Active and Cooperative Learning in a Freshman Digital Design Course: Impact on Persistence in Engineering and Student Motivational Orientation

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Abstract - **In an effort to retain students in the electrical and computer science/engineering programs at Arizona State University, a freshman-level introductory digital logic design course was designed with extensive active learning components in cooperative student teams as well as hardware and software (simulation) labs. This paper reports on an evaluation of the impact of the course on the persistence of the students in the program. The recently proposed persistence in engineering (PIE) survey instrument was adapted for our setting and combined with mastery, performance, and alienation survey items to obtain deeper insights into the motivational orientations of the students. The survey was conducted both at the beginning of the course and at the end of the course to assess the impact of the course on persistence and motivational orientations. Evaluation data for two years worth of offerings of the course to a diverse population of over 450 students revealed a significant positive impact of the course on student perceptions of their skills applying science and math to real-world problems as well as of their performance on teams. On the other hand, the course significantly negatively impacted the students' perceptions of the course workload and intensified their alienation motivation tendencies.**

Index Terms – Digital design course, Motivational orientation, Persistence.

INTRODUCTION

As reported recently at FIE, we developed a freshman-level course on digital systems design with extensive use of active and cooperative (team) learning [1]. One of the goals of having this course at the freshman level in the electrical and computer engineering curriculum at Arizona State University – Tempe campus was to expose students early to core electrical and computer engineering content and thus improve their persistency and retention in the program. In this paper we present a comparative evaluation of the persistence and motivational tendencies of the students before and after they complete this digital systems course. We employ the recently developed persistence in engineering (PIE) survey instrument [2], and the motivational tendencies inventory developed by Archer [3]. These surveys were administered both at the beginning and at the end of the course for the Spring and Fall semester offerings in 2005 and 2006 involving over 450 students.

RELATED WORK

The main conceptual areas related to our work are *(i)* the area of teaching digital systems design, and *(ii)* the area of assessing and improving persistence in engineering programs. Digital systems design is a core competency in both electrical and computer engineering programs as it provides a foundation for the study of many advanced electrical systems as well as computer architectures. Teaching methodologies for digital systems design have been examined, for instance, in Amaral et al. [4] and Hall [5], and many textbooks provide a detailed coverage of this topic, see for instance Marcovitz [6], Vahid [7], and Wakerly [8]. Our course uses Marcovitz [6] as textbook, but relies extensively on the animated slide presentation and lab manual presented in Tylavsky [1,9].

Persistence of students in engineering programs and their resulting retention in the programs has received significant attention in recent years. A number of studies have identified general factors and indicators of persistence and retention, see [10-13]. More closely related to our work are the efforts to assess the impact of first-year courses and curricula on the persistence and retention, see [14-18]. Our work considers this same issue of first-year courses and their impact on persistence, but in the context of a digital systems design course that provides a foundation for further studies in both electrical and computer science and engineering.

PERSISTENCE IN ENGINEERING

In this section we describe our survey methodology as well as present and discuss the survey results for the persistence in engineering.

I. Method

We employed selected items from the Persistence in Engineering (PIE) survey instrument [2]. In order to keep our survey to a reasonable length that different instructors could accommodate in their classes, we generally selected items that had shown high item-total correlation (0.5 or higher) from

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rubrics with high internal consistency reliabilities (alpha values of 0.7 or higher) in [2]. We also included a few items that had lower correlations and reliabilities, such as items on applying math and science to real-world problems, solving problems with multiple solutions, as well as satisfaction with faculty and teaching assistants. These items were included because we felt that these provide valuable insights in students views of engineering and the quality of instruction and attention they received from faculty and teaching assistants. The selected items are listed in Table I. For each item, the students indicated their agreement with the positive survey statements on a five-point Likert scale ranging from Strongly Disagree (scored as 1), Disagree (2), Neither Agree nor Disagree (3), Agree (4), to Strongly Agree (5). In addition to these survey items, students were asked to provide open-ended comments on the course. Aside from the survey, we employed a 10-item content-specific test as a pre-test to assess the level of knowledge of students entering the course, and as a post-test to assess learning gains through the course.

The survey was anonymous and was administered both at the beginning of the course and at the end of the course. Our evaluation covers four semesters, each offering typically four sections of the course. A total of 469 completed surveys from the beginning of the semester and a total of 241 surveys from the end of the semester were collected. The smaller number of completed post-course surveys is a limitation of this study and is primarily due to

- students "sampling" the class during the add-drop period (first week of the semester) being captured in the pre-course survey;
- fewer students taking the time to complete the survey at the busy end of the semester;
- and some students having dropped the class by the end of the semester.

