A LONGITUDINAL STUDY OF INTELLECTUAL DEVELOPMENT OF ENGINEERING STUDENTS: WHAT REALLY COUNTS IN OUR CURRICULUM?

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Abstract — *In the early 1990's several national reports called for reform in engineering education and suggested that the current preparation of engineering students fell short of the skills and competencies that would be required of practicing engineers. Many engineering colleges across the country sought to address these problems with curricular reforms that incorporated more hands-on design work into the engineering curricula. The task of assessing the effectiveness of these design-infused curricula presents a critical challenge for engineering educators. At Penn State, we developed a longitudinal assessment program to evaluate the qualitative changes in students' thinking as they progressed through the engineering curriculum. This paper presents a summary of the results of the first longitudinal component of this assessment.*

Index Terms ¾ assessment, cognitive growth, intellectual development, Perry scheme

INTRODUCTION

In the early 1990's several national reports called for reform in engineering education and suggested that the current preparation of engineering students at the baccalaureate level fell short of the skills and competencies that would be required of practicing engineers [1]-[3]. Several of these reports suggested that while graduates of engineering programs were competent at solving textbook problems, these graduates were not proficient at solving engineering problems within the ambiguous and continually changing contexts of the "real world." Many engineering colleges across the country sought to address these problems with curricular reforms that incorporated more hands-on design work into the engineering curricula. The task of assessing the effectiveness of these design-infused curricula presents a critical challenge for engineering educators.

At the Pennsylvania State University, we developed a longitudinal assessment program that attempts to address this challenge. Specifically, we sought to evaluate the qualitative changes in students' thinking as they progressed through the engineering curriculum. We focused our study to determine if we are attaining our overall educational goal of helping graduates be able to operate effectively in the necessarily ambiguous world of engineering problem solving. Thus our study, in particular, examines how students' thinking moves away from relying on rote memorization and toward thinking about problems contextually. This paper presents a summary of the results of the first longitudinal component of this assessment effort and addresses the following research questions:

- Does the quality of students' thinking change from their first to third year of college?
- Does a previously measured positive effect of a first-year design course persist into the third year?
- Can we relate the changes in students' thinking to the engineering curriculum?

THEORETICAL AND RESEARCH FOUNDATIONS

This study is based upon a theory of intellectual development proposed by William Perry in the 1960s. In general, theories of intellectual development posit that adult problem solving requires something beyond simply critical thinking and formal reasoning skills. Several theorists have operationalized an understanding of these cognitive capacities [4]-[6]. Perry's theory suggests that college students qualitatively change their perspectives on knowledge and learning in predictable ways as they proceed through the challenges of higher education. The Perry model has a range of "positions" from 1 to 9, each representing an increasingly complex and mature level of intellectual development. Essentially, the nine positions can be grouped into three overall stages. Students generally begin in a dualistic right-versus-wrong stage (positions 1 – 2), then progress to a relativistic stage where all things are seen as having potentially equal value and correctness (positions 3 – 4), and then to a stage where they can make intellectual commitments and decisions within a relativistic context (positions 5 – 9).

Several research studies provide evidence of the progression of college students through Perry's positions and other measures of intellectual development that are similar to Perry. Longitudinal studies of intellectual development based upon the Reflective Judgement Model (see Kitchener and King [4]) have consistently found statistically significant gains throughout college (see Pascarelli and Terenzini, [7]).

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Similarly, Baxter Magolda reports statistically significant gains from the freshman to sophomore years as measured by the Measure of Epistemological Reflection [6].

The most noted Perry-based study in engineering education [8] was conducted at the Colorado School of Mines (CSM) where researchers studied a cross-sectional sample of freshman, sophomore, and senior volunteers. Freshman CSM students were rated at 3.27 on average. Compared across the three groups, students evidenced an increase of one position over the course of their four years of undergraduate study. Researchers used this study's results to inform curricular change and, subsequently, to measure the effects of these changes.

Our initial interviews with the sample of students we are analyzing in this study have been reported elsewhere [9]. These results suggested not only a dispersion of Perry positions across the original sample of 53 students, but also a significantly higher distribution of Perry ratings for those students who had completed a first-year design course as compared to those students who had not. While our initial study yielded interesting results, many unanswered questions remained. For instance, do students grow significantly when we re-measure intellectual development periodically, and do the differences discovered in the freshman year last throughout college? These unanswered questions together with the small amount of longitudinal Perry data in the literature encouraged us to continue our investigations.

METHOD

Design

This study used a simple longitudinal interview design with a random sample of students from the college of engineering. Students were interviewed during the spring semester of their first-year of college and were interviewed again in the fall semester of their junior year. This same cohort of students will be recontacted during the spring semester of their senior year as a final follow-up data collection point.

Population and Sample

The population for this study consisted of the 871 pre-engineering first-year students at the University Park campus of the Pennsylvania State University for the fall 1996 semester. All students who had designated a desire to pursue engineering as a major and who met the initial admission criteria for pre-engineering status were eligible for the study. From this population, we randomly sampled a group of 100 students to initially invite for interviews. From this sample, several students had already left engineering, could not be contacted because their address had changed, or declined to participate. Fifty-three students completed the initial phase of the study by consenting to an hour-long in-person interview during the spring semester of 1997. One of these interviews was dropped because of language and cultural disparities. In addition, after the initial interview, one student declined to continue participating in the longitudinal portion of the study.

