Faculty Development and Patterns of Student Grouping in Flipped Classrooms Enabled by Personal Instrumentation

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Abstract

This paper presents new and extended research on the impact of integrated hand-held mobile technology used in support of experiment centric learning within flipped engineering classrooms. The settings reflect courses serving two levels of students and content (1st year students taking their first engineering course and 2nd – 4th year STEM majors from outside of ECE) who are learning circuit content. The key support for hand-held learning was the Analog Discovery Board (ADB); the major characteristics of the flipped classroom pedagogy were instructor prepared videos and reading materials used by students outside the classroom and classroom activities to support a decreased use of instructor lecture with an increase in student experimentation under instructor guidance. Variables of interest include examination of student and faculty prerequisites of learning, immediate self-reported learning, and potential long-term transferable outcomes. Observed and faculty reported changes in instructional practices are used to develop patterns of instructor change in pedagogy and supports needed to change instructional practices. The overall purpose of the paper is to present 1) patterns of faculty refinement of the pedagogy, 2) resulting changes in student outcomes; 3) four patterns of student group-learning processes evolving from the use of experiential learning in flipped classrooms; and 4) a discussion of how flipped classroom pedagogy and hands-on experimental practice promotes the hierarchy of student learning in groups. The paper concludes with a discussion of need for further research on faculty developmental patterns, how they are impacted by varied supports, and the need for more research on the role of student grouping and related outcomes.

Introduction

Instructional processes and supporting curriculum in higher education STEM settings are undergoing rapid reform; institutions are now striving to match the needs of incoming students, the expectations of business and industry, and the requirements of technological advances. New or refined pedagogy is now being implemented that reflects real-world problem solving; the emphasis in today's STEM classroom is no longer on learning facts but on learning how to obtain and work with facts across many different settings. Students are now learning to directly engage with facts and develop potential solutions, through instructional strategies that emphasize more hands on work, more visual stimulation, and more experiential/authentic learning (Brown, Hansen-Brown, & Conte, 2011). In this environment, learners are not simply consumers of knowledge, they socially create knowledge for themselves (Boticki, Hoic-Bozie, & Budiscak, 2009); students in STEM classes are now expected to be co-creators of knowledge and solutions. The development of new and improved technology, the decrease in cost of these devices, and the increase it their mobility is now making this a reality, one that can be achieved in most instructional settings. (Adrasheedi, Capretz, & Raza, 2016). According to Wagner (2005) the value of employing mobile technologies in the service of learning and teaching is both self-evident and unavoidable. This belief is supported by research showing that technology plays an active and successful role in providing hands-on experiment centered constructivist learning (Akhras & Self, 2000; Cheng, 2006; Newman & Gullie, 2009).

The inclusion of more hands-on experiment centered instruction, however, requires that courses move away from their traditional lecture based format to one that allows facilitated problem solving and practice of learning. Pedagogy that includes a flipped classroom approach meets this need by allowing students to learn key theoretical concepts autonomously, outside of class via online video lectures with supervised/guided practice occurring in the common meeting place (Bergmann and Sams, 2012). This type of classroom supports experimental learning while supporting and enhancing content-based learning, by offering more time for individualized practice and skills acquisition (Simba Information, 2011). Research on flipped classrooms in higher education STEM suggests that how to best format this new in-class practice, problem solving time is now a major area of focus within STEM education (Connor, Newman and Morris-Deyoe, 2013). This need is supported by studies showing that problem-based learning methods can be much more effective in fulfilling ABET 3a-k outcomes (Felder and Bren, 2003). Because curricula for engineering programs are already tightly packed (Bishop & Verleger, 2013), research on the use of flipped classrooms within STEM education is now focusing on efficient use of class time, that is, finding a way to offer/increase hands-on experiment centered instruction that will accommodate different learning styles, engage with different levels and types of problem-based/experiential learning, increase student-teacher interaction, and allow students to take responsibility for learning in a way that facilitates learner-building and learner-transfer of content and processes to other contexts (Arnold-Gaza, 2014). Ten years of research by the current authors has yielded positive patterns of implementing a flipped classroom as well as successful patterns of integrating hands-on real world problem solving. There is a lack of documented patterns, however, on how to sustain this process with new instructors and within new content. A key need has been identified for information on expected outcomes, needs, challenges, and barriers as a department attempts to sustain and transfer hands-on, experiment based learning.

At the same time, while administrators and faculty are grappling with the need for learners to be more autonomous in their learning, industry is requiring that STEM professionals be better prepared to function more collaboratively in real-world problem solving; potential employers want more and better problem solvers, but require that they be able to work together. Use of a constructivist, hands-on, experimental form of learning that takes place in group settings supports this need. Schunk (2012) summarized multiple group approaches to hands-on learning, noting grouping patterns, differentiation of tasks, variations in performance evaluation, and factors that should be addressed in the structure of instruction. Newman and Morris-Dayoe (2012) identified many of these factors as present when observing engineering classes that were implementing a flipped classroom approach and determined the presence of four dominant types of grouping patterns, along with benefits to learning and practice. A need for validation and refinement of these learning patterns was identified by the LESA ERC, yielding continued development of the pattern.

Purpose of the Paper

This paper presents new and extended research on the impact of integrated hand-held mobile technology used in support of experiment centric learning within flipped engineering classrooms. The settings reflect courses serving two levels of students and content (1st year students taking an intro to ECE course and 2nd – 4th year STEM majors from outside of ECE) who are learning circuit content. The key support for hand-held learning was the Analog Discovery Board (ADB); the major characteristics of the flipped classroom pedagogy were instructor prepared videos and reading materials used by students outside the classroom and a change of classroom activities to support a decreased use of instructor lecture with an increase in student experimentation under instructor guidance. Variables of interest include examination of student and faculty prerequisites of learning, immediate self-reported learning, and potential long-term transferable outcomes. In addition, observed and faculty reported changes in instructional practices are used to develop patterns of instructor change in pedagogy and supports needed to change instructional practices. Integrated with in the paper are discussions of: 1) patterns of faculty refinement of the pedagogy, 2) resulting changes in student outcomes; 3) four patterns of student group-learning processes evolving from the use of experiential learning in flipped classrooms; and 4) a discussion of how flipped classroom pedagogy and hands-on experimental practice promotes the hierarchy of student learning in groups.

