Tolerance of Ambiguity, Development of Cognitive Models and Engineering Identity

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Abstract

The cognitive models of students' perceptions of the real world lie on a spectrum spanning a dualistic understanding of the worldview on one end and a relativistic view on the other end. Students who are dualistic in their understanding of concepts have difficulty in solving problems which do not lend themselves to a well-defined single answer or solution. One would therefore assume that engineering students would rapidly develop a relativistic understanding of the solution space. It is also expected that this developmental process would also manifest itself in the strengthening of an engineering identity. The focus of the research presented in this paper is to explore the relationships of the cognitive models of the solution space, tolerance of ambiguity and the development of engineering identity. A cross-sectional study of the cognitive models of undergraduate students, their tolerance to ambiguity and perception of engineering identity was conducted at an historically black university. The modified Rydell-Rosen Ambiguity Tolerance (RRAT) instrument for tolerance of ambiguity and the Bateman-McDonald (BD) instrument for determining their location on the cognitive spectrum were used in this study. The students were also administered the Godwin Engineering Identity (GEI) survey. Data analysis indicated that students' tolerance of ambiguity increased on only few items of the RRAT instrument with the time spent in college. The analysis of the engineering identity indicated positive changes on several of the items of the instrument for the freshmen while reduction on some items of the GEI survey were observed. This research is supported by NSF Grant# 1832041.

Introduction

It is expected that by 2025 the US will require an additional 3.5 million science, technology, engineering and mathematics (STEM) qualified persons to fill the growing need [1]. However, the challenge being faced is the retention and subsequent graduation of students in STEM fields, particularly in engineering. According to a 2017 report [2] by the American Society of Engineering Education (ASEE), there was a small (5%) increase from 78% (2003) to 82% (2014) in the first-year persistence of White students. However, the persistence numbers remained flat at about 75% for African-American students. The ASEE report [2] also noted the 4-year and 6-year graduation rates in 2014 for white students to be 33% and 60% respectively, while for African-American students the rate was 20% and 38% respectively. Research on determining the reasons and designing empirically supported intervention strategies to increase retention and graduation rates in engineering has been prolific [3] – [7].

One of the several constructs that have been identified as having an impact on the academic success of undergraduate students is their professional identity. There is extensive research on identity and its development. Identity of an individual consists of several intersecting sub-identities such as a personal identity (individual characteristics), social identity (group characteristics, cultural characteristics), and professional identity. Bragg [8] defines professional identity as “internalization of the norms of the profession into the individual’s self-image . . . [and] the acquisition of the specific competence in knowledge and skills, autonomy of judgment, and responsibility and commitment of the profession” as cited by Lidell et al. [9]. Ibarra [10] has

summed up the definition of Schein [11] as professional identity to be the “relatively stable and enduring constellation of attributes, values, motives, and experiences in terms of which people define themselves in a professional role”. The adaptability and mutability of professional identity early in one’s career has been alluded to by Ibarra [10]. External validation by other professionals in the field is an important element of professional identity [12, page 68]. Carlone and Johnson [13] noted competence, performance and recognition as dimensions of professional identity.

Professional identity development has been studied in context of various professions such as medicine [14], health care [15], pharmacy [16], and higher education [8, 9]. There is a reasonable body of literature that focuses specifically on engineering identity, its development and impact on engineering students. Dehing, Baartman and Joachems [17] have proposed two main groups of theories on engineering identity development; one that emphasized professional apprenticeship, and the other, participating and experimenting with professional roles. It has also been reported that low identity level students increased their engineering identity, and students with high levels of engineering identity did not gain as much from the work place learning [18]. Factors such as making competent design decisions, working with others to share ideas and accepting responsibility had been observed to impact the development of an engineering identity [19], [20]. An exhaustive literature review pertinent to engineering identity can be found in [21] and [22]. Among other observations such as standardized use of the construct, it was noted in [21] that engineering identity “has not been conceptualized or measured directly to date”.

