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A systematic review of undergraduate engineering students' perception of the types of activities used to teach electric circuits

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Introduction

Traditionally, the design of electrical circuits courses is a lecture format during which concepts are introduced and sample problems solved [1], [2]. This lecture approach is often discussed and preferred by engineering professors as the most effective approach to cover vast amounts of content within the time period slotted for the class [3], [4]. An advantage of the use of lecturing is the opportunity to disseminate a great deal of information in a short period of time. However this approach is limited by the fact that it assumes students are "empty receptacles waiting to be filled with knowledge" [4] (p. 1520). In addition, according to Borrego and Bernhard [5] "lectures are an efficient means of delivering material to large numbers of students, however evidence is mounting that this format does not necessarily promote a high level of learning or retention of knowledge" (p. 19). It has also been argued that "good instruction involves more than just asking students questions or putting them to work on activities; it also means helping to move students toward the types of expert thinking that characterize knowledge and practices of a discipline" [6] (p. 17). Consequently, traditional lecturing has been classified as ineffective in helping students develop critical thinking skills necessary to take up their roles as engineers in more professional settings [6]–[8].

In most cases the lecture classes are followed by a laboratory component. For the laboratory sessions students are given a booklet consisting of specific circuit exercises related to the lecture of each given week to be completed prior to the class. During the lab, they are required to construct the given circuit, measure required values and discuss the comparison between calculated and measured values. Consequently, laboratory classes have been described as the point at which theoretical learning about concepts meets practical application. Laboratories have also been classified as "superior to lectures and tutorials in enhancing manual skills, introducing the application of theory to practice and developing inquiry skills" [9] p. 231. However, the main point of concern that might arise is the fact that lab classes are usually only compulsory for electrical engineering (EE) majors hence non-EE majors are only exposed to circuit concepts during the lecture class. This therefore means within lecture classes professors are tasked with the responsibility of creating opportunities for deep learning of these concepts.

The process of deep learning has been characterized by an interactive exchange whereby students are presented with the opportunity to actively engage with the material they are expected to retain [10]. To this end, engineering education researchers have suggested for the last twenty years the benefits of implementing active learning approaches to engineering learning environments since various studies have found achievement gains significantly improve when students take a more active role in their own learning [11]. This call for more active learning approaches within engineering classrooms, with specific focus on the teaching and learning of abstract concepts such as electricity, has sparked research into innovative ways to engage students without much disruption to the current design. Some of these approaches have been centred on the use technological devices e.g. clickers students use to respond to questions individually then discuss with their immediate peers [12], interactive learning tools students use within the classroom while solving examples [4], [13],[14], instructional videos students are required to watch before or during class aimed at reducing the length of time spent in class on introducing concepts or formulas [15]–[17], among other classroom approaches such as enhanced guided notes which require students to pay direct attention to in-class discussion in order to complete note sheets [1], [18]. A recent publication by the National Academies of Science [6] provides extensive discussion and examples of interactive approaches utilized in large lecture classes and their benefits in not only engaging students but increasing their learning experiences. Though it is recommended learning environments should be designed to actively engage students, professors should also be mindful of how these activities are perceived by the students.

The purpose of this paper is to investigate the types of activities used to teach electric circuits and students' reported perceptions of these activities. This systematic literature review is aimed at answering the following questions: "How are engineering learning environments designed to promote students' understanding of electric circuits? What are students' perceptions of the types of activities used in enhancing their understanding of circuit concepts?" Systematic literature reviews as opposed to the traditional literature reviews employ a more rigorous and comprehensive approach to reviewing and synthesizing work on a particular topic [19]. According to Mosteller and Colditz [20], a research synthesis such as a systematic review helps the researcher to create for readers a general overview of previous work done on a topic under study while highlighting new knowledge on a common topic. A systematic approach to synthesizing literature therefore offers three main benefits to the researcher. These are:

1. The opportunity to explore areas among previous studies that can be combined to provide answers to new research questions,
2. The ability to generally summarize many issues of research described by previous studies relating to a common area of study,
3. The opportunity to demonstrate gaps in previous work and highlights areas of little evidence that can be used to support a particular concept [21].