Methodology

Multiple methods were used to document the outcomes of transfer of instruction to a new faculty member and to new content; these methods included multiple surveys of students (pre, post, topic specific and a comparison of results by term and class), interviews with faculty members, and continued observations of classrooms and selected student groups. Student surveys, distributed at the end of each course, addressed the role of the flipped classroom, the use of videos, compatibility of group learning, and perceptions of the use of the ADB as a support to experimental learning. Interviews with the instructor occurred both formally and informally, throughout the courses and at the end of the academic year. External observations also were conducted by the evaluator to document student reactions to instructional practices and to document fidelity of implementation. Presented in Appendix B is a summary of student demographics for each study. Information included within this report reflects an aggregation of these data. Presented in Appendix C are comparative tables for the first two studies.

Transfer to a New Instructor—Defining and Refining Instruction in Electronic Instrumentation

The Setting/Process

The course addressed in this phase of the paper is Electronic Instrumentation (EI), which is the main electronics course taken by students outside of Electrical and Computer Engineering. The course is offered each semester in two sections of approximately 60 students per section, one in the early morning and one in the late afternoon. The course was developed in the late 1990s as one of the few general engineering courses implementing Studio-Based pedagogy with benchtop instrumentation. Benchtop instruments were replaced by the Rensselaer Mobile Studio board several years later and then to flipped instruction in 2010, again using the Mobile Studio as student-owned personal instrumentation. The flipped environment evolved with basically the same instrumentation toolset through the fall of 2013, after which the Digilent Analog Discovery became the platform of choice and course development continued through the spring of 2015. During this period a single instructor developed and delivered the course[1].

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[1] Documentation of the process of continual development used to refine the implementation of the flipped classroom approach, student and faculty perceptions of the use of online video lectures, and the in-class activities used to support experiential learning are documented in a series of papers and book chapters. See Newman, D.L., Deyoe, M.M., Connor, K.A. and Lamendola, J (2014) "Flipping STEM learning: Impact on students' process of learning and

In the fall of 2015, an experienced instructor, unfamiliar with the flipped classroom approach for this content, volunteered to teach both sections of Electronic Instrumentation. This instructor continued to teach one section of the course in the spring of 2016 and is currently continuing in this role. This "new to the approach" instructor had taught the content previously but had not used a flipped classroom or hands-on experimental pedagogy for this content. This paper presents, compares, and discusses the findings resulting from use by a new instructor for fall 2015 and spring 2016 terms.

A total of 184 students were enrolled across the three sections of the course documenting "new" instructor use--two sections taught in the fall of 2015 (Section 1 n=53, Section 2 n=72), and one section in the spring of 2016 (n=59). Self-reported student information indicate that the majority of students were male (80%), reported ethnicity as White (72%), and used English as their primary language (92%). The primary student majors included mechanical engineering and aeronautical engineering in their 2nd through 4th year undergraduates.

Evaluators noted and the instructor self-reported a developing approach to initiating a flipped pedagogy that began by blending both lecture and hands-on work with increasing use of external video lectures and increasing experimental problem solving. Instructional practices in the fall tended to use mini lectures supported by hands-on experimentation. Instructional practices in the spring of 2016 decreased use of mini-lectures, increased out of class preparation, and utilized more in-class hands-on experimentation using the AD Board. Evaluators also noted a change in instructor student interactions. In first uses of experimental flipped tools, students tended to ask more "how" questions but gradually shifted to "why" questions. In addition, the instructor gradually shifted student discussion to include more encouragement of exploration and justification and less direct technical/expert response. Students' reported use of instructional techniques validated those observed by evaluators and reported by the instructor. Survey responses, and student interviews noted an increase in instructor use of hands-on experimental learning within the classroom supported by use of the AD-Board as well as more real-world examples. Instructor demonstration of use, both in how to use the tool and in exemplifying discussions of real world problems increased from "occasionally" to "often". Similarly, independent use in class increased from "occasionally" to "occasionally/often" as did cooperative work with 2 or more peers (a change from "occasionally" to "often"). Work with one peer in the classroom remained at "most of the time". Use of ADB as a support to autonomous learning, either as a required effort via homework or as a volunteer effort, remained the same for independent use; student reported only "rare" or "occasional" out-of-class use by themselves. Outside work with a peer decreased from "occasional" use to "rare" use. Efforts with larger groups of students continued at the "rare" or "occasional". This may indicate that outside use is being used more in multi-student discussions and trials and less for solo-tinkering.

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faculty instructional activities" in S. Keengwe, G. Onchwari & J. Oigara, (Eds) Promoting active learning through a flipped classroom model (pp. 113-131) Hershey, PA: IGI Global for a summary of the findings.

Table 1
Transfer to New Instructor
Student Reported Use of AD Board/Experimental Learning

Instructional Modality*	**Instructional Setting Current Median Response (initial use response)**			
	In Class/Lab		**As Part of Homework**	
	First use	Refined Use	First Use	Refined Use
Instructor Demonstration	Occasionally	Often (increase)	---	---
Cooperatively with 1 peer	Most of the time	Most of the time (same)	Occasionally	Rarely (decrease)
Cooperative with 2 or more peers	Occasionally	Often (increase)	Rarely-Occasionally	Rarely-Occasionally (same)
Independently	Occasionally	Occasionally/Often (increase)	Rarely-Occasionally	Rarely-Occasionally (same)

*Responses based on a 4 point scale of Rarely, Occasionally, Often, Most of the Time, n=69

Results of Transfer to a New Instructor and Continued Refinement

How the method helped learning. Students reported positive impact of the instructional process on key indicators of pre-requisites to learning, immediate classroom learning, and long-term learning. <u>Pre-requisites to learning</u> that were influenced by the experimental hands-on approach included student confidence and student perceptions of importance of the information/skill. Important changes in confidence reflected ability to learn class specific material; this included confidence in completing the required lab work (after working with the ADB) (61%), and overall confidence in learning and using the course material (72%). These responses were generally 5 percentage points lower than reported during initial use; examination of the data indicate that many of the lower responses came from the second session in the fall term which had 72 students. Approximately three fourths of the students (72%) reported that use of the ADB helped them to see the importance of the material they were learning. This change is an increase of 13 percentage points over the initial implementation pilot. When queried, many cited the examples given by the instructor during demonstrations and their ability to try out the process and work toward different solutions. Students who had limited prior experience with lab equipment, experimental learning, and problem solving indicated that the integrated use of these teaching/learning tools increased their interest and motivation, noting that their self confidence in ability to be successful in the course had increased.