There are limited studies exploring the relationship between engineering identity, the ‘tolerance of ambiguity’, and ‘intellectual/cognitive models’ of undergraduate students. Ambiguity has been defined as ‘lack of information to understand the situation or the possible outcomes’, and tolerance of ambiguity as “the way an individual (or group) perceives and processes information about ambiguous situations or stimuli when confronted by an array of unfamiliar, complex or incongruent clues” [23], [24]. It was proposed by Perry [25] that the intellectual models of college students lie on spectrum spanning a dualistic understanding (position 1) of the world to a more nuanced relativistic world view (position 9). In light of what engineers are expected to do, one could therefore safely predict that the experience of an engineering curriculum should develop students’ tolerance of an ambiguous problem space, and acceptance of a solution space that admits multiple solutions. However, this does not seem to be the case. It has been shown [26], [27] as cited in [28] that undergraduate engineering students did not develop beyond an average of 2.8 on the Perry’s scale. This is in contrast with the result of Perry’s sample of liberal arts students who were in position 7 or 8 at graduation [25]. Bateman and Donald [29] measured the location of the intellectual/cognitive models of undergraduate students and reported that the students preferred agreement with statements that were toward higher level of intellectual development.

This paper provides exploratory data and understanding of how undergraduate engineering students progressed in developing their engineering identity, tolerance of ambiguity, and intellectual models.

Method

The study was a between-group quasi-experimental design. The data was collected from a cross-section of undergraduate engineering students consisting of freshmen, sophomores, juniors, and seniors at an HBCU through various validated survey instruments. The number of respondents (N)

are indicated in the various charts and tables. The surveys were administered online as Google Forms. Response to the surveys was voluntary. The data on engineering identity were collected using the Godwin Engineering Identity (GEI) instrument [30]. This is an 11-item instrument that measures three dimensions of engineering identity (Recognition, Interest, Performance). The tolerance of ambiguity was measured using the modified 20-item Rydel-Rosen Ambiguity Tolerance (RRAT) instrument [31]. The location of the students on intellectual spectrum was measured using Bateman-Donald (BD) survey instrument [30] which consists of 16-items, with 4-items for each of the four dimensions (Dualism, Multiplicity, Relativity, Commitment). All instruments were 5-point Likert scale surveys (5-strongly agree, 4-Agree, 3-Neutral, 2-Disagree, 1-Strongly disagree).

Results and Discussion

The GEI data was analyzed using independent-sample two-tailed t-tests ($p < 0.05$) and a one-way ANOVA. No statistically significant differences were observed between the students of the various academic standings.

The data was then analyzed to identify trends. The GEI survey results are shown in Table I, and

Fig.1a for all participants, males and females (N = 138).

The mean of responses of male students (N = 109) are shown in Table I(b) and Fig. 1b. It was observed (Table I) that the mean of the responses of freshmen were either equal to or higher than that of the seniors for all except three

statements which refer to interest (item #4), confidence in learning outside the class

(item #8), and others asking

for help (item #11). When

the data was analyzed for only male students (Table I),

it was noted that on the

average male freshmen were

enjoying engineering

(item #5) more than male

seniors. Additionally, the

mean of the responses of

male seniors (Table II) was

lower on seven of the eleven statements as compared to the combined average of male and female seniors

(Table I). This comparison

shows that even though the number of female participants is low, it impacted the results in the sense that their engineering identity was stronger as indicated by these statements.

