No Excuses: Use of Simple Active Learning in Electrical and Computer Engineering

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Abstract

Student-centered active learning, in which students are called upon to “do” something during class beyond listening and note taking, should be used to some degree in STEM courses. Active learning has a significant positive impact on learning, understanding, and retention of information. Fortunately, active learning can be incorporated into a course in many ways, from simple approaches that require little-to-no preparation to more complex approaches such as problem based learning. Simple approaches offer the advantages of being readily accessible to newer or time-constrained instructors, not requiring a radical change or overhaul of a course, and providing stepping stones to more complex approaches. In this study, we explored the repeated use of simple active learning techniques (i.e., think-pair-share and the minute paper) in an introductory electrical and computer engineering course in digital logic in the fall 2016. This course had previously been taught in a traditional lecture fashion. With the think-pair-share activities, students were asked to individually (and then in pairs) answer a question or solve a problem involving (for example) the illustration of a circuit and/or its mathematical expression. With the minute paper, students were asked at the end of class to write down their muddiest points, main takeaways, and/or questions based upon their lecture notes. To directly assess the effectiveness of this new approach, current rubric-derived exam results were compared with previous exam results, taking GPA into account. We obtained significantly-higher final exam scores during the active semester. Semi-structured student interviews were also conducted before class sessions and content-analyzed by two analysts to indirectly assess the impact of the techniques on student learning. Based on the interview data, the very large majority of students found the techniques to be helpful to their learning, with most citing the ability to talk to and work with their classmates to solve problems. In addition, the classroom was observed using the COPUS observation protocol to describe it and determine the level of activity and interaction. The instructor’s main takeaway from his first use of these techniques is that they lead to large gains with little-to-no extra time or preparation. Although he had previously not used them due to a perceived lack of time, his advice to new faculty is to try these techniques in their courses. Additional instructor insights and reflections will also be discussed.

1. Introduction

Active learning has been defined as anything that students “do” in class beyond listening to lecture and taking notes (Felder & Brent, 2016). The theory and experimental research on active learning has established its benefits and enhanced effectiveness relative to traditional lecturing in regards to problem solving, conceptual gains, exam performance, and in-class engagement and skills application (Prince, 2004; Chi, 2009; Bonwell & Eison, 1991; Hake, 2001; Freeman et al., 2014; Wieman, 2014). Interestingly, even though active learning has been proven to be effective, the number of STEM faculty members using active learning techniques in the classroom appears surprisingly low, with most STEM courses still taught by lecture (Wieman, 2014). Yet, this void is not due to a lack of interest in learner-centered instructional
techniques. Based on a recent survey of over 1,000 *Faculty Focus* readers, 90% had an interest in learner-centered teaching articles (Bart, 2016).

Therefore, in this paper, we propose that the long-term solution to this problem is to place faculty members on a positive trajectory of using learner-centered techniques at the very start of their academic careers. One effective way to achieve success with this goal is to encourage and enable new faculty members to see for themselves that the benefits of active learning to both students and instructors are real and that most perceived obstacles can be easily overcome. As a case study, we present the transformation of an introductory electrical and computer engineering course on digital logic design from a passive (i.e., lecture-only) to an active learning course in the fall 2016 semester. The instructor was a new faculty member and had previously taught the course in a traditional, lecture-only manner. In our work, we provide an approach for course transformation that is simple and effective with highly positive results that new faculty can easily adopt and replicate in their respective engineering courses.

2. Literature Review

When considering the use of active learning, faculty members commonly have concerns about student acceptance, content coverage, preparation time, and logistics, and research has shown that the likelihood of adoption of new, research-based instructional approaches is directly related to the ease of implementation (Prince et al., 2013). This is particularly true of new faculty members who have yet to gain much in the way of teaching experience and have to be cautious in how they manage their time. However, to this end, in-class active learning can range from the very simple to the very involved (Allen & Tanner, 2005). Examples of simple active learning techniques that do not require large amounts of preparation or changes in the classroom structure include the minute paper and think-pair-share. Conversely, techniques such as the flipped classroom or problem based learning (PBL) are examples of more involved techniques that require significant preparation by the instructor or large changes in the traditional classroom format. In fact, leading engineering educators have recommended a gradual introduction of active learning techniques to the classroom for those who are contemplating using it (Felder & Brent, 2016; Felder & Brent, 1996). This can enable instructors to deal with student resistance or logistical issues on a smaller scale and may pave the way towards implementation of more complex approaches, such as PBL (Felder & Brent, 2016).