Self-reported <u>immediate learning outcomes</u> followed a similar pattern. Students identified a direct relationship between use of experimental/ADB based learning opportunities and direct course content. Overall, 69% of the students reported a positive outcome for learning how AC/DC circuits are used in practical applications (a decrease of 9 percentage points from initial trial, again most of the lower scores from the larger section), but 72% (71% initial trial) reported that their overall knowledge in the course had improved because of the use (e.g.*" It helped me visually see what is happening with each circuit in real time", " "helped me understanding how circuits work. . . to understand what was happening in the circuit",* and *"made it super easy to* *learn circuit content in a clear, applicable way*”). When queried further students noted that the ability to tryout different types of problems helped them move the theory to practice (e.g. “*[Use] helped solidify the concepts by showing them actually working in a physical system and also by showing what happened when something went wrong*”), and 71% noted that they “thought about problems in graphical/pictorial ways” based on their work when they worked with practical applications*(e.g. “It was helpful to see all the graphs we learned about”, “[I] better visually understood how to make circuits and follow the processes.”, and “[It] provided a visual representation of what a circuit is doing.”)*. Similar to the pilot trial, approximately two thirds of the students (62% compared to 66% at pilot) reported that this work helped them develop skills in problem solving within the course content. A further indicator of students perceived professional learning that resulted from the process of instruction was students’ report that were not just using the process to improve grades (41%) or only for recall (63%). These latter response are slightly lower (approximately 8 percentage points) than initial pilot responses Sample student responses are: “*I’ve been able to change input systems on the fly and get a clear view of the resultant output*”, and *“[Use] provided a hands on experience for circuits that are not intuitive for me*”.

Indicators of <u>long-term outcomes</u> that are positive characteristics of a well-prepared professional engineer also were noted. Students noted that the hands-on experimental group work make them better prepared to work collaboratively with others (47%) and helped them to develop self-direction and self-responsibility (58%). These responses represent a marked decrease in self-reported long term outcomes of 24 percentage points for collaborative work and 10 points for self-direction and responsibility. This was accompanied by increases in developing their general problem-solving skills (current 52%; pilot 63%), applying the information learned in the course to new problems (current 53%; pilot 59%) and in transferring that information to problems outside the course (current 44%; 53%). Students noted that their ability to work with others included better communication and planning skills were influenced by the use of both hands-on and group problem solving, and noted that they were more confident and interested in applying their knowledge and skills to real world problems. Student responses included the following “*Use of [ADB] every day in class [for] the integration . . . made getting the technical stuff easy”, “By remembering the picture of the circuit I’ve built, I did relatively well on tests,”* and *“Physically building circuits and analyzing them is how I learn best. AD allowed for that*”.

Facilitators, Barriers, and Needs for Future Replication

When queried about facilitators to transition, the new instructor indicated that having an experienced instructor available for consultation is extremely valuable; it was beneficial to have someone to discuss means and methods with. The instructor also noted that it is difficult to institute a completely flipped classroom in one semester, especially for an existing class, noting that this is not unexpected as most instructors make sequential unit changes in practice. It was recommended that future implementers plan for a sequential continuous implementation (e.g. though the format works best when fully implemented, it will take refinement over multiple semesters.) Class size may be a challenging factor during intimal implementation of a student-centered approach, but that over-time, as instructional practices are refined and the instructor’s confidence level and experience increases, class size is not a problem. Other co-occurring factors such as the specific TAs assigned and the training provided by the professor to those TAs may have greater influence on student comfort level with hands-on use (e.g. "[I] *learned the importance of training the TAs on their roles, and the importance of having outgoing TAs. Hiring undergraduates to be in the classroom was a critical way to compensate for TAs that may be new to the [method] or not comfortable working one on one with undergraduates."*)

Transfer to a New Course—Introducing and Refining Use in an Introductory Course

The Setting/Process

The second course in this study is a new first year course (Introduction to Electrical, Computer, and Systems Engineering) for ECE majors piloted in one section of about 30 students in fall 2015 and refined spring 2016. No specific pre-requisites are assumed for these students other than the general level of preparation expected of first year engineering students. This course is intended to be the first discipline-requirement for electrical and computer engineering students, its major focus is on preparation of students for the first part of several courses including circuits, electronics, signals & systems, electromagnetics, digital logic and embedded systems. For most students outside of ECE (except for mechatronics and controls students) a key objective is preparation for design course projects. The developer of the new introductory course served as the original developer of the flipped course described in the previous section; hence, many of the successful instructional techniques developed in that course were adapted and then transferred as part of the initial pilot. This includes: 1) use of online video lectures and problems (associated with specific class days rather than addressing broader, cross-cutting topics used for EI), and 2) dedication of class time to hands-on activities stressing experimentation (single day, focused experiments, each with an LMS-based problem set, rather than the much smaller number of multi-day experiments in EI). A more in-depth description of the supporting instructional activities may be found in Appendix A.

As noted, the instructor for this course had prior experience with the content, with hands-on experimental learning, and with flipping a classroom. Participation in development of the new course was voluntary as was continued refinement. The instructor continues to teach the course during current terms.

A total of 52 students were enrolled in two sections of Intro to ECSE (one section in the fall--pilot implementation and one section in the spring--refinement). Self-reported student information indicate that the majority were male (92%); 41% of the students self-reported their ethnicity as White, 37% as Asian, and 15% as a classified minority group. Of these students 44% did not use English as their primary language. The majority of the students in the class were first year under-graduates with a major in either electrical engineering or computer and systems engineering.

Students' responses concurred with evaluator observations and faculty reports of extensive, integrated use of experiment centric learning supported by the ADB in a flipped classroom environment. During the second, refined semester, almost all students (92%) reported that they experienced the ADB in an experiential setting at least 10 times during the semester. In addition, 84% of the students reported that they had access to the ADB as part of homework at least 10 times per term.

Table 2
Student Reported Use of AD Board
in Varied Instructional Modalities

Instructional Modality	**% Students reporting 10+ uses per term**
Location/Setting of Use*	
In integrated class/lab setting	92
As part of homework assignment	84
Method of Use*	
Instructor Demonstration	55
Cooperatively with a peer	74
Independently	63

**selection of multiple responses allowed*

The method of use also demonstrated variability and flexibility of integration into teaching and learning for these students; 74% reported using the device cooperatively with a peer and 63% independently at least 10+ times per term (e.g. "*I got most of the experiments done at home," "did not have to come to lab to work", "helped me understand how real-life circuits react,"* and, *"I was able to do experiments at home and learn more about the subject matter outside of class*"). Use of the ADB as part of instructor demonstration was reported but further inquiry revealed two specific intention purposes. Student comments indicated while demonstrations on how to use the device were used and were helpful (and more were needed), demonstrations of use in solving real world problems increased with implementation and that students had a growing appreciation of this "example of use" within their learning process. It was noted that student in the refined introductory classes continued to show a need for demonstrations of initial set up noting that these presentations decreased their anxiety related to learning the "how" of engineering. As the course continued, however, students noted less need for continued "how to" demonstrations and wanted more "why" problem-solving demonstrations with subsequent "tinkering" time. Slight increases in desire for real-world problem solving and time for "tinkering" were also noted as the course was refined. Many students reported that this balanced instructor demonstration led to greater self-confidence in ability to succeed in engineering curriculum and increased their interest in taking advanced courses. The instructor also noted an increased level of questioning as more practice was experienced.