The remaining 51 students were contacted the following academic year and asked to complete a learning styles inventory. A year later, these same 51 students were contacted again and asked to complete a second in-person interview. Thirteen students had either left the university or declined to be interviewed. Thirty-nine students from the original sample completed a second interview. Due to equipment failure, seven interviews were not useable leaving a final sample size of 32 students.

Based upon data collected from the sample during the initial interview, the group of students who continued to the second phase of data collection were not significant different from the non-respondents on Math or Verbal SAT scores, GPA in their first-year, or initial interview Perry position. The junior year non-respondent group also did not differ from the respondent group in proportion of male and female students nor in the proportion of students who had taken a first-year design course.

Instrumentation

Students were contacted by phone or email and asked to participate in an interview about their college experiences. Trained interviewers conducted the hour-long, videotaped, semi-structured interviews. First-year and third-year interview protocols were slightly different, although both protocols contained questions regarding their views on learning, classroom activities, knowledge, problem-solving approaches, and ways of reconciling views they encounter that are different from their own. Sample questions are shown in Figure 1. After each interview, students completed a short personal information form that asked them about their participation in various university activities. In addition, students were asked to release their transcript information for the purposes of the study.

What stands out for you so far in your college experience?

Should a student change as a result of going to college and if so, how?

Could you describe for me a course that would represent the ideal learning experience for you?

What is the role of the faculty / student member in the ideal learning situation?

What does it mean to you to learn something?

What is the relationship between knowledge and truth?

FIGURE 1
SAMPLE PERRY INTERVIEW QUESTIONS

Variables

For the purposes of this analysis we were most concerned with nine variables. The dependent measure was the Perry position rating given to the student at the second interview (fall semester of the junior year). Independent variables were: gender, previous enrollment in a first-year design course, experience in the honors program, COOP experience, and retention in the college of engineering. Control variables were math and verbal SAT scores, GPA at the time of the first interview, and Perry position rating at the first interview (spring semester of the first year.)

Analysis

The data were analyzed using a variety of statistical methods including paired t-tests, independent samples t-tests, chi-square analyses, and multiple regression analyses.

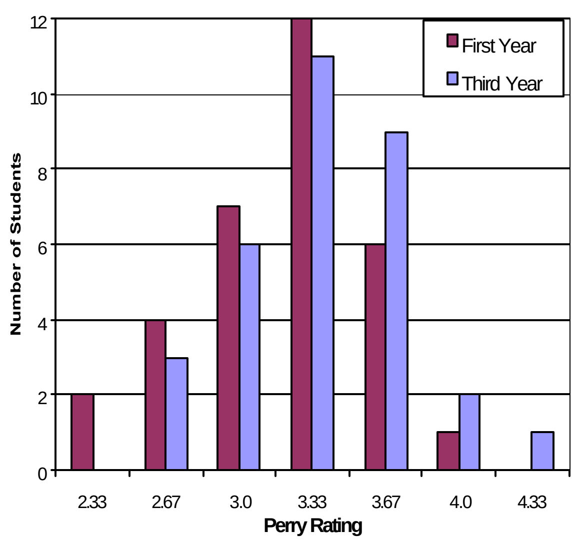

FIGURE 2.
PERRY RATINGS IN YEAR ONE AND THREE

RESULTS

Of the students who completed both first- and third-year interviews 21 (66%) were male and 11 (34%) were female. Their average verbal SAT score was 612 and the average math SAT score was 651. Five students were participating in the university's honors program and half (16) had completed an internship or Coop experience prior to the interview. The majority of the sample had been retained in the college of engineering to their junior year (78%). Seven students had officially changed to a major outside the College of Engineering. One of these students was pursuing a degree in geo-environmental engineering that is housed in the College of Earth and Mineral Sciences. Two students had changed to degree programs in the College of Business. The other four students were pursuing degrees in telecommunications, English, labor and industrial relations, and science.

Figure 1 presents the results for this sample of students. The modal first-year and third-year ratings for this sample of students are both at Perry position three. However, the distribution of ratings in the third year is skewed toward a slightly higher range as can be seen in Figure 1, with an average first-year rating of 3.20 and third year of 3.38. To test whether students had made significant gains in Perry rating from the first to the third year, we conducted a paired t-test. This test approached traditional levels of significance ($t=1.977$, $df=31$, $p=.057$), which, given the small sample size, is an indication that these students showed positive development in their thinking.