Method

Cooper [22] developed a model of a systematic research synthesis which outlines the process of conducting and reporting findings in seven steps: formulating the problem, searching the literature, gathering information from studies, evaluating the quality of studies, analyzing and integrating the outcomes of studies, interpreting the evidence and presenting the results. In addition, Borrego et al. [21] outlines six steps in developing a systematic review of literature: deciding to do a systematic review, identifying scope and research questions, defining inclusion criteria, finding and cataloging sources, critique and appraisal, and synthesis. For the purpose of this study both frameworks will be referenced as guiding principles to conduct the review. The review will follow the seven steps as described by Cooper [22] however the Borrego et al. [21] framework will be used to conduct a deeper exploration of the organization and analysis of the literature selected for inclusion in the review.

Formulating the problem

The research questions "How are engineering learning environments designed to promote students' understanding of electric circuits? What are students' perceptions of the types of activities used in enhancing their understanding of circuit concepts?" were developed to investigate previous work on engineering learning environments, specifically for the topic of electric circuits and the reported findings on increasing students' conceptual understanding of circuit concepts. The active-constructive-interactive-passive, I-C-A-P, framework developed by Chi [23] discusses the advantage of engaging students in interactive activities over constructive, active and passive activities. The claim of this framework is that students learn more not only when they engage with the learning material but with each other and/or the instructor. These activities are termed interactive activities. Constructive activities are the type that requires students to exert some level of cognitive effort however students only engage with the material. Active activities require less cognitive effort while passive activities require little to no participation outside of paying attention in classes. As the overall guiding approach to the selection of literature, this framework was used to classify learning environments in terms of the activities students engaged in and the reported learning gains from each implementation.

Searching the literature

An extensive database search of Compendex and Scopus was conducted using the following keywords: *engineering, circuits AND "students' perceptions"*. Compendex and Scopus are the two main databases compiled of engineering and engineering related work e.g. engineering conference proceedings such as International Conference on Circuits and Systems and engineering journals such as IEEE Transactions on Education. The search returned 57 articles in Compendex and 41 duplicate results in Scopus. Specific to the research questions and what the study was meant to uncover, an abstract evaluation was done to determine which studies would be included in the review. The inclusion/exclusion criteria were:

i. Published work (conference or journal)
ii. Reported students' perception
iii. Undergraduate circuits course (engineering or science focus)
iv. Description of the activity used

The application of the criteria returned 12 articles.

Gathering information from the studies

The main focus of this review was to investigate strategies employed in engineering learning environments and their reported benefits on student learning. To this end the information gathered from these studies came directly from the methods, results and discussion of findings section of the articles selected. Pertinent information on what made the study relevant to the review was determined through an iterative data extraction process. In addition, the classification of the studies in passive, active, constructive and interactive categories of Chi's I-C-A-P framework served as a guiding principle against which information was gathered. A data extraction table was developed to categorize preliminary information from the studies. Based on the work of Cronin et al. [19], data extraction tables present a summary of information required in a review which are; title of the paper, author, source and year (journal or conference), type of study, setting, data collection method and major findings. Table 1 shows the overall general information drawn from the included studies.

Evaluating the quality of studies

The suitability of each study was determined based on the inclusion/exclusion criteria against which the study was subjected when the initial literature search was conducted. In addition, the type of intervention utilized in collecting data and how the study was conducted was of importance to determine which study would be included or excluded from the review. For this work, it was important that learning strategies be implemented and tested within an engineering or science learning environment and that the activities the students engaged in fell somewhere along the active-constructive-interactive continuum. Upon completion of the data extraction table, the selected articles were read a second time in order to retrieve more specific information. This was captured using a more in-depth table represented by Table 2. The categories used as an organizing principle for Table 2 which are description of activity, description of data collection, reported students' perception and limitations were developed using the I-C-A-P framework and conditions derived from the research questions. In creating Table 2, two of the studies were found to be no longer applicable. These studies were excluded because the second round of data extraction uncovered their unsuitability in terms of not having explicitly reported the students' perception and insufficient description of the implemented activity. This phenomena is explicitly explained by Cronin et al. [19] as a part of the process of being critical in the evaluation of the usefulness of selected articles.

Analyzing and integrating the outcomes of the studies

From the two data extraction tables emerging themes were documented. Supporting evidence for each theme was also retrieved from the studies and a thematic analysis conducted. This approach to data analysis was selected for two primary reasons as discussed by Braun and Clarke [24]: 1. A thematic analysis is most commonly used in qualitative research when patterns within the data are important in answering the research question, and 2. thematic analysis affords the researcher greater flexibility in pulling out themes from the data that can always be analyzed using other methods such as inductive or interpretative analyses.