The two active-learning techniques that we applied in this course were think-pair-share and the minute paper due to their low stakes and potential high-gains for the instructor. With the think-pair-share technique, students work on tasks or problems individually and then form pairs to discuss and potentially improve upon their answers, with eventual sharing with the rest of the class (Felder & Brent, 2016). An approach we often used in conjunction with the think-pair-share activities was inductive teaching, in which the instructor introduced the practical problem, application, or challenge before introducing the underlying theory, as a means of better demonstrating the connections (Felder & Brent, 2016).

The minute paper is a well-known classroom assessment technique that provides a simple way to collect written feedback by asking students to respond (in two to three minutes) to questions such as the most important items learned in class or the “muddiest” or most unclear point of a lecture
or reading (Angelo & Cross, 1993). Writing minute papers is not unlike the reflection that students are asked to do with journaling, where they pose questions about their difficulties and express concerns about their work to the instructor (Sharp et al., 1999; Fulwiler, 1987).

Active learning techniques such as think-pair-share and the minute-paper have (and are) being advocated by educators from a host of STEM as well as non-STEM fields, including medicine, pharmacy, engineering, and accounting (Wolff et al., 2015; Gleason et al., 2011; Deshpande & Salman, 2016; Almer at el. 1998). Educators who have used think-pair-share activities in their classrooms have experienced both positive student perceptions and enhanced student performance, as we did. STEM-related studies in which a substantial majority of students agreed that think-pair-share helped them to learn the course material and concepts included a core course in computer science and engineering, an introductory freshman engineering programming course, and a sophomore human physiology course (Dol, 2014; Kothiyal et al., 2014; Wilke, 2003). Two of these studies also found statistically better test scores associated with the use of think-pair-share (Kothiyal et al., 2014; Wilke, 2003). An additional study of an educational psychology course found statistically enhanced test performance with think-pair-share (Bataineh, 2015).

A survey of the literature found somewhat mixed student reactions to minute papers in various non-STEM courses, citing benefits such as the ability to respond anonymously and criticisms such as the need to always have questions to ask (Stead, 2005). However, in a statistics class of 77 students, all respondents stated that the minute paper was helpful to them (Chiu et al., 2014). Relative to student achievement, in an introductory accounting course with over 800 participants, students who wrote minute papers had significantly better (both statistically and practically) essay-quiz performance, when compared to students who did not write the minute papers (Almer at el. 1998). In an introductory economics class with over 500 participants, a statistically and practically significant improvement on a multiple-choice test was found with the repeated use of the minute paper (Chizmar & Ostrosky, 1998). Finally, in the previously-mentioned statistics class, there was significantly better test achievement with the group that wrote minute papers at the end of each class (Chiu, 2014).

A noteworthy point is that our literature review uncovered only a few examples of the use of simple active learning in the form of think-pair-share or the minute paper in computer engineering or computer science courses (Kothiyal et al., 2014; Dol, 2014), with no examples of its use in the present course in introductory digital logic. As a result, the instructor developed and used new instructional activities to implement simple active learning in this course for the first time.

3. Methods

3.1 Classroom Instructional Methods

The instructor employed at least one of the active learning techniques (i.e., minute paper or think-pair-share) during each class period in which he presented content, excluding exam or guest-speaker days. Think-pair-share (TPS) was used most frequently (i.e., approximately 80% of the time), with the minute paper used on the other occasions. This was due to the problem-
solving nature of the course, for which TPS was a natural fit. Interestingly, the instructor found himself naturally determining TPS activities “on the fly” in response to students’ difficulties during class, without necessarily any preparation entailed. The minute paper exercises, and in particular the muddy points questions, were generally posed at the beginning of class and addressed during the next class after review by the instructor.