Results of Transfer to a New Course and Refinement of Transfer

How the method helped learning. Students in the introductory class reported positive impact of the instructional process on key indicators of *pre-requisites to learning*, immediate classroom learning, and long-term learning but in slightly different patterns than found for the EI class. <u>Pre-requisites to learning</u> for introductory students that were influenced by the experimental hands-on flipped classroom approach continued to include student confidence; for introductory engineering students, confidence in their ability to learn the content was impacted the most; 82% of the introductory students reported that use of hands-on work increased their confidence in learning general content. One student responded "*I could perform my own mini-experiments at home using the tools with the knowledge from class*." Students also reported that involvement in hands-on work increased their perception of experimental problem-solving as important in preparing to be an engineer (84%). Students' increase in confidence and importance of learning general content responses to need to learn specific content. Approximately two-thirds of the introductory level students noted that the hands-on experimental approach allowed through the flipped classroom increased their motivation (64%) and interest (61%) to learn course specific content and their confidence in carrying out course specific assignments (66%).

A similar pattern was found for indicators of <u>immediate learning.</u> Students in the introductory class overwhelmingly reported that use of hands-on experimental learning increased their knowledge (97%), and agreed the process helped them in leaning how AC/DC circuits are used in a practical application (87%). Specific student examples included "*designing experiments," "preparing for the next class"*, and "*helped to debug my work*". Approximately three fourths of these students also noted that they had developed greater problem solving skills within the specific content (76%) and that they now tended to think about problems and problem-solving in a graphical/pictorial way that was related to practice (76%) (e.g. *"[I] can visualize how certain circuits arrangements worked*"; and *"[through visualizing] I now understand how many of the parts work together. . . I used this on the test)"*. Overall introductory students noted that the use of hands-on experimental work done in the class helped them to recall content (79%) and to a lesser degree (50%) helped to increase their grade. These response are similar to those of advanced students in the EI classroom; however, the latter students reported more focus on content than on general learning.

Indicators of the beginning <u>long-term learning outcomes</u> also were noted for the introductory students who piloted the hands-on experimental approach available through a flipped classroom. The responses of students enrolled in this class generally provided higher indicators of all of the long-term indicators than did advanced students. This included noting an impact on their ability to work with others (89%), to apply knowledge to new problems within the course (71%), to transfer knowledge to problems outside the course (76%) (e.g. "*I learned skills that helped me contribute to a hardware project outside of this course*."), and in developing different ways of solving problems (59%). Overall, these students reported that they now had increased their attitudes of self-direction and self-responsibility (74%). When queried, students noted that experimenting with others in the classroom, under the guidance of the instructor, gave them greater confidence in their overall ability and the more they experimented the more comfortable they were in learning new content and in their future ability to solve more advanced problems. Sample responses from students include *"Can do my labs better"; "use it for the test"; "it motivates me to do more experiments at home",* and *"[I am] more confident in following classes*".

Facilitators, Barriers, and Needs for Future Replication

Faculty, students, and evaluators noted several activities that contributed to the transfer of flipped classroom pedagogy in this setting. Two key facilitators were related to experience—the experience of the developing instructor and the experience of the department/institution. The instructor in this setting had successfully transformed the pedagogy of another class; this experience allowed the instructor to identify potential barriers and develop methods of efficiently and effectively transferring content and practices as applicable. The department/institutions past experience with the process of changing and evaluating engineering education provided administrative support as well as general faculty support. Personal, peer, and institutional support were seen a very beneficial to the planning, initial implementation, and long-term sustainability of the new course in its present format. In addition to these broader facilitators, multiple course specific supports were noted. These include: 1) a pre-survey of students' backgrounds, interests, and knowledge of basic concepts that can be used to individualize or sequence instruction; 2) constant access to blended learning activities that allow students choice in when and where to use on-line materials further supporting individual and group learning styles; 3) immediate immersion via one day projects that use hands-on, experimental learning thereby giving students confidence in their ability to learn by doing; 4) accessibility of instructor and TAs within the classroom and through external after-hours technology (e.g. open shop, office hours, online, piazza, email, camera phones, etc.) and 5) a culminating project that reinforces and enhances students' confidence and skills in problem solving. Additional information on these tools and approaches may be found in Appendix A.

Changes Resulting in Group Practices and Learning

As the project enhanced and increased use of student-centered, hands-on learning via a flipped classroom, a greater emphasis was placed on in-class teamwork to design, develop, and solve problems. One early outcome of this process was the unexpected development of four types of group interactions that reflected problem solving techniques. External evaluators first noted and documented this shift in student-student interactions during ongoing observations of student-instructor activities (Newman & Morris-Deyoe, March, 2012). These interaction types included: 1) a "traditional partnership," in which the students moved toward efficiency and completion of each assignment; 2) a "formal partnership," in which there was a clear leader to guide the process and clarify, summarize, and monitor time on task and sub-partner(s) were minimally involved; 3) an "assigned task partnership," in which each partner worked on a task in silo and used the instructor as the expert to check their work (gradually one partner took on more of a leadership role); and 4) the "collaborative partnership," which used a peer-regulated process in which everyone checked in with each other, questions and comments were shared and the partnership self-monitored their progress. Observations of the EI classroom before the flipped pedagogy was fully implemented indicated at each of these four types were present approximately 25% of the time.

As part of the external evaluation process, observers continued to group interactions resulting in over 90 semester long observations of random and selected groupings of students. Ethnographic and social analysis of these observations resulted in refined and clarified descriptions of the four types of group interactions within the flipped EI classrooms. Evaluators also were able to note how the use of flipped classroom pedagogy supported shifts in the dynamics of these groups that supported shared problem solving Following is a brief description of the revised four groups.