Interpreting the evidence

For the studies that were included the category of methods, type of learning activity determined by Chi's I-C-A-P framework, reported learning gains and how the study was executed was used as the organizational tool.

Presenting the results

A discussion of what was found from the literature search and subsequent review is presented based specifically on how previous work done answers the research questions and what future recommendations can be made. The patterns reflected in the data were also discussed to show how the conclusions made from the review are warranted. This paper concludes with a discussion about gap in the literature that the review uncovered and suggestions for future work or directions.

Findings

At the first stage of data extraction of the 12 selected studies, eight were found to have primarily qualitatively collected data while the other four were quantitative. There were five cases of the activity being implemented in lecture classes, five in laboratory classes and two in a combination of lecture/lab classes. While there were 12 studies that met the inclusion criteria (shown in Table 1), 10 studies (shown in Table 2) were used for the final round of analysis. Of the 10 studies, there were five studies in which interactive activities were implemented, two studies had constructive activities, two had active activities and one had a passive activity.

Structure of studies

There were overall similarities in all the studies based on their structure. In all 10 cases, the researchers described the need to make learning more beneficial to the students by engaging them in activities that went beyond showing up for class and taking notes. The argument was made that by including the students more actively they would experience significant learning gains. It was also expected that students would report a deeper appreciation for the course material and by extension the implemented activity. To this end, nine of the 10 studies used open ended items on surveys or pre- and post-course surveys to measure students' perception of the activity used and how they felt their learning and overall class experience was affected. One study collected data solely from reflective journals the students were expected to maintain. In addition, the four studies that collected primarily quantitative data did so with the use of pre- and post-testing and in two instances concept inventories.

Structure of activities

Table 3 summary of findings based on implemented activity

Setting	Number of studies
Lecture classes	5
Lab classes	3
Lecture/lab combination	2

Five of the activities were implemented in lecture settings where the aim was to use an approach that would provide students with the ability to maximize their learning while making the most of the allotted class time. Two of the studies [25], [26]] utilized instructional videos the students were required to watch before class while the class time was used for problem solving and conceptual discussions through assignments and reflective documents. In two other studies [1], [27], the students were given the course notes before the start of class while the lecture time was focused primarily on having discussions and solving examples related to the concept being covered. The last of the five studies [28] utilized an experimental design whereby one of three course sections was taught as an experimental group using a conceptual change framework informed module. While the structure of the class remained the same, the students in the experimental section were instructed using an approach aimed specifically at reducing the possibility of developing misconceptions while presenting the material in a hierarchical conceptual manner.

Three of the activities were implemented in a laboratory class aimed at helping students better understand or visualize the abstract concepts associated with the course. In one of the studies [15] students interacted with simulation software to synchronize schematic diagrams with instructional videos. In the second study [29], students' roles were rotated every week but the primary role that was important to the activity was that of note-taker as a means of actively involving the students individually. In the third study [30], students were given lab exercises to complete in an iterative manner with the objective to develop and increase their conceptual understanding while building on the basic to more complex concepts.

Two of the activities were implemented in a combined lecture/lab setting. In the first study [31] students were introduced to the class material using a range of activities aimed at combining theoretical and practical constructs. Primarily, students used a virtual keyboard to project and modify waves along a frequency spectrum to provide students with the ability to see and hear how changes in frequency can be represented. In the second study [32] a holistic approach to lectures, recitations and lab exercises was done through the use of a technology interactive tool to engage students with the material and each other.

Structure of students' response

In the 10 studies students' perceptions were assessed using open-ended survey items, affective evaluation instruments or reflective documents. Nine of the 10 studies discussed students having positive responses on open-ended surveys or reflective documents to the activities that were used. Students also reported the influence of the activities in helping them to better understand the concepts being taught. Most commonly reported was the ability to visualize or having a better conceptual understanding of concepts that would have otherwise been abstract. This was a common theme for the activities that were conducted within the context of laboratory classes. However in one study [29], students actually responded more favourably on the pre-course survey than they did on the post-course survey. Where instructional videos were used, whether in lectures or labs, students reported being able to view the videos as often as they wanted or being able to access just the section they were unsure about as a definite advantage. On the flip side, students reported not being able to ask clarifying questions especially during the lecture time as a disadvantage of this approach.

