raymond Wickliff and Cortlan Wickliff.

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So Yoon Yoon, Ph.D., is a post-doctoral research associate at Texas A&M University. She received her Ph.D. and M.S.Ed.in Educational Psychology with specialties in Gifted Education and Research Methods & Measurement from Purdue University. She also holds a M.S. in Astronomy & Astrophysics and a B.S. in Astronomy & Meteorology from Kyungpook National University in South Korea. Her work centers on P-16 engineering education research as a psychometrician, program evaluator, and institutional data analyst. As a psychometrician, she revised the PSVT:R for secondary and undergraduate students, developed the TESS (Teaching Engineering Self-efficacy Scale) for K-12 teachers, and rescaled the SASI (Student Attitudinal Success Inventory) for engineering students. As a program evaluator, she evaluated the effects of teacher professional development (TPD) programs on elementary teachers' attitudes toward engineering and students' STEM knowledge through a NSF DRK-12 project. As an institutional data analyst, she is investigating engineering students' pathways to their success.

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Abstract

This paper describes a Work-in-Progress (WIP) on analyses of engineering enculturation constructs and the way diverse groups adopt engineering practices as performed in the field. Studies of socialization processes by which engineering students come into engineering practices provide impetus for further study about enculturation. The studies of socialization processes investigate how students start with pre-conceived notions of successful engineers and how they could eventually adopt proper work practices actually realized in the field. In the workplace, communication and teamwork are highly valued. Yet many engineering students value individual accomplishment and competitiveness as the tactic to succeed. Our approach seeks to quantify students' enculturation related to engineering communications and teamwork taught in a first-year engineering course to large diverse classes at a southwestern institution. The study seeks to help understand how enculturation may contribute to the development of engineering students adopting favorable behavior and engineering practices for eventual usefulness and success in the workplace.

I. Introduction

The purpose of this work is to seek to quantify the relationship between instruction on engineering skills and the mechanisms or constructs of enculturation of these skills into engineering practices by first-year students. The formation of engineers is a phenomenon of global interest. Students' lack of interest and lack of preparation to pursue engineering constitute a major concern in the United States[1,2,3], where the current generation of engineers has no replacement in the short or the long terms. Such concerns have led to the creation of multiple initiatives from multiple agencies, private and public, and at all levels of education. Centers at the K-12 (pre-college) and college levels have seen light with the purposes of increasing the number of engineers; to name a few, the INSPIRE Research Institute for Pre-College Engineering at Purdue University or the Center for the Advancement of Engineering Education (CAEE) at the University of Washington.

Under such national agenda, the first-year engineering initiatives across the country have been revised and modified. Even a conference, the First-Year Engineering Experience (FYEE) Conference, brings together, once a year, representatives of first-year engineering programs for the sole purpose of sharing innovative approaches, interventions, and lessons learned. Motivated by its 25 by 25 initiative, the first-year engineering program at Texas A&M University (TAMU) has undergone numerous changes. TAMU Dwight College of Engineering seeks to increase enrollment and to provide better instruction to 25,000 students by 2025. This projected growth calls for a continuous, first-year engineering program revision, well-grounded in research and best practices.

This study attempted to conduct research about students' enculturation process to be an engineer from a theoretical perspective based on first-year engineering experience. The overall goal of this study is to explore (a) the relationship of enculturation factors and its' practices as part of the first-year engineering program, and (b) the practices of this first-year engineering program to inform a theory of enculturation.

A. Theoretical Background

The Merriam-Webster dictionary defines culture as the set of "beliefs, customs, arts, etc., of a particular society, group, place, or time as well as the way of thinking, behaving, or working that exists in a place or organization" [4]. In other works, culture can also be understood as the composite of knowledge, beliefs, and practices of a group[5]. Figure 1 depicts many factors that affect the formation of culture. Enculturation is a sociological and psychological concept that have been investigated extensively in the humanities but with little connections to the engineering profession[6, 7]. Here, enculturation is defined as the process by which an individual learns the traditional content of a culture and assimilates its knowledge, practices, and values. Then, engineering enculturation can be defined as the process by which an engineering student learns the traditional content of an engineering culture and assimilates engineering practices and values.