Autocratic Leader: Group one, the "traditional partnership" has been redefined to "autonomous (autocratic) leader". Within this grouping, one partner takes on sole leadership of the group, completing the project "so that it will be done right". In doing so, other partners are either excluded from the process by the leader, or willingly step aside. The major goal of this partnership is to most efficiently complete lab work and "get the grade". An example of this type of group work was noted in a triad where one student was actively working on the assignment, attaching leads, taking notes, and silently following required procedure. A second group member was present but communicating via text and computer. A third group member, watching the first member's work, attempted to ask "why" questions and follow development of steps and outcomes with no responses from the team leader and a comment of "just let him get it done" from the second member. (Note, subsequent observation notes indicated that the third member left the group and went to another group to ask the questions, returning several times with the answers, which were ignored by members one and two. Member three eventually left the group permanently.) Observations of the EI classroom, as taught by the experienced instructor, now indicates that this type of group interaction occurs approximately 10% of the time.

Directive Leader: The second group "formal partnership" has been redefined to reflect "directive leadership" and has characteristics of the "silo" effect found in the former group three. In this revised type grouping, one member of the group is immediately designated as "leader", frequently self-selected. This person immediately lays out the tasks, delegates them to the other(s) team member(s) and monitors the flow of tasks. There is little interaction between members as the tasks are performed, if questions arise, the members go to the instructor or TA to receive assistance and do not share needs with other team members. At the completion of all tasks, the team leader or a delegated team member integrates all tasks into a whole. The major goal of this group structure appears to be "shared efficiency". This type of group work was noted in both dyad and triad work. The "leader" had pre-read the assignment (others had skimmed or listened only to what was required); when the group met the leader quickly outlined all tasks, noted what was needed to accomplish each and assigned the varied steps/procedures. Each group member then separately accomplished the task assigned, without asking questions of the other partner(s) and the results were aggregated into a "whole". The only questioning that occurred was when outcomes from one step did not match the input or pattern of a follow-up step. No effort was made to re-check or self-reflect on the work, instead the instructor or the TA was asked to "tell us what we did wrong here". Observations of the EI classroom, as taught by the experienced instructor, now indicates that this type of group interaction occurs approximately 20% of the time.

Cooperative Group: The third group, "assigned task" partnership has been redefined to reflect "cooperative task grouping". In this group, initial leadership is shared; the team as a group delineates the tasks each takes on after brief discussion and the work is done "in silo". This group differs, however, from group 2 in that answers are shared as they are developed and if incongruities are noted, the students in the separate silos review the other's work. If the discrepancy is not resolved, one member will approach the instructor or TA for help and then return to the other member and share the response. Over time, a "leader" frequently emerges from continued interactions, but the leader takes on a more "suggestive style" of interaction, asking for the other's opinion and encouraging involvement within the proscribed steps. The major goal of this group appears to be "efficiency but let's get it right". An example of this type of group interaction generally occurs when all members of the team have prepared for the lab (in later sessions, the group self-assigns everyone to read or view materials before lab—to be ready); in the initial meeting, someone lays out or reviews the tasks and asks "who wants to do what". After a quick review, the members separate, conduct the work but at the end of each stage they ask each other to "double-check" the findings or transition steps. The work is "summarized" as the tasks are conducted, at least in draft form, and questions are addressed as needed. When questions over math or leads occurred, only one member asked the TA questions, the TA addressed that one person's needs, however, the questioner returned to the group or re-explained the solution to the other partner after the TA left. The group cooperated in completing the work, sharing only when differences were noted. Observations of the EI classroom, as taught by the experienced instructor, now indicates that this type of group interaction occurs approximately 30% of the time.

Collaborative Partnership: The fourth group, "collaborative partnership", continued to exhibit the characteristics of collaborative learning. The team members had no real leader, frequently tasks were rotated so that everyone, over time had all leadership experiences. This team, sometimes prepared ahead of time, sometimes prepared after the fact, jointly reviewed and identified all steps and stages and if needed inserted sub-steps or stages as "double-checks". The team members usually conducted all, concurrently, the major stages/steps of the process and continually checked each other's responses. If discrepancies are found, the team works together to find the error. If a solution is not found, the group as a whole requests assistance, and all members are present for and responding to the TA and/or instructor assistance. The group strives to move forward but brings everyone with them as they complete the task. While tasks may be silos, partners are working in the same or parallel silos as the project is completed. Frequently the group tries out or discovers an alternative approach to the solution as they progress. If this appears to be an unexpected/unexplained outcome the group will often check with other groups to see if they got a "similar" response or with the instructor to see "can we do this? Is this possible?" The interactions within this group are frequent, may be "loud", but also seem to be creating shared problem-solving and a long-term dynamic. In many instances, these team members were heard to mention shared out-of-class work on further exploration of class projects. The main purpose of this group appears to be "let's figure this out and see what we can get". While there is a need for efficiency, there is a stronger need to jointly explore the task and develop a shared solution. An example of this type of team is often found when group members each have their own tools but also have a drive to explore answers and welcome unexpected results. Lab assignments are not viewed as "must do" projects but as opportunities to try out equipment or learn new things. Curious members from other groups frequently gravitate toward this type of group, especially if they are unhappy members of groups one and two (e.g. that group does not meet their learning style). Members of group four are generally welcoming of others questioning and frequently interrupt their own work to explain to another group what they found. This group does have one major drawback for its members, however, they frequently are not good at "efficiency" in completing the task and need assistance or guidance from the instructor on how to "move on" and/or "leave some one behind". It is important in this situation for the instructor/TA to know when to provide independent assistance to a group member. Observations of the EI classroom, as taught by the experienced instructor, now indicates that this type of group interaction occurs approximately 40% of the time.

Student Perceptions of Group Work

As part of this project, the evaluators not only monitored group activities each term but also collected student perception of the process and value of work. The data presented below were gathered during the spring 2016 semester from students in the section of Electronic

Instrumentation taught by the instructor with multiple years of experience with flipped classrooms, use of experiment centered instruction and hand-held devices.

Findings are primarily derived from surveys (n=42), administered to students at the end of the course. Respondents were non-EE majors, predominantly White (68%) or Asian (27%) and male (71%). The majority of students were third or fourth year undergraduates studying mechanical or dual aeronautical and mechanical engineering. 14% of students' primary language was a language other than English.