Discussion

The benefits of a systematic literature review as previously discussed are: exploring areas among previous studies to provide answers to new research questions, summarizing issues of research described by previous studies that relate to a common area of study and demonstrating gaps in previous work and highlighting areas of little evidence that can be used to support a particular concept. In this section we will describe how those benefits were attained in this work.

Using previous studies to answer new research questions

Our objective was to synthesize literature on electric circuits learning environments aimed at promoting students' conceptual understanding. More specifically, our focus was the use of activities and how students perceived these activities in enhancing their learning of the content. It was therefore imperative that the studies included in this review met a specific inclusion criteria. This criteria not only ensured that our pool of studies align with our research questions but that we were able to have clear evidence of the phenomena being investigated. The results of this study indicate that within learning environments aimed at teaching electric circuits some steps have been taken to address the issue of increasing student engagement in the learning process. Specifically, the nature of learning activities implemented spanned a wide range of student engagement. For example, one activity required students to watch videos before attending class then engaging in discussions while in class whereas another required students to only complete specific tasks within the class period.

Across the selected studies used in the review the results were aligned well with posits made by I-C-A-P framework. Researchers of active learning have purported that any level of involvement on the part of the student will have positive impact on their learning [8], [33]. However, Chi's I-C-A-P framework explicitly discussed the benefits of interactive, constructive and active learning activities with the recommendation for the implementation of more interactive type activities. This was evident in the selected studies as the cases that reported the most significant learning gains where statistical analyses were utilized, the type of activity implemented aligned with Chi's definition of interactive activities. In these cases, students were reported to have shown significant increases in their conceptual gains which were attributed to the use of the activity. In addition, four of the five activities classified as interactive were implemented in lab classes or a combination of lecture and lab classes. This can be attributed to the fact that interactive activities require students to interact either with each other and/or the instructor. This kind of interaction is most times better facilitated in lab classes as labs tend to be longer than the average lecture class. The one lecture class where the activity implemented was classified as interactive incorporated the use of Tablet PCs. In this activity, the students could solve exercises on their own while the instructor monitored their progress from the front of the class and could respond individually to students' concerns. The two activities classified as constructive were implemented in a lecture class and a combination of lecture and lab class. The two active activities were implemented in lecture classes while the one passive activity was also in a lecture class.

The finding of how the activities were perceived by the students related to the second part of the research question. In all but one study, students reported the activity implemented to have increased their knowledge about the concept being taught. Most commonly, students discussed the benefit of the activity as having the opportunity to better visualize concepts of an abstract nature. Visualizing of abstract concepts is a very important factor in learning about electric circuits. The nature of electric circuits, especially fundamental parameters such as voltage, current and resistance dictates the use of approaches which allows students to create mental models of the concept. Consequently, the nine studies in which students reported their learning to have increased it was primarily because the activities used required them to go beyond memorization of facts. For example, in one study the students were required to complete lab exercises designed in such a manner that they progressed from simple to more complex problems in the same class. In all the studies, the activities used can be considered authentic tasks in that the students were required to solve a problem or explain a concept in an open-ended manner rather than choosing an answer from a set of given responses. This measure caused the students to engage with the material on a deeper level than would have been possible by simply taking notes in class.

Summarizing issues of research described by previous studies relating to a common area of study

The motivation of all 10 included studies was to implement new learning activities within learning environments aimed at teaching scientific concepts. In all cases the researchers reported their study stemmed from the need to help students better understand the complex abstract concept of electricity. This can be considered evidence of the fact that engineering professors are not only conducting research into student learning and using their classrooms as the context but that they have an intent to positively impact their students' experiences. Additionally, this finding indicates the critique of lecturing and calls for more active learning approaches have not gone unnoticed. Our literature search was conducted using specific key words and for the purposes of this study we had a strict inclusion/exclusion criteria. Specifically, we wanted to capture the types of activities being implemented and how students perceived these activities. It was therefore important that these two aspects be explicitly discussed in the studies used for our review. However, the number of studies included in the review is small thus it cannot speak for the body of literature that exist about other approaches being implemented in different types of electric engineering classes. Our study uncovered the fact that while innovative approaches have been utilized in engineering classrooms to elicit student engagement, there is not much work aimed at capturing students perception or thoughts about these approaches.