Due to privacy concerns, we were not able to track the individual students from completing the pre-course survey to the post-course survey, preventing a matched samples analysis. However, given the large number of completed surveys, we can reliably detect medium and large effects with an independent sample analysis. Also, the completed pre-course surveys give a valid reflection of the perceptions of an engineering student prior to taking the course (even if he or she is only sampling), while the completed post-course surveys give a valid account of the perception of students that have completed the course.

The survey included a few demographic questions, revealing that approximately 90% of the surveys were completed by male students and 10% by female students. The mean age of the respondents was M = 20.95 years with a standard deviation SD = 4.30 years. Approximately 40% of the respondents indicated that they were freshmen, 37% were sophomores, 19% were juniors, and 4% were seniors. About 89% indicated that they were taking the course for the first time, 9% for the second time, and 1% for the third time. Approximately one third of the students characterized themselves as Electrical Eng. Majors, one third as Computer Eng., majors, and one third as Computer Science majors. Approximately 67% of the surveys were completed by Caucasians, 11% by Hispanics, 3% by Native Americans, 4% by Asians, and 6% by Blacks, and 9% did not indicate their ethnicity. The respondents indicated that they were enrolled in M = 13.79 credit hours (SD = 2.48) and worked a job for M = 14.00 hours/week (SD = 13.78). The students indicated that on average they had a commute of M = 10.82 miles one-way to campus (SD = 11.92).

II. Results

Table I presents the means M and standard deviations SD of the rating scores for the individual survey items. The pre-course and post-course scores for each item were analyzed with an independent-samples t-test and the resulting significance level p is reported in the table, whereby a p value of .05 or less indicates a significant difference between the pre- and post-course means. The Cronbach α for these 30 survey items is .87, indicating a high level of internal consistency of the survey.

TABLE I
MEAN SCORES M AND STANDARD DEVIATIONS SD OF PERSISTENCE IN ENGINEERING SURVEY ITEMS BEFORE AND AFTER THE COURSE. SIGNIFICANT DIFFERENCES ARE INDICATED BY A $p < 0.5$.

	Pre		Post		
Survey Item	M	SD	M	SD	p
1. I want to continue taking engineering courses.	4.45	0.78	4.33	1.00	.08
2. I want to major in engineering.	4.41	0.92	4.39	0.96	.81
3. After graduation I want to become an engineer.	4.29	0.96	4.28	1.01	.96
4. I think that I will do well in this course.	4.17	0.70	4.02	0.83	.01
5. I have good math skills.	4.30	0.66	4.24	0.75	.27
6. I have good science knowledge.	4.03	0.70	4.19	0.72	.01
7. I am good at applying math and science to real-world problems.	4.02	0.70	4.14	0.77	.04
8. I like working in teams.	3.90	0.89	4.03	0.91	.06
9. I perform well on teams.	4.07	0.75	4.20	0.76	.04
10. Creative thinking is one of my strengths.	3.98	0.82	4.10	0.80	.08
11. I am skilled at solving problems that can have multiple solutions.	3.99	0.66	4.06	0.69	.15
12. Math skills are important for engineers.	4.75	0.48	4.65	0.57	.02
13. Science knowledge is important for engineers.	4.62	0.59	4.58	0.60	.43
14. Ability to apply math and science principles to real-world problems is important for engineers.	4.71	0.55	4.76	0.45	.27
15. Ability to perform on teams is important for	4.57	0.61	4.53	0.66	.44

engineers.					
16. The quality of instruction by faculty is good.	4.10	0.76	4.22	0.88	.07
17. There are enough opportunities to interact with faculty.	3.80	0.81	3.96	0.87	.02
18. The quality of instruction by teaching assistants is good.	3.60	0.84	3.70	1.02	.16
19. There are enough opportunities to interact with teaching assistants.	3.64	0.81	3.86	0.92	.00
20. The computer facilities are good.	3.97	0.77	4.11	.096	.04
21. The library services are good.	3.93	0.75	3.94	0.72	.83
22. The classroom facilities are good.	4.13	0.66	4.24	0.70	.04
23. The tutoring services are good.	3.56	0.77	3.54	0.88	.79
24. The academic advising is good.	3.71	0.93	3.68	0.99	.76
25. The hardware lab facilities are good.	3.72	0.77	3.83	1.02	.11
26. The software lab facilities are good.	3.74	0.78	3.78	0.96	.47
27. I feel stressed about the course load for this class.	3.34	1.06	4.25	0.91	.00
28. This is going to be a worthwhile course.	4.16	0.73	4.04	1.01	.07
29. This is going to be an enjoyable course.	3.85	0.85	3.60	1.18	.00
30. I think that I will learn a lot in this course.	4.37	0.71	4.26	0.97	.09

The average pre-test score was $M = 2.29$ ($SD = 1.52$) and the average post-test score was $M = 7.99$ ($SD = 1.78$), which was significantly higher than the mean pre-test score $p < 0.001$.