Overall, data from the post-surveys verified the implementation of the four group learning structure. As noted in Table 3, the role of the instructor was perceived as that of setting the context for the hands-on learning sitting. Perceptions of decision-making on the remaining tasks reflect the four types of group interactions styles. The first group, Autocratic Learner, may be identified decisions as being "decided by self" or "team leader". Members of the second group, "Directive Leader", is exemplified by decisions primarily made by "team leader" or "a member of my team". The third group, Cooperative, can be identified by responses to "member of my team" or "my team as a group". The overwhelming responses to decision-maker for the Collaborative Partnership group was "my team as a whole". A comparison of these data with those identified in the 2012 report indicate a growing response for the "my team as a whole" category.

Table 3
Primary Decision-Maker by Activity*

Activities	Decision-maker					
	Instructor	TAs	Team Leader	A member of my team	My team as a group	Decided myself
Setting the content of the lab.	85	3	0	0	8	0
Establishing short-term goals.	13	3	10	5	50	18
Dividing the tasks.	5	0	5	15	70	3
Documenting progress.	3	0	5	18	65	3
Deciding to move on to the next task.	0	0	10	15	60	13
Completing the lab write-ups.	0	0	5	15	75	5

**Numbers represent the percent of students who selected the decision-maker for each activity.*

Further perceptions noted by students who have experienced a flipped classroom approach to group work are presented in Table 4. Approximately 60% of the students believe that skills in group work will be valued by future employees and approximately half (49%) indicate that learning to work in groups is part of their professional preparation and to learn to share and collaborate (51%). These numbers indicated that faculty may need to discuss the professional status of group work as part of classroom learning exercises that relate to the real world. Faculty and TAs also may need support in identifying and working with students who are participants in a non-functioning group identity; only 57% of the students were at ease with their partner while only 54% expressed support from group members. While these latter responses may reflect students who are comfortably placed in autocratic or directive groups, instructors need to tools to assist these and miss-placed students in settings that will enhance their learning motivation, process, and outcomes. Only 21% of the respondents did not want to participate in flipped experiment centered instruction in the future.

Table 4
General Perceptions of Group Learning*

Statements	(n=42)
I was at ease when working with my lab partner.	57
In the future, I would prefer to take courses using instructor-directed learning instead of learning in a group.	21
Taking a course using group work was more difficult than an instructor-directed course.	24
I prefer to set my own learning tasks and goals.	24
Using group work has provided me with better opportunity to learn content.	24
Group work has provided me with more opportunity to receive feedback.	29
Interpersonal skills I developed through group work are valued by companies I am likely to work for.	60
Participation in a group situation in this course was relevant to my professional learning.	49
Group participation allowed me to learn to work with others to collaborate and share ideas.	51
Working in groups helped me to learn content and concepts.	34
Topics covered during group work were just as relevant/useful as the ones covered alone.	32
I received support from group members when I implemented something I learned or discussed during group meetings.	54
My understanding of the topic increased as a result of participation in group learning.	39

**Percentages include students who responded "Agree" and "Strongly Agree" on a 6-point Likert-type scale.*

Overall, these findings verify that students enrolled in a flipped classroom were involved in group learning. The findings of specific decision making activities, when viewed by type of group indicated that the variations of grouping type exist and that an instructor in a flipped classroom must be prepared to work with multiple group formations. Students' perceptions of the benefits of group learning were found to be related to the type of group formation and the students' expectations of the reason for "grouping". Students noted specific benefits to collaborative learning including increased opportunity to share ideas/tasks and communicate, and increased understanding of concepts as a result of communicating with their partners. Data from the surveys and open-ended items indicated that students had a high comfort level and previous experience working and learning in group settings; however, their lack of experience and comfort level in learning without any teacher-directed instruction remained a prevalent factor related to their learning.

Conclusions and Implications for Flipping Classrooms

This paper addressed changes that may result from the implementation and sustainability of a flipped classroom within engineering education. While earlier papers addressed the initial outcomes, the findings presented here indicate that there are specific outcomes that occur when hands-on experiment centered approaches are transferred to new classes, new instructors, and groups of students. The findings provide useful information on ways to improve transfer of flipped classroom pedagogy when blended with hands-on experiment centric learning in both new classes and to new instructors. In both settings, flipped pedagogy supports such as homework problems available from day one, the use of technological support for improved communication, the integrated implementation of the ADB or similar mobile devices available in and out of class support the enhanced and refined student learning. Further, findings of report offer expected patterns of implementation, including barriers and needed supports for new uses. Instructors who are new to the approach can now make transitional plans that reflect initial piloting as well as the need for refinement and expansion. These faculty can also expect that students will be better served by this approach. The use of more in-class hands-on learning allows instructors to better recognize students having a particular problem that is unnecessarily holding them back using differentiated, personalized instructional steps[2]. As a result, faculty, departments, and institutions may expect increased retention of students as well as improved skill indicators.

While the findings of this and previous studies indicate that the use of flipped classroom pedagogy is beneficial and supportive of engineering education, further research is needed. This includes documentation of long-term and transferable outcomes, evidence based impacts on student cognitive outcomes, efficient and cost effective means of integrating technology into the entire process of learning, and variations that may occur due to student differences and faculty ease of learning.

The use of hands-on experimental learning, the ability to problem solve, and the need to work in groups have been identified as key constructs within 21st Century STEM learning. Use of flipped classroom pedagogy supports the inclusion of these constructs; the use of experiment centric, student centered learning also supports the inclusion of these constructs. Studies such as these that integrate the two approaches continue to reinforce the value of these approaches and provide guidance for continued and new research on engineering education.

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[2] For example, a significant number of students in both courses have had little experience with protoboards. The scale of this issue was first identified by a new instructor in the first year course. The experienced instructor had missed it because he was working on topics that he thought were of higher priority but, struggling with protoboards was causing many students to get behind during the first two weeks and they were not able to quickly catch up. The report templates were also developed by the new instructor.