Demonstrating gaps in previous work

Our analysis of the studies used in this work highlighted the benefits of the activities used to increase students understanding. However we found common gaps among the studies. The common gaps that emerged from the data and will be discussed separately are:

1. How measurement of learning gains corresponds with students reported perceptions
2. Lack of varied learning activities/preferences
3. Use of multiple representations within activities

Measurement of learning gains corresponds with students reported perceptions

Six of the 10 studies were done using qualitatively collected data in the form of surveys and attitudinal open-ended items. In most cases where the students self-reported or rated their responses based on the given prompts, there was very little evidence within these studies of actual measurement of their learning. Owing to the fact that students' perception can potentially be subjective, the use of other means of verifying their actual learning is therefore necessary. The four studies that had primarily quantitative data presented statistically the increase in students' learning as well as having short attitudinal surveys or open-ended items by which the students' perceptions were recorded. Additionally, the most common method of data collection across the studies was pre-and post-testing or post-surveying. While the use of this data collection method indicates a change in learning or attitude, by itself this method is not specific enough to identify what exactly was the cause of the change or how the activity elicited the change.

Lack of varied learning activities/preferences

The types of activities implemented were not conducive to varied learning styles or preferences. This was a common theme among all 10 studies. In some cases (can be seen from the limitations column of Table 2) students even reported feeling overwhelmed by the requirements of the activity or that working in groups did not attend to their preferred learning approach. It can therefore be argued that the lack in the use of differentiated approaches can work to the detriment of the intervention. It was evident that while the activity was very engaging and aimed at increasing the students' knowledge, the students lost interest due to the magnitude of work or the activity's inability to align with how best they learn.

Use of multiple representations within activities

Within the studies selected for this review, there was a lack of discussion on the use of multiple modes of representation to convey knowledge of the concept being taught. The description of the activities was centred on the particular procedures the students had to follow or the stated requirements they had to meet in order to complete the given tasks. However, there was no indication given as to whether or not the concepts were presented using multiple formats such as a combination of qualitative discussions, mathematical solutions and/or graphical representations.

In this paper we discussed previous studies on the use of implemented activities in electrical engineering environments aimed at engaging students in the process of learning electric circuits. We focused primarily on the students' perception of the activity being used and how their knowledge increased through their engagement with the material contingent upon the requirements of the activity. From our analysis we found alignment among the studies that were included in this review and the suppositions of the I-C-A-P framework. The most interactive learning activities had the most reported learning gains when compared to constructive, active and passive activities. Most importantly, our study provided evidence for the benefits of conducting a systematic literature review.

Conclusion

Based on what was found from the 10 studies we were able to answer our research questions. *How are engineering learning environments designed to promote students' understanding of electric circuits? What are students' perceptions of the types of activities used in enhancing their understanding of circuit concepts?* We found that though there were varied implemented activities used to engage students in both lecture and lab classes in all but one case there were reported increase in students' learning. From the data we can conclude that the suggestions, as made by the I-C-A-P framework, holds true in that the different types of activities implemented in the classes were reported to have significant impact on the students' learning and understanding of circuit concepts. Even though our data set could be considered limited, our study still holds significant implications for engineering professors. Currently, the move for implementing more active learning approaches in engineering learning environments have led to the development of innovative and introductory activities. Professors, should however, be cognizant of the fact that in one particular classroom there might be varied learning styles/preferences. Hence, the implemented activity should appeal to varied learning preferences as much as possible. In addition, the level of demand the activity might have on the students should be considered. The lack of discussion about multiple modes of representation is a significant gap in the previous studies. Abstract concepts such as electricity are discussed by conceptual change researchers as best taught in a manner that provides the students with multiple ways of considering the content.

The small number of studies found when the initial database search was conducted and the resulting number of studies that were included in this work when the criteria was applied speaks volume to the dearth of work done in this space. In addition, the findings of the small number of studies that actually measured if the students' perceptions of their learning could be validated by learning gains indicates a significant gap in the field. For future work, studies could be conducted to measure the impact of an intervention, such as learning activities, but with better assessment of student learning gains that is beyond surface learning. Assessments that would measure knowledge transfer or deep conceptual learning would allow for more in-depth investigation into what professors are doing and what actual difference is being made to students' learning.