Mean by Academic Standing	Freshmen N = 95	Sophomores N = 15	Juniors N = 14	Seniors N = 14
1. My parents see me as an engineer	4.33	4.40	4.00	4.21
2. My instructors see me as an engineer.	3.91	3.60	3.71	3.79
3. My peers see me as an engineer.	4.00	3.80	4.14	4.00
4. I am interested in learning more about engineering.	4.52	4.33	4.29	4.86
5. I enjoy learning engineering.	4.40	4.07	4.36	4.36
6. I find fulfillment in doing engineering.	4.26	4.07	4.36	4.00
7. I am confident that I can understand engineering in class.	4.13	4.20	4.43	4.07
8. I am confident that I can understand engineering outside of class.	3.97	4.20	4.43	4.36
9. I can do well on exams in engineering.	4.05	4.07	4.36	3.93
10. I understand concepts I am studying in engineering.	4.08	3.93	4.43	4.07
11. Others ask me for help in engineering/math subjects	3.80	4.27	3.86	4.07

Table I. Mean responses to GEI survey (all students)	Freshmen N = 76	Sophomores N = 13	Juniors N = 10	Seniors N = 10
Mean by Academic Standing				
1. My parents see me as an engineer	4.36	4.38	3.70	4.00
2. My instructors see me as an engineer.	3.89	3.69	3.70	3.60
3. My peers see me as an engineer.	4.08	3.77	4.20	3.80
4. I am interested in learning more about engineering.	4.51	4.31	4.30	4.90
5. I enjoy learning engineering.	4.46	4.08	4.40	4.50
6. I find fulfillment in doing engineering.	4.33	4.08	4.40	4.00
7. I am confident that I can understand engineering in class.	4.18	4.23	4.20	3.90
8. I am confident that I can understand engineering outside of class.	4.07	4.23	4.30	4.40
9. I can do well on exams in engineering.	4.11	4.08	4.10	3.70
10. I understand concepts I am studying in engineering.	4.21	3.92	4.40	3.90
11. Others ask me for help in engineering/math subjects	3.88	4.23	3.70	3.90

Table II. Mean responses to GEI survey (male students)

The mean values of the responses to the GEI were plotted for all the participants (Fig. 1a) and for male participants (Fig. 1b). It was observed that the male students who had spent more time in college (more than a year) were less confident of recognition as engineers by their instructors (item #2). The confidence of the male seniors in doing well in the exams (item #9), and understanding engineering in class (item #7) were lower as compared to the male students from lower academic standing.

In contrast, the male seniors indicated higher confidence in their understanding of engineering outside the class students (item #8) as compared to the male students from lower academic standing.

The largest mean agreement of the male seniors was with the statement pertaining to interest in learning more about engineering (item #4) in comparison to their responses to all other items (Fig. 1b). In fact, the average of the response of the seniors to item #4 was the highest of all responses by all male students (Fig. 1b).

The responses to the GEI survey were compared by gender (Fig. 2). The means of the responses to seven of the eleven statements for males were higher except for two statements (item #1, item #2). The female students felt more recognized as engineers by the instructors and their parents.

Figure 1a. Mean responses to GEI (all students)

Figure 1b. Mean responses to GEI (male students)

The analysis of the data (Fig. 3a) by the three dimensions, D1: Recognition (items #1, #2, #3), D2: Interest (items #5, #5, #6), and D3: Performance/Competence (items # 9, #10, #11) for the male students provided additional insight into the engineering identity of students. These results show

a reduction in the feeling of recognition with the time spent in college. As was observed previously, one of the factors impacting this dimension is the lower confidence of the male students in being seen as engineers by the instructors. A reduction in interest with time spent was also observed. The mean of the responses to the dimension of performance/competence was higher for the seniors as compared to the other male students. The combined data of female and male students (Fig. 3b) in comparison to Fig. 3a which is for only male students, indicates the impact of the responses of female students on the dimensions of interest, and recognition.

Figure 2. Mean responses to GEI by gender

The analysis of the data (Fig. 3a) by the three dimensions, D1: Recognition (items #1, #2, #3), D2: Interest (items #4, #5, #6), and D3: Performance/Competence (items #7, #8, #9, #10, #11) for the male students provided additional insight into the engineering identity of students. These results show a reduction in the feeling of recognition with the time spent in college. As was observed previously, one of the factors impacting this dimension is the lower confidence of the male students in being seen as engineers by the instructors.