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Appendix A

Description of Introduction to Electrical, Computer, and Systems Engineering

The second course in this study is a new first year course (Introduction to Electrical, Computer, and Systems Engineering) for ECE majors piloted in one section of about 30 students in fall 2015 and spring 2016. While organized in a similar manner to Electronic Instrumentation (e.g. flipped, with online video lectures and problem sets and class time nearly fully dedicated to hands-on activities stressing experimentation) there are a few significant differences, most of which are based on lessons learned from Electronic Instrumentation. Key changes include a large number of single day, focused experiments, each with an LMS-based problem set, rather than the much smaller number of multi-day experiments in EI. Most videos and readings are associated with specific class days rather than addressing broader, cross-cutting topics. No specific pre-requisites are assumed, only the general level of preparation expected of first year engineering students. This course is also assumed to be the first disciplinary requirement for electrical and computer engineering students and thus there is a major focus on preparing students for the first part of several courses including circuits, electronics, signals & systems, electromagnetics, digital logic and embedded systems. Except for mechatronics and controls students, for most students outside of ECE, EI is the only circuits, electronics, instrumentation course they will every take, so the focus is almost entirely on preparing students for their design course projects

The development of this new course had four sources of inspiration. First, while teaching Electronic Instrumentation, it was noticed by more than one instructor that most activities would be of benefit to and were not presently available to ECE students. Second, some outstanding new first year courses were being created by talented faculty at US universities, based on the application of personal instrumentation like National Instruments' myDAQ and Digilent's Analog Discovery. Third, the first general engineering course for all majors was seen by both faculty and students as not serving the needs of ECE students largely because of its emphasis on Engineering Statics. Fourth, the transition of new students from high school to college was not being addressed directly. A corollary to the fourth item is the desire to incorporate real engineering content into the high school learning experience. This is one of the advantages of having faculty who are strongly committed to and involved in K-12 outreach, especially in middle and high school, as are both instructors in Electronic Instrumentation. Educational materials of use in high schools are the inevitable result of a focus on what makes content appropriate for this transition.

The pilot versions of this new course, and the present course now required of all ECE students, have the same general structure as Electronic Instrumentation, with its blend of learning experiences (e.g. flipped class with online videos to be viewed at home, very short discussions and extensive hands-on learning experiences in class, the use of personal instrumentation (Analog Discovery in this case) so that students can work on all course activities without spatial and temporal limitations, the use of piazza to make it possible to obtain answers to questions 24/7, open shop times to permit students with weaker backgrounds time to catch up, online problem sets to prepare for in-class activities completed through the campus LMS, the use of a readily available SPICE program for circuit simulation, required attendance to facilitate teamwork, having standard formula sheets available for quizzes rather than requiring students to create their own crib sheets, and the use of Matlab for data analysis and system control. Significant changes from Electronic Instrumentation include using Linear's LT-Spice rather than OrCAD's PSpice; 22 one-day experiments and three days dedicated to projects rather than experiments (8) and projects (4), all of which are multi-day activities; more and shorter problem sets; nearly all course materials created to be associated with specific days rather than addressing cross-cutting topics; the use of a general purpose commercial parts (from Digilent or Analog Devices) rather than a specially designed and, therefore, focused parts kit; and more flexible ad-hoc teams rather than requiring students to work with the same partners throughout the term.

During the two terms in which the course was piloted and continuing now that it has permanent status, the student learning experience has been changed on almost a weekly basis. Most changes are minor (e.g. slightly different parts selection for experiments) but many have been quite significant. Some features were also phased in, including, for example, the attendance and participation requirements. The in-class activity checklist requiring instructor or TA signatures was also phased in each term, with the requirements started early in each semester.

Some changes also occurred because the course depends so much on the capabilities of the hardware and software used. The Analog Discovery boards can be controlled using both Python and Matlab. However, what works and what does not changed significantly between Analog Discovery versions 1 and 2. Thus, several activities had to be dropped and replaced. This was less of a problem than it might have been because all first year ECE students learn Python in their first Computer Science course so it was possible to address the interface between hardware and software by changing some activities from Matlab to Python-based. Fewer students than anticipated had some experience working with protoboards, so some simple exercises were added to the first week of classes before introducing the full capabilities of Analog Discovery.

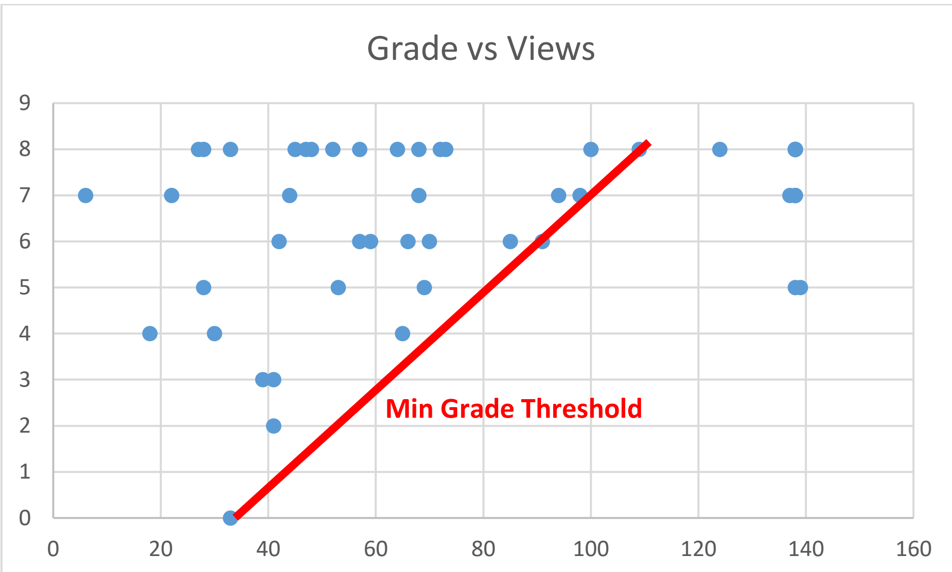
Most experiments were either too long or too short for the 110 minute class time, so some the activities were somewhat redistributed. In addition, report templates were developed to provide more structure. Getting students in Electronic Instrumentation to understand the required report structure required a lot of effort, so it was thought that the use of templates would make the process work much better, especially with first year students.

The quiz structure was also changed to help students prepare better by moving 20-25% of the questions online using LMS. These questions are released about three days before the in-class quiz and students are permitted an unlimited number of attempts to complete them. The questions focus on competency at the lowest Blooms' levels. For example, students are asked to solve straight forward two-resistor Voltage Divider problems where all resistances and the DC voltage source are clearly specified. In class, they are asked to address more complex configurations requiring some simplification to reduce to a two-resistor case or to recognize that the circuit of interest is a voltage divider and then set up equations to solve for some unknown parameter like the internal resistance of a battery. All daily activities (experiments, videos, projects, think-pair-share questions to facilitate teamwork and preparation, past quizzes, etc.) are posted and available from day one each semester. The two exceptions have been the daily problem sets and quizzes. To encourage students to work ahead when possible, all problem sets are now also available on day one, so some of the top students (in talent and motivation) complete all problem sets in the first month.