Table 1. First round of data extraction for primary sources

Title	Author	Source	Purpose of study	Type of Study	Setting	Data collection	Major Findings
Student perception of lecture video use as a means to increase time for in class problem solving applications	Dolan, Dale S.L., Prodanov, Vladimir I. Taufik, T.	ASEE Conference Proceedings, 2011	To examine students perceptions of lecture video as a means to increase available time for in class problem solving in a teaching and learning context	Qualitative	Lecture	Pre and Post Online surveys	Results indicated strong support for the format of the course and students perceived they were better able to learn the material.
Levels of practical skills in basic electronic laboratory: Students' perceptions	Salim, Kamilah Radin, Puteh, Marlia, Daud, Mohd Salwani	IEEE Global Engineering Conference, 2011	To investigate students' perceptions on the practical skills acquired after conducting laboratory experiment for one semester.	Qualitative	Lab	Online surveys	Results indicate some variations in students' perceptions with regards to their ability in recognizing the electronic components, constructing the circuit, operating the instruments and interpreting measurement.
Learning outside of the classroom - Flipping an undergraduate circuits analysis course	Rockland, Ronald H. Hirsch, Linda. Burr-Alexander, Levelle. Carpinelli, John D. Kimmel, Howard S	ASEE Conference Proceedings, 2013	To document the process of how videos for an introductory course was developed and how the structure of the course was rearranged to accommodate the use of the videos and students' report of the effectiveness of this endeavour	Qualitative	Lecture	Reflection documents	Students reported enjoying being able to revisit challenging concepts through the videos. Overall the approach received mostly positive assessment owing to the fact that students were able to use videos repeatedly to prepare for exams
Analog-circuit - based activities to improve introductory continuous-time signals and systems courses	Simoni, Mario. Aburdene, Maurice. Fayyaz, Farrah	ASEE Conference Proceedings, 2013	To present a series of analog-circuit based activities that can help students visualize complex mathematical concepts and gain better appreciation for how concepts are useful in real-world situations	Quantitative	Lab	Surveys	The activities used in the laboratory was reported to have given students an opportunity to relate the highly mathematical concepts with real-world problems through the use of hands-on activities. Students reported gaining a more application-oriented appreciation but did not feel their confidence in learning the material improved much.

Using Tablet PCs to enhance student performance in an introductory circuits course	Enriquez, Amelito	ASEE Conference Proceedings, 2010	To show how Tablet PCs and wireless technology can be used during classroom instruction to create an Interactive Learning Network that is designed to enhance instructor's ability to solicit active participation from all students during lectures, to conduct immediate and meaningful assessment of student learning, and to provide needed real-time feedback and assistance to maximize student learning.	Qualitative	Lecture	Surveys	Results of student surveys shows "overwhelmingly" positive student perception of the effects of this classroom environment on their learning experience. Additionally the interactive classroom environment developed using wireless Tablet PCs has the potential to be a more effective teaching pedagogy in problem-solving intensive courses compared to traditional instructor-centred teaching environments.
Audio-visual lab tutorials to develop independent learners	Walter, Deborah	ASEE Conference Proceedings, 2011	To describe the development and use of audio-visual lab tutorials to outline pertinent circuit concepts to novice students aimed at developing independent learners	Qualitative	Lab	Surveys	Results indicated the use of the lab tutorials reduced the time students were in the lab, accommodated varied levels of experiences and learning styles, developed students' capacity for independent learning and are preferred by most students over text-based resources.
Augmented reality to improve STEM motivation	Restivo, Teresa. Chouzal, Fatima. Rodriques Jose. Menezes, Paulo. Lopes, J. Bernardino	IEEE Global Engineering Conference, 2014	Aims to characterize student involvement using an augmented reality application as well as its use as an additional experimental tools, to characterize how students perceive their experience and learning through use of this application	Qualitative	Lab	Surveys	Preliminary results show induced student satisfaction and revealed very good student perceptions about learning perspectives. This application showed good potential for application in teaching DC circuits.
Increasing hands-on laboratory equipment experience via rotation of notebook recording duties	Jansson, Peter Mark. Kelley, David	ASEE Conference Proceedings, 2012	To show how the pedagogical strategy of having the role of note-taker within a group in a lab setting helped students to increase their competency in using laboratory equipment and learning subsequent circuits	Qualitative	Lab	Pre and Post surveys, Notebook assessment and in class observations	Results showed skills and competencies was significantly improved over the course of the semester. On post survey students reported a great appreciation for the use of this approach to improve their knowledge about circuits and use of lab equipment