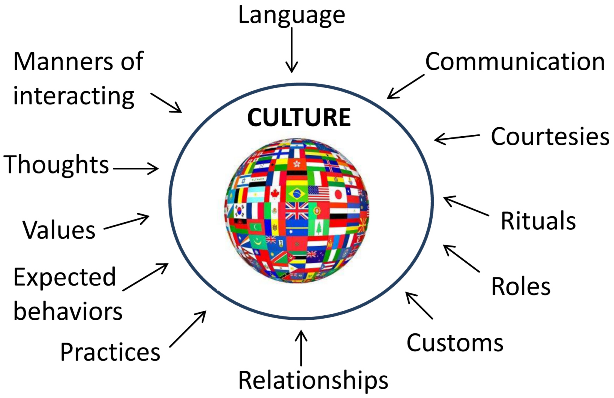

Figure 1. Factors that affect the formation of culture[8]

Therefore, in engineering education, engineering enculturation is related to the concept of communities of practice. Becoming a professional engineer means entering into a particular engineering community of practice, one that communicates in a way that is specific to that community of practice in engineering[9, 10]. In this sense, the first-year engineering college experiences constitute the first exposure to engineering communities of practice through topics like the introduction to the engineering sciences[11]. This introduction to the engineering sciences could be understood as the "introduction of mathematical and scientific concepts in the context of engineering applications"[12]. Since our understanding of enculturation is primarily related to the acquisition of a culture within a particular community of practice, or in other words, the assimilation to the engineering culture, the processes that involve indigenous cultures, to prevail or not to prevail are not of relevance for this study[13]. As a socialization process, engineering enculturation can be explored through a probe into how engineering students start with pre-conceived notions of successful engineers and how they could eventually adopt proper work practices actually realized in the field.

B. Setting: First-Year Engineering Education Program at Texas A&M University

Speaking of 30 sessions of each engineering foundational courses encompass the first-year engineering experience at TAMU, which are two semester-long courses: ENGR 111 - Foundations of Engineering I and ENGR112 - Foundations of Engineering II. The course goals for each course are listed as follows and Figure 2 shows the schematic of learning outcomes from the course organization.

ENGR111- Foundations of Engineering I -Course Goals:

1. Describe the engineering disciplines at Texas A&M and the interrelationships among them as well as know what graduates of at least three disciplines of engineering do.
2. Individually, or as a member of a technical team, understand and apply a structured engineering problem solving using a design process.
3. Develop algorithmic thinking by implementing simple algorithmic forms of engineering models/problems using MATLAB.
4. Communicate technical information via written, oral, and visual communication tools.
5. Recognize the advantages and challenges of problem solving using a team.

ENGR112- Foundations of Engineering II -Course Goals:

1. Describe, in greater depth, the engineering disciplines at Texas A&M.
2. Individually, or as a member of a technical team, apply knowledge of a structured engineering problem solving process, engineering fundamentals and basic engineering science concepts to create more advanced engineering criteria, discovered using a design process, that satisfy a problem of engineering interest.
3. Design processes to communicate technical information orally and visually.
4. Implement complex algorithmic solutions to engineering problems/designs using an appropriate computer tool (Excel, LABVIEW, and MATLAB) and be able to explain your rationale for your choice;
5. Synthesize your knowledge of effective and ethical membership on a technical team (i.e., teaming skills) to refine your conduct as a member of the team.
6. Exhibit a work ethic appropriate for the engineering profession.