One of the first activities students complete is a short survey on their background, interests and knowledge of some basic concepts. This has been very useful in understanding what can work with these new university students. Roughly, about 25% of students have a lot of advanced placement and transfer courses, often with total credits sufficient for sophomore status. About 25% have no AP at all. The remainder have 2-4 technical courses like Calculus I & II and Physics I. Thus, there is no way to design a one-size-fits-all course. The personalized instruction possible with the blend of learning activities utilized in this course has been very responsive to the needs of all students, except possibly those who believe that a first year course is beneath them. Thus far, those students are very rare and do not perform well.

The focus on Experiment Centric Pedagogy requires that students rapidly develop their skills as experimenters. This has also worked out well in spite of the fact that many students feel like they are living at the business end of a fire hose during the first few weeks of the term. The help provided in class, during open shop/office hours and online through piazza and email get almost every past the small but significant barriers that result from their lack of experience. Little things like identifying a particular capacitor, inductor or integrated circuit can create an insurmountable barrier that is easy to address with a short exchange of messages. Every student now has a phone with a camera so they can take photos of their apparatus and the instructor or TA can easily identify wiring or component selection issues. Ending the term with a culminating project of their choice (with approval to assure it can be done and it is relevant) is also working well. In almost every case, students try something that is a mistake involving a concept we have only partially addressed. Common examples include the use of a Voltage Divider to step down a power supply voltage or trying to drive a load with a device like a microprocessor that cannot source enough current. In every case, a short discussion of the concepts involved and a lot of encouragement to show them how much fun it is to take a chance and learn from what does not work, and everything is fine. The pre-approval process assures them that what they are attempting can be done, so they are nearly always willing to try a few things to get their ideas to work.

A tool that has been found to be very useful in both classes is piazza because it addresses a big issue seen in earlier semesters – students are frustrated watching videos if they cannot ask questions. Piazza was designed just for this type of situation. To make it work, it is necessary for the instructors and TAs to be vigilant and respond as quickly as possible, but not too quickly. Being too fast does not leave time for other students to respond, which is necessary if overall fast response time is to be achieved. In Introduction to ECSE, the new instructor responded to about 20% of the questions, which made up for a particularly reticent bunch of TAs. The average response time was 18 minutes, which is close to the 15 minute response time for Electronic Instrumentation. The more established course had a group of very good TAs who liked answering student questions and had some juniors and seniors who also like helping their classmates. For one section in the fall 2016 Intro to ECSE course, a scatter plot comparing the course grade with piazza activity level was constructed. In the figure below, A = 8 and D+ = 0 for the vertical scale and the horizontal scale is the total number of views in the semester (max = 140). It can be seen that even just watching the activities on the site helped to create a minimum threshold grade (red line) for all but a few outliers. The more views the more likely students would obtain a higher grade. Clearly there are many other issues, but if students want to avoid a low grade, using piazza is quite effective.



Piazza Views vs Course Grade (Intro to ECSE)

Appendix B

Demographic Summary for Instructional Units

Table B1
Transferring to A New Instructor
Electronics Instrumentation Student Demographics

Gender	Gender %	Ethnicity	Ethnicity %
Male	80	Black	0
Female	20	Asian	24
English Primary Language	**Language %**	Multi-racial	0
Yes	92	White	72
No	8	Hispanic	5

n=184

Table B2
Introductory Engineering Student Demographics

Gender	Gender %	Ethnicity	Ethnicity %
Male	92	Black	6
Female	8	Asian	37
English Primary Language	**Language %**	Multi-racial	3
Yes	56	White	42
No	44	Hispanic	6

n=52

Table B3
Impacts of Group Work
Introductory Engineering Student Demographics

Gender	Gender %	Ethnicity	Ethnicity %
Male	71	Black	0
Female	29	Asian	27
English Primary Language	**Language %**	Other	2
Yes	86	White	68
No	14	Hispanic	5

n=42

Appendix C
Comparative Tables for
Transfer of Flipped Classrooms Using Experiment Centric Learning

Table C1-A
Transferring to a New Instructor
How the Method Helped Learning

Type of Learning	Areas of Growth	%*
Pre-requisite to Learning	Confidence in completing lab assignments.	67
Pre-requisite to Learning	Confidence in content area	58
Pre-requisite to Learning	Important in my preparation as an engineer.	72
Pre-requisite to Learning	Motivated to learn course content.	42
Pre-requisite to Learning	Develop interest in the content area.	45
Immediate Learning	Learn how AC and DC circuits are used in practical applications.	61
Immediate Learning	Think about problems in graphical/pictorial or practical ways.	71
Immediate Learning	My knowledge has increased as a result of use.	72
Immediate Learning	Develop skills in problem solving in the content area.	62
Immediate Learning	Recall course content.	53
Immediate Learning	Improve grades	41

*percent responses "*Strongly Agree*" or "*Agree*" on a 6 point Likert-type scale, n=66

Table C1-B
Transfer to an Introductory Class
How the Method Helped Learning

Type of Learning	Areas of Growth	%*
Pre-requisite to Learning	Confidence in content area	82
Pre-requisite to Learning	Important in my preparation as an engineer.	84
Pre-requisite to Learning	Confidence in completing lab assignments.	66
Pre-requisite to Learning	Become motivated to learn course content.	61
Pre-requisite to Learning	Develop interest in the content area.	61
Immediate Learning	My knowledge has increased as a result of use.	97
Immediate Learning	Learn how AC and DC circuits are used in practical applications.	87
Immediate Learning	Develop skills in problem solving in the content area.	76
Immediate Learning	Think about problems in graphical/pictorial or practical ways.	76
Immediate Learning	Recall course content.	79
Immediate Learning	Improve grades	50

**Percent responding "Strongly Agree"/"Agree" on a six point Likert-type survey; n=38*

Appendix C (Continued)

Table C2-A
Transfer to a New Instructor
Initial Long-term Outcomes

General Effects of Use of the AD Board	%
Work collaboratively with fellow students.	47
Develop attitudes of self-direction and self-responsibility	58
Develop different ways of solving problems	52
Apply course content to new problems.	53
Transfer knowledge/skills to problems outside the course	44

**percent responses "Strongly Agree" or "Agree" on six point Likert-type scale; n=66*

Table C2-B
Transfer to Introductory Class
Initial Long-term Outcomes

General Effects of Use of the AD Board	%
Work collaboratively with fellow students.	89
Transfer knowledge/skills to problems outside the course	76
Apply course content to new problems.	71
Develop attitudes of self-direction and self-responsibility	74
Develop different ways of solving problems	59

**Percent responding "Strongly Agree"/"Agree" on a six point Likert-type survey; n=38*