Teaching strategy focused on sensory perception, students' interest and enjoyment	Sivaramakrishan Sudarshan. Ganago, Alexander	IEEE, 2013	To create a learning environment that would engage students' senses; provide hands-on experience to which they can easily relate, and to stimulate intuitive understanding of EE concepts.	Qualitative	Lecture/ Lab	Multiple choice survey	Findings indicate positive results and experiences on the part of student learning, understanding and interest. Students also express a deeper appreciation for EE concepts in real world contexts.
The use of enhanced guided notes in an electric circuit class: An exploratory study	Lawanto, Oenardi	IEEE Transactions on Education, 2012	To evaluate students' learning performance after their participation in lectures using enhanced guided notes in an electric circuits course.	Quantitative	Lecture	Concept Inventory	Results indicated significant increase in student performance and reported gains in students' understanding of concept based on method used.
How does Technology-Enabled active learning affect undergraduate students' understanding of electromagnetism concepts?	Dori, Yehudit J. Belcher, John	Journal of the Learning Sciences, 2009	To analyze the effects of a unique learning environments of the TEAL project on students' cognitive and affective outcomes. Students' conceptual understanding before and after studying electromagnetism in a media-rich environments	Quantitative	Lecture/ Lab	Pre and post standardized tests, multiple choice and open ended items	Test scores indicated increased performance on the tests. Students also reported an appreciation for the learning experience and that their understanding was significantly impacted by the innovative approach used.
Conceptual understanding of resistive electric circuits among first-year engineering students	Sangam, D Jesiek, B.	ASEE Conference Proceedings, 2012	To discuss the details of an instructional module implemented and present findings on its effect on student learning as well as to report students' perception of the module in increasing their understanding	Quantitative	Lecture	Pre and post concept inventory test, open ended survey items	Test scores indicate significant increase in students learning which can be attributed to the different learning module that was applied. Students' open-ended response indicated their agreement to the instructional method that influenced their understanding.

Table 2. Second round in-depth data extraction based

Study title	Description of activity	Description of data collection	Reported students' perceptions	Limitations	I-C-A-P
Student perception of lecture video as a means to increase time for in class problem solving applications *(Dolan, Prodanov and Taufik, 2011)*	A portion of face to face to lectures were replaced with pre-recorded instructional videos assigned as homework. The scheduled lecture time was then used for problem solving	A survey was developed to assess the students' perception of the videos. Instrument included 15 sets of five level Likert items students were expected to respond to. 90 students were surveyed from two electrical engineering courses: a required sophomore level course and a senior technical elective	The survey results indicated a general appreciation for the approach. Students reported the videos as a faster means of covering lecture material, a major advantage reported was the ability to go through the lecture material at their own pace and having the ability to review the material. Students preferred solving problems in class but also expressed the need for having face to face lectures as well.	Students reported missing the ability to ask clarifying questions	Active
Learning outside of the classroom - Flipping an undergraduate circuits analysis course *(Rockland, Hirsch, Burr-Alexander, Carpinelli and Kimmel, 2013)*	A series of instructional videos were created for a junior level circuits course. Students were expected to review videos for the week before attending classes. The main difference with this activity as opposed to other approaches is that the videos were made into learning objects 10 minutes long	In addition to the videos the students were assigned weekly assignments required to be uploaded before the class. These assignments were an assessment of the quality of the learning objects by means of a questionnaire and an assessment of the learning objectives for the course for that week. Students were also required to submit a reflection document in which they would express problems or concerns along with positive results of the week's learning and assignments.	The activity was met with mixed feelings by the students. While the students appreciated being able to access the videos repeatedly as an aid in developing their understanding there was also the comment of there not being enough information in the short duration of the videos. Students also reported being able to watch the videos, paused where necessary to reference the text and class notes when more information was needed.	Students reported that the activity used did not cater to their learning styles as they would have wanted more face to face interaction with the material in the classroom. Students also felt the examples used in the videos could have been more challenging.	Active