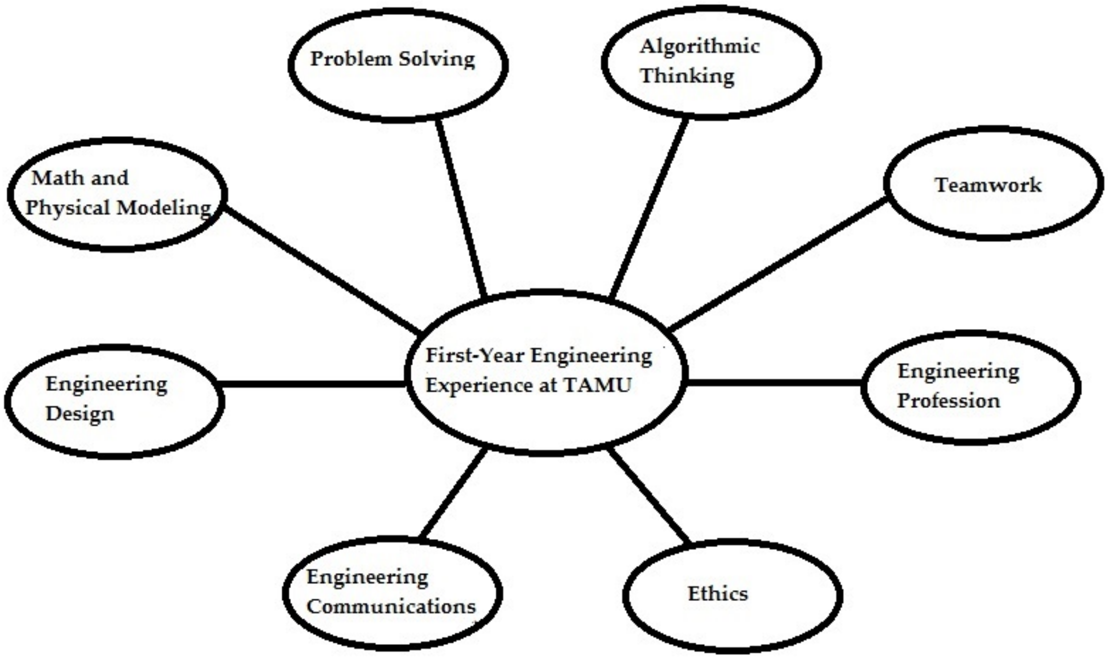

Figure 2. Schematic of outcomes from the course organization
for the first-year engineering experience at Texas A&M University

C. Identification of Enculturation Factors in the Context of Engineering Education Practice

Given the aforementioned definition of culture, we define engineering culture as the set of knowledge, beliefs and practices, unique to the engineering profession that manifest in its community of practice. Extrapolating our definition of enculturation to the ABET outcomes and TAMU course goals, a more granulated definition of engineering culture is produced. The major enculturation factors to be a professional engineer during first-year engineering education were classified in three areas as follows.

- Knowledge
  - Mathematical and Physical Modeling in Engineering
  - Algorithmic Thinking
- Beliefs
  - Ethics
- Practices
  - Engineering Profession
  - Engineering Communications
  - Engineering Problem Solving
  - Engineering Design
  - Engineering Teamwork

D. Research Questions

Our approach to the formation of engineers for the first-year engineering (FYE) experience is as a process of culture acquisition in a community of practice. Therefore, the overarching goal of this project is to explore the enculturation of FYE students to the engineering profession during the first-year foundational engineering courses. Among the several enculturation factors, this study solely focused on engineering communications and teamwork in engineering practice and investigated the effects of team characteristics on their team performance. The following research questions guided this project.

1. Are there any subgroup differences (i.e., gender and race/ethnicity) in the enculturation process of engineering communications and teamwork?
2. How do team characteristics (in terms of diversity) relate to their performance on engineering communications and teamwork?

II. Method

The study attempts action research that involves two first authors (Instructor A and B) as instructors of engineering foundational courses, ENGR 111 and ENGR 112 at Texas A&M University. During the first fall semester of 2015, teaching ENGR 111, they (a) delivered various engineering activities that help the development of enculturation factors for first-year engineering students, (b) collected student performance data on enculturation factors, and (c) analyzed students' data to identify students' enculturation process.

A. Participants

A total number of 460 students from two sessions taught by Instructor A and three sessions taught by Instructor B were the target population of this study. Table 1 shows the demographic characteristics of the FYE students by instructor. The population of students consists of about 25 % female and 35 % minority students, including 21% Hispanic students, which implies relatively diverse student population compared to the general college population in the United States. Here, minority students indicate other racial/ethnic groups who are not White. Each section formed teams of four students per team, which were consistent across the semester.

Table 1. Demographic Information of Student Participants

Category	Subcategory	Instructor		Total	
		A	B	*N*	%
Gender	Female	48	66	114	24.8
	Male	136	210	346	75.2
	Unknown	0	13	13	2.8
Race/Ethnicity	Hispanic	34	61	95	20.7
	American Indian/Alaskan Native	0	0	0	0.0
	Asian/Pacific Islander	20	18	38	8.3
	Black	5	9	14	3.1
	White	125	174	299	65.1
Total		184	276	460	100.0

B. Measures

Several measures were utilized to assess students' status of enculturation on the enculturation factors of engineering communications and teamwork, such as (a) Checks for Understanding (CFUs), (b) Rubrics on Team Project, and (c) Design Notebook. Checks for Understanding (CFUs) are quizzes with five questions given at the end of class to assess the understanding of the topic covered during the class. Team Project Rubrics and Design Notebook constitute the part pertaining to the semester-long, team-based project; a robotics type of team project were expected to deliver, in sequential phases, as a solution for a crisis response vehicle. Rubrics were specifically designed to assess each target enculturation factor during the course. While both instructors delivered the same curriculum into their sessions, some measures were not utilized by Instructor B.