A theme-based analysis of the constructed open-ended comments revealed a total of 74 comments which in decreasing order of frequency addressed the following issues:

1. Workload too high (36 comments): The students complained that the workload of the course, which included bi-weekly extensive homework assignments, and weekly labs was too high for a 3 credit hour class.
2. Praise for course (18 comments): These comments pointed out that the course was very interesting, provided deep insight into the functioning of electrical and computer systems, and was a good foundation for further study in electrical and computer science and engineering.
3. Praise for instructors (12 comments): The students noted that the instructors provided very good and helpful instruction of the intricate digital logic materials.
4. Organizational improvements (8 comments): These comments suggested specific improvements to the flow of lab reports from submission to return to the students, the timing of the lab hours, and the reading assignments from the textbook.

III. Discussion

We observe from the first three items that the course had no significant impact of the motivation for taking more engineering courses or becoming an engineer after graduation. We observe, however, a non-significant trend of lowered motivation for taking more engineering courses, while all these three motivational indicators from [2] are at relatively high values.

Survey Item 4, the interpersonal confidence item from [2], indicates that the students are significantly less optimistic about doing well in the course at the end of the class compared to the beginning of the class. This perception is to be contrasted with the results from the content-specific pre- and post-test, which indicates significant learning gains and average mastery levels close to 8 out of 10 points. It is possible that the students had initially high expectations for their mastery that they felt they could not meet at the conclusion of the course. Also, the high workload, as discussed below, may have negatively affected their interpersonal confidence.

On the other hand, the course significantly positively influenced the students' perceptions about their confidence in engineering knowledge and skills, both in regards to technical knowledge (Items 5-7) and professional team work skills (Items 8,9). These results suggest that the active learning approach in the course has instilled technical skills that the students feel very confident about. Also, the team learning in the course has succeeded in providing the students with team learning and working skills that they feel confident about.

Survey items 8 and 9 on the ability to solve open-ended problems indicate tendencies that the students have improved their open-ended problem solving, but these effects are not strong enough to result in a significant difference.

The students' perceptions of the importance of engineering knowledge and skills (Items 12-15) indicate that the students viewed math and science knowledge and its application to real-world problems very favorably (with more students giving Strong Agree ratings than Agree or lower rating). The perceived importance of math skills has dropped significantly, but remains at a high level of 4.65 after the course, indicating that the students had perhaps overly inflated perceptions of the relevance of math skills for engineering at the outset of the course. An alternative explanation for this drop is that due to the subject matter, the course used relatively little traditional mathematics and contained only two weeks of instruction on Boolean algebra. The course may therefore have conveyed a somewhat distorted picture of the general relevance of mathematics in the field of engineering.

The perceptions of the quality of instruction and opportunities of interaction with faculty and teaching assistants (Items 16-19) include two items with significantly improved perceptions and two items with improvements not strong enough to reach statistical significance. Overall, the students seemed to have appreciated the active and cooperative learning instruction provided in the mediated classroom and the extensive labs supported by teaching assistants.

The facilities, tutoring, and academic advising support received consistently high ratings, with the students perceptions of the mediated classroom and its computer equipment improving significantly. Apparently, they felt positive about experiencing the animated slides and having the opportunity to conduct their in-class team work on computers.

The curriculum overload item from [2], Item 27 in our survey, deserves particular attention as it showed by far the most pronounced change. The feeling of stress about the course workload increased from M = 3.34 at the beginning to M = 4.25 the end of the class. Consistent with this numerical rating, the vast majority of the open-ended survey comments were in regard to the course workload. With many students noting that this digital design course, which is currently worth 3 credits in our curriculum, represents as much work as most of the 4 and 5 credit hour courses that our students take. This student feedback will be very useful as we iterate through our ABET-prescribed continuous improvement process.