Mean differences for each of the independent variables were tested at a bivariate level using an independent samples t-test. Mean ratings for students who had left the college of engineering versus those who were retained were not significantly different ($t=.037$, $df=30$, $p=0.971$). Students with experience in the honors program ($t=0.654$, $df=30$, $p=0.518$) and in internships/coops ($t=0.00$, $df=30$, $p=1.00$) were not significantly different from their peers who had not participated in these experiences. We initially found a significant t –value in comparing male and female students ($t=2.10$, $df=30$, $p=.044$), with men (M=3.48) having higher average ratings than women (M=3.18). However, with further analysis using multiple regression, this difference disappeared when we controlled for the effects of other variables, in this case initial rating, math SAT, and interviewer. The lack of a gender effect is consistent with the earlier result that there were not significant gender differences in Perry ratings during the first year for either the original 52 student sample ($t= 1.05$, $df = 50$, $p=.298$) or for the smaller sample of 32 students ($t= .465$, $df=30$, $p=.645$). Finally, there was not a significant difference between students who had completed the first year design course and students who had not ($t=0.390$, $df=30$, $p=0.699$).

DISCUSSION

In answer to our first research question posed in the introduction, the overall results show an increase in average Perry rating from 3.20 to 3.38, and therefore, cognitive development, from the first to the third year, although the margin of change is admittedly small. And while we find it somewhat encouraging that the overall means between the entire first and third year samples did increase we must also recognize that several students in the third-year sample actually had substantially lower ($\geq .67$) Perry ratings than in their first year. Perry referred to this phenomenon as a retreat in cognitive development.

Figure 3 provides a useful graphical representation of the longitudinal data, plotting student's first rating (x-axis) against their change in rating between the first and third year (y-axis). If we "separate" the sample by the mean first-year rating (3.20), we can visually see that, overall, students who were rated below the sample mean at the first year experienced more positive gains than those who began with higher Perry ratings. Essentially those who began lower, caught up with the other students. Perhaps, most importantly, none of the students moved beyond position four – meaning they are all still exhibiting multiplistic thinking.

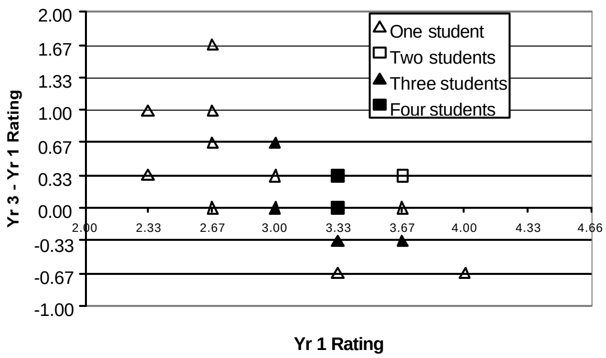

FIGURE 3
CHANGE IN PERRY RATING FROM YEAR ONE TO THREE

Another question posed in the introduction was whether those who had completed the first-year design course would sustain significantly higher ratings than those who had not. The analysis of the means of the students with and without the first-year design experience indicate that the difference is not sustained.

Finally, we turn our attention to the implications of these result in terms of the curriculum, bearing in mind that the discussion at this point is hypothetical, as we have not yet done sufficient analysis to support it. We must be cautious in our interpretations because the sample represents only approximately 3% of all juniors. Clearly these 32 students have experienced only a portion of the numerous courses and instructors available at Penn State.

For students in the College of Engineering, the curriculum in the first-two years is heavily laden with pre-requisite math, science, engineering science, and general education courses. The lack of substantial progress in intellectual development may arise from both the way these courses are typically taught and their content. Concerning pedagogy, courses during these years are taught using traditional pedagogies. Typical course activities include lecture, well-defined homework problems (meaning they are problems with one right answer), and exams, and other activities that require students to work, primarily, on their own. Noticeably absent from this list are the hands-on or open-ended, team-based projects, and other experiences. While certainly some courses do break this mold and involve students in discussions and some open-ended projects, they are currently the exception, not the rule.

There is a body of evidence to suggest that certain types of curricular activities can facilitate development along the Perry scale. In all cases intellectual development was facilitated when an instructor specifically developed activities that would initially meet students at their intellectual development level, then challenge them in a supported environment to think in broader, more complex ways.

Our initial results from our first contact with these students also support this strategy. The first-year design course asks predominantly dualistic students to solve open-ended design problems. Problems are carefully planned to have multiple solutions and challenge students' views of a "one right answer". Additionally and just as importantly, the classes facilitate this transition from dualism by coaching students initially with guided examples and eventually a gradually fading level of support so students must operate more independently. Given the current longitudinal results and our knowledge of the engineering curriculum during the freshman and sophomore years, it would appear that these types of classroom activities are not occurring with the frequency needed to positively influence Perry ratings.

CONCLUSION

Based upon the results for the first longitudinal ratings, we can make the following conclusions:

- On average, the students experience a significant increase in Perry rating from the first-year to the junior year, from 3.20 to 3.38.
- The higher Perry rating of first-year students who completed the first-year design course was not sustained in the junior year.
- The students who had the lowest initial Perry ratings showed the most substantial gains.
- The experiences of these students in the first two years did not move them beyond the multiplistic thinking of a position four.

The implication of these findings is that we need to restructure the experiences in the first two years of the curriculum if we wish the students to make substantial gains in Perry rating. Efforts to teach the math and science curriculum, arguably necessary for students to become proficient engineers, within a more meaningful context may help to challenge students' thinking between their first and third years of study [13][14]. Changes are currently underway in many of our engineering programs to implement such changes.

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