Figure 1(a) shows an example in-class TPS activity used by the instructor during the course transformation to an active classroom. One fundamental technique taught in introductory Digital Logic courses is the use of Karnaugh maps to minimize Boolean logic functions (Brown & Vranesic, 2009). Previously, the instructor presented the technique by way of example. However, during the course transformation, the instructor used that same example as the basis of an in-class, inductive think-pair-share activity. First, time was spent demonstrating to students how to represent a four variable sum-of-products logic function as a Karnaugh map but students were not shown how to use the map to reduce the function (figure 1(a)). The students were then asked to form groups and discover a way to determine the minimum-cost circuit realization by grouping together adjacent entries in the map. Students were asked to share their solutions on the whiteboard as they finished, allowing the entire class to see the wide range of approaches (figure 1(b)). Rather than simply presenting the correct solution, time was spent reviewing the various mistakes made before finally discussing the correct answer. Activities such these proved to be very beneficial to student learning, as students were able to learn from their own mistakes and their classmates’ mistakes in real-time. Furthermore, such high-payoff activities required very little preparation time on the part of the instructor, but rather just a simple modification in approach. In addition, the instructor had no issues with covering the necessary or desired content in the course, as also evident by the final exam scores, since the final exam was the same across the semesters. When the instructor sensed being behind schedule, he simply compensated by doing fewer examples or activities.
Figure 1. Sample in class activity. a) Logic circuit minimization problem as presented to students. Students were asked to try to minimize the circuit before they were shown all of the necessary steps. b) Sampling of student responses shared and discussed during the in class activity.
3.2 Evaluation: Student and Instructor Interviews

Individual students were interviewed to assess their perspectives towards and valuation of the in-class active learning techniques, including perceived benefits and desirable professional behaviors. The assessment analyst talked with individual students before scheduled class meetings throughout the semester. Approximately 63% of the enrolled students were interviewed. Of those interviewed, approximately 54% were computer engineering majors, 41% were electrical engineering majors, and the remainder consisted of bioengineering majors. The question in Table 1 was posed to those interviewed.

<table>
<thead>
<tr>
<th>Table 1: Student Interview Question</th>
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<tbody>
<tr>
<td>Have the in-class activities the instructor is using this semester (i.e., the minute paper/muddy points question and problem solving with turn-to-your-neighbor) helped you to learn the lecture material?</td>
</tr>
</tbody>
</table>

The responses to this question were content-analyzed by two engineers using the coding scheme in Table 2, and all responses were double-coded. One of the coders was the assessment analyst for the project and the other was a senior-level engineering student. We calculated our first time inter-rater reliability, which indicated fair to good initial agreement, with Cohen’s κ = 0.69 (Norusis, 2005).

Our coding scheme in Table 2 was developed using a grounded, emergent qualitative analysis of the students’ responses (Neuendorf, 2002). Each category of the coding scheme is defined and described in Table 2. The categories at the top of the table pertain to benefits of or desirable student behaviors associated with the active learning techniques. The categories in our coding scheme are supported by the STEM education literature, in particular two noteworthy educators (Felder & Brent, 2016). The last two categories were associated with student perceptions as to why the techniques did not support their learning. To obtain instructor feedback and for triangulation purposes, the assessment analyst also interviewed the instructor at the end of the semester using a semi-structured interview protocol, with questions that aligned with the instructional and research goals (Boulmetis & Dutwin, 2011).

<table>
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<th>Table 2: Coding Scheme for Student Interview Responses</th>
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<tr>
<td>Category Description/Definition</td>
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<tr>
<td><strong>Benefits</strong></td>
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<tr>
<td>Promotes liveliness, energy, motivation, or engagement in class</td>
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<tr>
<td>Talk &amp; communication with peers or instructor; teamwork, group work, and community feeling with peers is promoted; other students’ thought processes or explanations are revealed; one’s own knowledge revealed via talking</td>
</tr>
<tr>
<td>Lecture amount is reduced</td>
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<tr>
<td>In-class problem solving, practice, application, activities; activity or active learning is good or working well</td>
</tr>
<tr>
<td>Real life applications shown</td>
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</tbody>
</table>
### Category Description/Definition | Code
--- | ---
Possible test scenarios revealed | TEST
Trying problems on one’s own; independent thought occurred | OWN
Repetition or reinforcement of material; memory aided; clarification of difficult items or any confusion | REP CLARIFY