Figure 3a. Mean responses to GEI by Dimension (all students)

A reduction in interest with time spent was also observed. The mean of the responses to the

performance/competence dimension was higher for the seniors as compared to the other male students. The combined data of female and male students (Fig. 3a) in comparison to Fig. 3b which is for only male students, indicates the impact of the responses of female students on the dimensions of interest, and recognition.

As part of this study, the freshmen “Introduction to Aerospace Engineering” which is a one-credit hour course was redesigned in Fall 2019 to include hands-on activities such as paper aircraft competition, quadcopter programming, and a commercial aircraft passenger cabin layout design. The students enrolled in this course (N = 16) were administered the GEI survey at the start of the semester and then at the end of semester. The averages of the pretest and posttest responses of the students to the GEI survey are given in Fig. 4. While there is no statistically significant ($p < 0.05$) change between posttest and pretest, a positive change was registered (Fig 4a). The analysis by dimension (Fig. 4b) clearly shows the impact of the intervention on the engineering identity of the students.

Figure 3b. Mean responses to GEI by Dimension (male)

Figure 4a. Mean responses to GEI of freshmen

Figure 4b. Freshmen responses to GEI dimensions

The RRAT survey data is shown in Fig 5. Four out of twenty statements of the survey registered statistically significant changes between lower division (LD) students (freshmen and sophomores) and upper division (UD) students (juniors and seniors). These statements were:

#6 I get pretty anxious when I am in a social situation over which I have no control.

59% of the LD students disagreed with the statement (the correct response) and only 30% UD students answered it correctly.

#14 If I were a scientist, it would bother me that my work would never be completed (because science will always make new discoveries). 39% of the LD students disagreed with the statement (the correct response), while 78% of the UD students disagreed with the statement.

#17 Sometimes I rather enjoy going against the rules and doing things I am not supposed to do.

66% of the LD students responded correctly to this statement as compared to 44% of UD students.

#20 Perfect balance is the essence of all good composition.

14 % of the LD students responded correctly to this statement while 30% of the UD responded correctly.

Of the 20 statements, a higher percentage of the LD students responded to 10 of the statements correctly while a higher percentage of UD students responded correctly to only 7 of the statements. An equal number of LD and UD students had correct responses to three of the statements.

An analysis was also done to determine if there is a correlation between the average of the responses to the engineering identity (GEI) and tolerance of ambiguity (RRAT) surveys. No correlation was observed between the GEI and the RRAT scores.

The data from the Bateman-Donald (BD) survey was administered to a group of engineering freshmen students (N = 30). The survey measured the students' anchoring in zones of Duality, Multiplicity, Relativity and Commitment. The analysis of the data is given in Table III. The data suggested that the students were anchored in the Relativity and Commitment zones. This result is consistent with the observations of Bateman and Donald [31].

	Duality	Multiplicity	Relativity	Commitment
% Agreement	72	84	90	83

Table III. Intellectual zones

Figure 5. Comparison of RRAT responses

Conclusion and Future Work

The study provided some interesting and useful insights into student learning. An important aspect that was identified was the students' reducing confidence in being recognized as an engineer by their instructors. The interest in learning engineering increased with time spent in college. The impact of incorporating hands-on activities in the introductory engineering class had a positive

impact on the engineering identity of the students. The students' tolerance to ambiguity was a complex mix of socially and technically ambiguous situations. Students in the upper division were uncomfortable in a socially ambiguous situation as compared to students in the lower division. The data analysis did not suggest a correlation between the scores on the tolerance of ambiguity survey and the engineering identity survey. The freshmen students' intellectual models were toward the higher levels and not the simple dualistic level.

The surveys will be administered to additional (STEM and non-STEM) students, especially upper division students to have a better understanding of tolerance of ambiguity, development of cognitive model and engineering identity.

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