The outcomes of student performance were categorized into two levels: (a) individual level performance and (b) team level performance. Here, individual level performance indicates individual students' scores from their own performance on enculturation factors and team level performance indicates that students in the same team received the same scores as reflection of teamwork for an activity on enculturation factors. The most frequent number of team members was four and a few teams had three, due to the lack of students or attrition. Table 2 shows characteristics of the measures utilized in this study, related enculturation factors of each measure, and the level of performance. Details of engineering activities were described in the following section.

Table 2. Measures to Assess FYE Students' Status in the Enculturation Process

Enculturation Factors	Engineering Activities	Measures	
		Individual Level	Team Level
Engineering Communications (EC)	Lectures on Engineering Communications (EC)	CFU-EC[a]	−
	Design Notebook (DN)		Rubric-DN
Teamwork (TW)	Lectures on Teamwork (TW)	CFU-TW[a]	−
	Design Subtask 1 (DS1)	−	Rubric-DS1
	Design Subtask 2 (DS2)	−	Rubric-DS2
	Final Project Demonstration (PD)	−	Rubric-PD
	Final Project Presentation (PP)	−	Rubric-PP
	Final Project Report (PR)	−	Rubric-PR

Note. [a]The measures were only used by Instructor A.

C. Activities Utilized to Enforce Engineering Communications and Teamwork

As a semester long project, students were divided into teams of 4 individuals on average and were presented with a technical scenario for which they would be required to follow the structured design process to arrive at a solution. As a team, they were to understand the technical problem presented, develop and vet potential solutions, utilize a structured decision making methodology to arrive at a preferred solution, build the prototype, demonstrate that it could perform the required task, and formally present the overall solution. To help mimic the real world aspect of engineering work in the field, smaller, individual teams were paired up with a second team to help better strategize the approach and more effectively utilize their human capital and material resources that were provided. The two teams combined were referred to as a task force. To help guide the process for the teams and monitor the progress of the teams, two formal check points, called Design Subtask, where incorporated into the process.

Design Subtask 1 (DS1). As a semester long project, the crisis responsive vehicle is composed of subtasks. The first subtask consists of an autonomous vehicle capable of following a black line, with starting and endpoints signaled by colored lines. The rubric include scores for reading appropriately the input color, turn into the correct direction of the black line and navigate through turns and stop.

Design Subtask 2 (DS2). The second subtask for the crisis responsive vehicle consists of an autonomous vehicle capable of following a black line, with starting and endpoints signaled by colored lines and obstacles (dowels) placed along the black line path. The rubric include scores for starting on command, turn into the correct direction of the black line and navigate through turns, over dowels and stop.

Final Project Demonstration (PD). At the end of the semester, one LEGO LabVIEW-Mindstorm semester-long project worked in teams of three or four individuals is demonstrated. It should cover the specific requirements and rubrics developed. The final demonstration of the crisis response vehicle involved the two subtasks, as well as the reading of a barcode card, pushing one of three buttons per the barcode reading and the beeping of the vehicle the number of times per the barcode as well.

Final Project Presentation (PP). At the end of the semester, one LEGO LabVIEW-Mindstorm semester-long project worked in teams of three or four individuals is presented in the form or an oral explanation accompanied with visual aids. The activity cover the specific requirements, such as proper PowerPoint size and color, technical information included (e.g. Functional Block Diagrams or Gantt Charts), which are evaluated by rubrics specifically developed for the presentation.

Final Project Report (PR). At the end of the semester, one LEGO LabVIEW-Mindstorm semester-long project worked in teams of three or four individuals is reported in the form of a technical report. It should cover the specific requirements and rubrics developed for the report. Such requirements included a memorandum to the contracting agency (a fictitious entity), and a detailed technical report.

Design Notebook (DN). At the end of the semester, there was one LEGO LabVIEW-Mindstorm semester-long project where students worked in teams of three or four individuals is reported in the form of a design notebook. The activity covers the specific requirements, such as sketches, team meeting minutes, and project management notes, which are evaluated through rubrics developed for the notebook.