### Points of Caution

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<th>Less</th>
<th>LEARN LESS</th>
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<tbody>
<tr>
<td>Difficult problems are hard to know how to solve upfront before formal presentation</td>
<td>HARD PROBLEMS</td>
</tr>
</tbody>
</table>

#### 3.3 Evaluation: Classroom Observation

Structured classroom observation using the COPUS (Classroom Observation Protocol for Undergraduate STEM) was also conducted to describe and assess instructional practices, student engagement and activity, and interactions in the classroom (Smith et al., 2013). The assessment analyst used the COPUS to observe four class sessions throughout the active-based fall 2016 semester. With the COPUS, the total class period was divided into a series of consecutive two-minute observation segments. For example, this 75-minute class period had 38 segments. In each segment, the activities of the students and instructor based upon the protocol were recorded. Thus, the percentage of segments containing activities such as student questions or responses, lecture, active problem solving, and instructor circulation among the student to assist, could be calculated. The assessment analyst had used the COPUS protocol in previous research and evaluation activities, having achieved inter-rater reliability scores with other analysts of $\kappa = 0.83$ and $\kappa = 0.96$, indicating strong agreement (Norusis, 2005).

#### 3.4 Evaluation: Student Performance Assessment

Finally, to directly assess the association between the use of the new active learning techniques and students’ performance, we ran an analysis of covariance using the final exam scores from the active (fall 2016) vs. the previous non-active sections of the course (spring 2015 & spring 2016) taught by the instructor. The cumulative GPA at the start of the course was used as the covariate, or control variable, in order to take historical academic performance into account. In addition, Cohen’s $d$ effect size was calculated to determine the practical significance of the difference. Values of $d$ below 0.50 are considered small, and values of 0.80 or above are large (Cohen, 1987; Sullivan & Feinn, 2012).

#### 4. Results

##### 4.1 Student and Instructor Interview Results

Based on the student interviews conducted, the very great majority of students interviewed (95%) indicated the active learning techniques used in class (i.e., the minute paper or think-pair-share) helped them to learn the lecture material. For those students who answered “no” to this question, one student indicated that he/she learns more from homework versus in-class activities,
and the other student indicated that he/she didn’t know how to solve the (difficult) problems upfront, leading to a distraction during class. Interestingly, both students were computer engineering students.

The majority of students interviewed (56%) indicated that the active learning techniques, and in particular the think-pair-share technique, were helpful to their learning because of the ability to talk to and communicate with their classmates or the instructor, sometimes making clear one’s own level of knowledge. Further, this team or group work created a community feeling and revealed students’ thought processes to one another. One third (32%) of students cited that it was the in-class problem solving, practice, application, or activity associated with the techniques that was helpful to their learning of the course content. One third (32%) also explained that the techniques were helpful to their learning because of the reinforcement or repetition, thereby aiding memory or clarifying difficult concepts. Finally, between 15% and 17% of students stated the techniques were helpful to learning due to the following benefits: 1) creating a lively in-class environment characterized by engagement and motivation, 2) the opportunity for independent thought and problem solving, and 3) reduction in the amount of lecture. The remaining categories in Table 2 were each mentioned by 5% or fewer of the students. Thus, to our great satisfaction, the students recognized the benefits of various professional behaviors, tendencies, skills, and mindsets, which the active learning techniques embodied or enabled.

The instructor was overwhelmingly pleased with the results and outcomes of the new active learning techniques that he used in class. He had never encountered as much interaction with students (in any course) as during the term in which he used the techniques. This included interaction during class as well as office hours. He believed that the active learning techniques enabled him to create an environment where students were comfortable asking questions and in which they were more open to communication with him. This was corroborated by the end-of-term teaching evaluation, in which 96% of respondents agreed or strongly agreed the instructor created an environment where they felt comfortable seeking assistance. In addition, he noticed an increase in attendance with the active techniques, and students did not arrive late (else possibly missing something important).