The high course workload likely contributed to the negative tendencies in the perceived course value (Items 28-30), with students being apparently disillusioned about the enjoyment and learning in the course. It is possible, that similarly, the self-confidence of the students (Item 4) has been significantly negatively affected by the workload.

Overall, the results appear to indicate diverging trends in the perceptions of the students: On the one hand, the survey items tied directly to this particular course, namely Items 4, 27, 28, 29, and 30 (and to some degree Item 1 as it relates to taking more engineering courses) showed decreased student ratings, with several rating drops being so pronounced to reach the level of statistically significance, namely Items 4, 27, and 29. (The score of Item 27 about the stress due to the course work load increased, which we view here as a decreased, less favorable student rating.) On the other hand, the items relating to the quality of instruction, facilities, and support in the course (Items 16-25) and the items relating to engineering careers as well as engineering knowledge and skills (Items 2, 3, and 5-15) remained unchanged at a relatively high level or showed improved student ratings, with Items 6, 7, and 9 experiencing statistically significant gains. Thus, these persistence in engineering (PIE) survey items from [2] appear to indicate that the course itself was viewed more negatively at the end compared to the expectations at the beginning, whereas the students general views of engineering and their engineering skills improved.

A limitation of this study that should be kept in mind when considering these interpretations is that this study focused on one course. The students' general views and skills, however, may have been influenced by other courses they were taking in parallel with the considered course or experiences outside the university. Another interesting consideration is that the students seem to distinguish between the course itself (course work load, enjoyment, usefulness, i.e., Items 4, 27-30) and the instruction and support for the course (instruction quality, instructor/TA availability, facilities, i.e., Items 16-26) with the ratings of the course itself decreasing while the rating for course instruction and support increased. This indicates perhaps that the active and cooperative learning course instruction had a positive effect but could not compensate for the high workload and resulting high stress level.

MOTIVATIONAL TENDENCIES: MASTERY, PERFORMANCE, AND ALIENATION

In this section we present the method employed for the part of our survey assessing the motivational tendencies of the students before and after our course. We also present and discuss the survey results and relate them to the PIE results presented in the preceding section.

I. Method

We employed the survey instrument developed by Archer [3], which had also been used in [19] to evaluate the impact of instruction on students' motivational tendencies. The survey items, which are listed in Table II, capture Mastery (M), Performance (P), and Alienation (A) goals. This survey was administered together with the PIE part of our survey at the beginning and end of the course. The students rated again their perceived level of agreement with the survey statements on a scale from Strongly Disagree (1) to Strongly Agree (5).

II. Results

The means and standard deviations of the pre-course and post-course survey scores along with the level of significance of their difference are reported in Table II. The Cronbach α for these 19 survey items is .84 indicating a high internal consistency.

TABLE II
MEANS M AND STANDARD DEVIATIONS SD FOR MASTERY (M), PERFORMANCE (P), AND ALIENATION (A) SURVEY ITEMS BEFORE AND AFTER COURSE

	Pre		Post		
Survey Item	*M*	*SD*	*M*	*SD*	*p*
When do you feel most successful …					
1. When a lecture or lab makes me think about things. (M)	4.07	0.70	4.07	0.74	.91
2. When I do almost no work and get away with it. (A)	2.32	1.06	2.72	1.20	.00

3. When I get a higher mark than other students. (P)	3.79	0.96	3.76	0.98	.62
4. When I learn something interesting. (M)	4.47	0.56	4.45	0.58	.64
5. When I show people that I am smart. (P)	3.42	1.06	3.57	0.96	.06
6. When something I learn makes me want to find out more. (M)	4.35	0.62	4.36	0.68	.95
7. When I don't have to work too hard. (A)	2.90	0.99	3.19	1.07	.00
8. When I am the only one who can answer the instructor's/TA's questions. (P)	3.23	1.11	3.43	1.06	.02
When do you feel most satisfied…					
9. When I learn something new. (M)	4.39	0.58	4.38	0.64	.72
10. When I do better then other students in the class. (P)	3.66	0.98	3.71	0.98	.57
11. When I realize I am getting through the course without having to work too hard. (A)	3.30	1.04	3.37	1.04	.39
12. When I read something interesting. (M)	4.10	0.67	4.05	0.84	.38
13. When I realize I don't have to prepare for lectures/labs. (A)	3.21	0.98	3.41	1.04	.01
14. When I work on a challenging task or assignment. (M)	3.93	0.78	3.91	0.80	.82
When do you feel greatly satisfied or positive ...					
15. When I accomplish something that others can't do. (P)	4.13	0.85	4.09	0.89	.57
16. When I understand something for the first time. (M)	4.45	0.58	4.48	0.61	.50
17. When I am involved totally in something I am doing. (M)	4.38	0.62	4.31	0.69	.21
18. When I receive recognition or prestige. (P)	3.97	0.91	3.99	0.89	.76
19. When I enhance my status in the class/ team. (P)	3.98	0.89	3.93	0.90	.47