On top of the above activities, students responded to Comprehensive Assessment of Team Member Effectiveness (CATME) surveys at the end of the semester[14]. Individuals get evaluated by peers in teams using the CATME system. The evaluation is related to their involvement in the one LEGO LabVIEW- Mindstorm semester-long project worked on in their teams of three or four individuals.

D. Data Analyses

To see the effects of team characteristics on students' team performance, students' mix of gender and diversity were utilized to categorize team characteristics in this study. Regarding gender, teams were categorized into two groups as there were no female only groups: all male student teams vs. mixed gender teams. Regarding diversity, teams were categorized as all White student teams vs. Diverse teams including minority students. For analyses, first, descriptive statistics were calculated to explore different modes of student performance at both individual and team levels on engineering communications and teamwork. Second, inferential statistical analyses, such as independent *t*-tests were applied for the differences by subgroups, such as gender and race/ethnicity. Spearman Pearson correlations were calculated at the 0.05 alpha level for all measures, including gender and ethnicity.

III. Results

A. Descriptive Statistics

Table 3 shows average scores of students on individual performance and team performance on engineering communications and teamwork.

Table 3. Average Student Performance on Measures

Enculturation Factors	Engineering Activities	Measures	Max. Score	N_S	N_T	*M*	*SD*
Engineering Communications (EC)	Lectures on EC	CFU-EC[b]	100	184	–	89.50	14.19
	Design Notebook	Rubric-DN	100	–	97	92.46	9.46
Teamwork (TW)	Lectures on TW	CFU-TW[b]	100	184	–	84.78	17.73
	Design Subtask 1	Rubric-DS1	100	–	97	95.26	11.30
	Design Subtask 2	Rubric-DS2	110	–	122	97.74	13.99
	Final Project Demonstration	Rubric-PD	110	–	122	100.14	13.81
	Final Project Presentation	Rubric-PP	100	–	122	94.69	4.41
	Final Project Report	Rubric-PR	132	–	122	89.53	11.22

Note. N_S = Number of students; N_T = Number of teams; *M* = Mean score; *SD* = Standard deviation

B. Inferential Statistics

Table 4 shows that students' gender and diversity did not make any differences on students' individual performance on engineering communications and teamwork.

Table 4. Subgroup Differences on Student Performance in Engineering Communications and Teamwork at the Individual Level

Enculturation Factors	Measures	Gender			Diversity		
		t	*df*	*p*	*t*	*df*	*p*
Engineering Communications (EC)	CFU-EC	-0.28	182	0.782	1.01	182	0.312
Teamwork (TW)	CFU-TW	-0.90	182	0.367	1.09	182	0.277

When team characteristics were considered, independent *t*-tests revealed no significant differences on the all team performance on engineering communications as teamwork as shown in Table 5. Similar to the findings from the individual level performance, there were no significant differences on team performances by team characteristics of gender and diversity.

Table 5. Effects of Team Characteristics on Team Performance

Enculturation Factors	Team Performance	Gender			Diversity		
		t	*df*	*p*	*t*	*df*	*p*
Engineering Communications (EC)	Design Notebook	.57	95	.572	-.60	95	.548
	Design Subtask1	-1.16	95	.250	1.95	95	.054
Engineering Teamwork (TW)	Design Subtask2	-.49	120	.622	-.22	120	.824
	Final Project Demonstration	1.62	120	.108	-.67	120	.507
	Final Project Presentation	.86	120	.392	-.95	120	.346
	Final Project Report	1.34	120	.184	-1.07	120	.286

C. Correlations among Measures

At the individual level performance, there were no significant correlations between student performances and student characteristics by gender and diversity. However, student performance on engineering communications and teamwork was significantly correlated.

Table 6. Correlations among Student Performance in Engineering Communications and Teamwork at the individual Level

Category	Variables	1	2	3	4
Student Demographics	1. Gender	1.000	0.043	- 0.021	-0.067
	2. Diversity	0.565	1.000	0.075	0.080
Engineering Communications (EC)	3. CFU-EC	0.782	0.312	1.000	0.220*
Teamwork (TW)	4. CFU-TW	0.367	0.277	0.003	1.000

Note. Gender was categorized as Male = 1 and Female = 0; Diversity was categorized URM (underrepresented minorities) was categorized as White (Majority) = 1 and the other racial/ethnic teams = 0. The upper diagonal shows Pearson correlation coefficients and the lower diagonal shows p-values.
$^{*}p < 0.05$

Table 7 shows correlations among student performance on engineering communications and teamwork at the team level. Student performance on design notebook, and design subtasks were significantly correlated each other. However, regarding on student performance on the final project, student performance on project demonstration was only significantly correlated with their final project report. Their project presentation was not significantly associated with the other two types of performance.