In the instructor’s assessment, the students participated in and engaged with the in-class activities, which was also observed by the assessment analyst, as discussed in the following section on the classroom observation. If the instructor noticed reluctance by students to begin talking during the TPS activities, he would pose everyday “icebreaker” questions to get students to start talking or circulate among the students who were not talking to generate conversation, and both methods were successful. The instructor observed that students made classroom collaborations and friendships based upon his use of the TPS activities during this first electrical/computer engineering course in the curriculum, and his prediction is that these small work groups will persist throughout the students’ undergraduate careers. This is a research question that we intend to pursue with this cohort of students.

Interestingly, in the instructor’s assessment, the minute-paper exercises were quite new to these students, and he believed the exercises demonstrated to students that he was doing something “different.” He noticed students’ satisfaction when he addressed their “muddy points” questions during the next class session, and he was actually quite surprised by the number of students who had the same question.
4.2 Classroom Observation Results

Upon combining the COPUS observation data from the four class sessions in which the new active-learning techniques were used, the classroom could be characterized as primarily a lecture-based classroom, with lecture occurring in 65% of the segments and verbal follow-up and feedback on activities occurring in 15%. However, the classroom also contained various forms of both individual and group-based active learning. Individual-based active learning occurred in 10% of the segments, and group-based active learning occurred in 3%-7% of the segments, depending on the type of group-based activity. Thus, the active learning exercises, which were typically think-pair-share activities, did not consume a large portion of the class time, but they nonetheless led to advantages from the students’ and instructor’s perspectives. In addition, the instructor was able to have one-on-one discussions with the students during the active learning (11% of segments) to directly monitor and assist. This was an outstanding use of instructional time because it enabled the instructor to directly support students in their problem solving and application efforts. The classroom environment was characterized by frequent student questions (28% of the segments). The class sessions were both active and interactive, with discussions occurring among students and between the students and the instructor.

4.2 Final Exam Results

To our added satisfaction, we uncovered a statistically significant difference in the final exam scores between the active and non-active sections of the course ($p=0.002$), as shown in Table 3, with about a nine-point increase during the active term compared to the two previous non-active terms. In addition, the effect size was medium at $d = 0.58$. The final exams were the same across the various semesters. The means shown in Table 3 are the adjusted means, in which the raw mean is adjusted using the mean of the control variable during the analysis of covariance (ANCOVA) procedure (Norusis, 2005).

\begin{table}[h]
\centering
\caption{Comparison of Final Exam Performance}
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Final Exam Score (/100) & Active & Non-Active & ANCOVA & Cohen's Effect & Active & Non-Active \\
\hline
Active: Fall 2016 & Adjusted Mean & $p$ & $d$ & Sample Size & & \\
Non-Active: Spring 2015 & 84.7 & 76.0 & 0.002 & 0.58 & 65 & 60 \\
& Spring 2016 & & & & & \\
\hline
\end{tabular}
\end{table}

5. Summary and Conclusions

When Rich Felder used in-class active and cooperative learning over 25 years ago in his chemical engineering courses, he encountered resistance to team homework as well as mixed responses on the helpfulness of in-class group work, as many other instructors since then have.
However, at that time, his experiences suggested to him that these instructional methods led to drastic improvements or overwhelmingly positive results with regard to grades, course evaluations, retention in chemical engineering, and a host of other important student outcomes (Felder, 1995). Unfortunately, lecture is still the predominant method of instruction in STEM courses, potentially due to concerns including preparation time, student acceptance, and content coverage. However, in our use of simple active learning in an introductory digital logic course, we were able to demonstrate highly positive student outcomes, including a high student acceptance rate and statistically better exam performance. Over 95% of the students interviewed indicated that the active learning techniques (i.e., the minute paper or think-pair-share) helped them to learn the lecture material. Furthermore, these simple active learning techniques are particularly accessible to new instructors, who are often time-constrained with limited teaching experience. For our future work, we plan to investigate these techniques in the next computer engineering course in the curriculum as well as determine the impact of these techniques on longer-term teamwork and student collaborations within computer engineering.

References