Averaging the scores for a given motivational category, we find a pre-course average of M = 4.27 for the eight mastery items, and a corresponding post-course average of M = 4.25. The seven performance items have a pre-course average of M = 3.74 and a post-course average of M = 3.78. The four alienation items have a pre-course average M = 2.93 and post-course average M = 3.17.

III. Discussion

We observe from the results that the students perceived their mastery motivation tendencies to be the strongest, and these mastery tendencies were not changed by the course. The performance motivational tendencies were the next strongest with a rating between Neither Agree nor Disagree and Agree that remained unchanged. On the other hand, the alienation tendencies significantly intensified from a mean rating of M = 2.93 to M = 3.17. Keeping in mind that a rating of 3.00 corresponding to Neither Agree nor Disagree, the increase from 2.93 to 3.17 may be interpreted as a shift from some students disagreeing with the alienation tendencies and the majority being neutral to the majority still being neutral, but a significant number of students agreeing with the alienation tendencies at the end of the course.

The consistently high rating of mastery motivation tendencies is an encouraging result as it indicates that students have strong intrinsic interest in learning and a tendency to work with high perseverance and effective meta-cognitive learning strategies on hard tasks to further their understanding of the course material [3]. Somewhat disappointing is that the extensive active and cooperative learning instruction did not further instill and strengthen this mastery motivation in the students. Enhancement of mastery motivation is in general a very desirable goal for university programs as it positively correlates with perseverance in challenging programs [3]. Realistically speaking though, the high mastery motivation at the outset of the course left little room for improvement.

The performance motivation of the students, which is generally less strongly coupled to the use of effective learning strategies and positive attitudes toward persisting in the program [3], stayed throughout at a reasonably high, but not exaggerated level.

The increase in alienation motivation tendencies is of concern since alienation generally indicates lack of a positive attitude toward learning and interests in activities other than the course [3]. Fortunately, the level of the alienation tendencies was not very high, rather in the vicinity of the neutral Neither Agree nor Disagree rating. Nevertheless, it would be preferable to see the alienation tendency decrease rather than increase. One strong contributing factor to the increase in alienation could be the high course workload in conjunction with the relatively low class credit of only 3 credit hours towards the degree.

CONCLUSION

We have conducted a comparative survey-based assessment of the student persistence and motivation tendencies at the beginning and end of a digital design course employing active and cooperative learning. This required core course of the electrical engineering, computer engineering, and computer science programs at Arizona State University – Tempe is currently a 3 credit hour class with 150 minutes of class contact time per week for lecture and active and cooperative in-class learning activities, extensive bi-weekly homework assignments, and weekly labs (which are conducted outside the class contact time and alternate between hardware lab one week, and simulation/software lab [9] the next week).

Overall, the results for the persistence in engineering [2] and motivation tendencies [3] survey items indicate that the student perceptions of their engineering skills and knowledge and the quality of instruction and support improved while the mastery and performance motivation tendencies remained unchanged at high levels. These results appear to support the active and cooperative learning strategies extensively employed in the course, as detailed in [1].

On the other hand, the perceptions relating directly to the course, such as the perception of doing well in the course and the enjoyment of the course, dropped significantly while the perception of stress due to the course workload increased significantly. In concert with these shifts in perception, alienation motivation tendencies increased. These results, in conjunction with constructed open-ended survey comments suggest that the course workload is too high, especially given that the class is worth only 3 credit hours. As a result, the students enrolling in courses according to the prescribed semester credit hour guidelines tend to overload themselves and spent a disproportionally large amount of their time and effort on the digital design class.

In our ongoing ABET continuous improvement process, we are seeking to increase the credit hours for the digital design course to 4 or possibly 5 credit hours to be commensurate with the extensive amount of material covered in class and labs and the resulting student workload. It would be very interesting to examine in future work how the student perceptions directly tied to the course (such as stress due to course workload and course enjoyment) and the alienation motivation tendencies develop when the credit hours are reflective of the true course workload.

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