Table 7. Correlations among Student Performance in Engineering Communications and Teamwork at the Team Level

Enculturation Factor	Variables	1	2	3	4	5	6
Engineering Communications (EC)	1. Rubric-DN	1.000	.420*	.248*	-0.108	-0.159	0.116
Teamwork (TW)	2. Rubric-DS1	0.000	1.000	.597*	-0.107	-0.196	0.026
	3. Rubric-DS2	0.014	0.000	1.000	0.018	-0.069	-0.122
	4. Rubric-PD	0.294	0.295	0.841	1.000	0.018	.297*
	5. Rubric-PP	0.120	0.054	0.453	0.844	1.000	0.018
	6. Rubric-PR	0.258	0.798	0.179	0.001	0.845	1.000

Note. Upper diagonal shows Pearson correlation coefficients and the lower diagonal shows p-values.
$^{*}p < 0.05$

VI. Discussion

This study relies on previous work about the first-year engineering program at Texas A&M University. However, the findings of this study are expected to advance the state of knowledge and understanding of (a) diverse pathways to and through engineering, and (b) the development of engineering-specific theories of how engineers are formed.

A pilot study conducted in 2014-2015 showed that RATS and CFU scores on activities related to algorithmic thinking (AT) were significantly correlated with moderate to large effect sizes, ranged from 0.31 to 0.73[15]. This implies that students who already had been exposed to algorithmic thinking seemed to perform better than students who were new to algorithmic thinking.

No subgroup effects by gender and race/ethnicity were observed in student performance on engineering communications and teamwork at the individual level: this trend is promising because this implies that students' understanding on engineering communications and teamwork does not differ by gender and race/ethnicity. Similarly, team characteristics by gender (all male vs. mixed gender teams) and diversity (all White vs. mixed race/ethnicity teams) do not make differences in their performance on engineering communications and teamwork.

The significant correlations between communications and teamwork at the individual level imply that students who scored well on engineering communications tended to score well on teamwork. No correlation was observed by gender and race/ethnicity.

The design notebook (DN) was collected after demonstrations of both design subtasks (DS1 and DS2). Therefore, student performance on design notebook (DN) reflects engineering communications leading up to the completion of the subtasks. Apparently, there were significant correlations between engineering communications appeared in the design notebook and engineering teamwork presented through two design subtasks as shown in Table 7.

Project presentations (PP), demonstrations (PD), and the final report (PR) were the final main tasks for the project but were structured as different types of teamwork. The final project presentation (PP) did not show significant correlation with the project demonstration (PD) and the report (PR) as shown in Table 7. Some teams have said that one person chose to work on the presentation while other team members worked on the report. This may be why there were no correlations between project demonstration and the other two performances, since some work was not conducted as a team. The divide-and-conquer approach seems to remove teamwork from their engineering process.

Therefore, diverse results of quantitative results can be attributed to the graders (peer teacher assistants or graduate assistants) and the way they interpreted the rubrics. Although instructors modeled the grading process for the majority of the assignments, graders were ultimately responsible of assessing the extent to which each team performed or reported their work.

Peer evaluations do not show drastic differences in the way students perceive their success as related to the dynamics of the team. Gender and ethnicity did not play any role in the way teams performed or were self-assessed. While CATME allowed the set-up of diverse teams in terms of gender and ethnicity, all teams seem to behave similarly regardless of their team characteristics. Future studies will warrant to understand the effects of team diversity in terms of gender (e.g., all males, all females, and gender mixed teams) or race/ethnicity (all Whites, all minorities, and race/ethnicity mixed teams) on their performance in engineering communications and teamwork.

The socialization that Leonardi[16] mentioned needs more time and more under-pinnings or underlying mechanisms to have students get that teamwork matters and not showing their individual strength off (my grades vs. ours). That we are teaching this and seeing some correlations between communication and teamwork (and the students in successful teams observe themselves) suggest some things we are teaching are leading to successful enculturation.

The study results suggest that enculturation may be more immediate while socialization may take longer and be more subconscious. They differ but both need to happen.
Can teamwork and communication skills really be called soft-skills? Intangibles? One clear outcome of this work is that the notion of these as soft skills needs to be reconsidered.

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