Study title	Description of activity	Description of data collection	Reported students' perceptions	Limitations	I-C-A-P
Analog-circuit - based activities to improve introductory continuous-time signals and systems courses *(Simoni, Aburdene and Fayyaz, 2013)*	Students work on a series of hands-on laboratory exercises designed to connect theoretical concepts to real-world practical applications. Students are given a lab document that outlines theory lab is meant to illustrate, a step by step procedure of activities to be conducted prior to lab session, procedure for completing the lab activity and a set of questions to be answered after the activities are completed.	Two types of data was collected for the project. A 13 item survey was administered to measure students' perceptions about the concepts, the exercises and their overall confidence with the material. Students' cognitive learning experience was measured using a concept inventory.	Statistical analysis revealed that students reported positive benefits to the implementation of the laboratory exercises. Students overall agreed that the activities helped them to understand the concepts they were previously taught. Additionally, the results of their performance on the concept inventory indicated that the students' cognitive knowledge was also increased.	Based on the manner of data collection it was impossible to determine if the change in the students learning gain can be completed attributed to the change in curriculum. Students also reported feeling overwhelmed by the nature of the activities and were unsure how they were related to the material of study.	Interactive

Study title	Description of activity	Description of data collection	Reported students' perceptions	Limitations	I-C-A-P
Using Tablet PCs to enhance student performance in an introductory circuits course *(Enriquez, 2010)*	A computer interactive learning environment where students use a set of Tablet PCs to access class material. Through the use of an interactive learning software the instructor was able to gauge the students' understanding and respond to their queries on a one to one basis.	During lecture classes focused on introducing students to new concepts and applying them to simple exercises then moving on to more complex examples students work individually or in groups on their Tablet PCs. Instructors are then able to monitor the students' progress through the instant surveys they complete when they have completed an exercise. A comparative case study was conducted to assess students increased learning through pre and posttests. Students were also assess through an attitudinal survey	Statistical analysis indicated overwhelmingly positive attitudes to the use of the interactive learning software and the Tablet PCs in the experiment group. Students reported the tools to have helped them improve their understanding, instructor's teaching efficiency and improved learning environment. Students also exhibited increased learning gains.	Results indicated increase in students' knowledge in both groups even though the students who used the interactive learning environment had significant differences in their learning gains.	Interactive
Audio-visual lab tutorials to develop independent learners *(Walter, 2011)*	Students are exposed to a dynamic innovative learning experience whereby they have access to instructional videos as they complete hands on lab activities. A Tablet PC is attached to a computer providing students with the ability to have the instructors video be synchronized with schematic diagrams and other lab tutorial materials	A post-class survey was used to capture students preference for the video tutorials compared to other text-based resources. Students were also instructed to self-report their video access each week.	Students reported preference for the use of the videos in that they were able to sufficiently prepare for the lab before the class. This they indicated gave them more time in class to focus on the required activities. Result indicated students had positive attitudes towards the use of videos over other text-based resources.	There was no determinant for which student accessed which video most hence conclusions cannot be made about student performance in direct relation to how often they watched the videos. Results indicated students tested differently when assessed individually even though they performed well in the lab groups.	Interactive

Study title	Description of activity	Description of data collection	Reported students' perceptions	Limitations	I-C-A-P
Increasing hands-on laboratory equipment experience via rotation of notebook recording duties *(Jansson and Kelley, 2012)*	To circumvent the equal dissemination of work in a lab group, this study describes the rotation of a lab notebook to actively involve students in the lab activity. Each member of the group is assigned a particular role that rotated each week.	Data was collected from students' rating of their role as note taker for the group as well as through the use of pre and post course surveys. Questions were designed to capture students' perception of the activity on their learning of the concepts being assessed as well as their self-reported appreciation for the teaching strategy.	There were very little statistically significant differences between students' pre- and post-course surveys. In most categories students reported the same attitude to the concepts being tested in the pre and post survey. Students in fact responded more favourably on the pre course survey.	Students reported an overall general dislike for the requirement of keeping and maintaining a notebook.	Interactive
Teaching strategy focused on sensory perception, students' interest and enjoyment *(Sivaramakrishan and Ganago, 2013)*	In a lab class aimed at covering the concept of Fourier series students were engaged in activities aimed at appealing to their sensory perception. Students were given a range of activities moving from learning theory to making hard wired circuits. In every lab students were instructed to use a series of notes on a virtual keyboard via keyboard or to modify the waveforms as a means of teaching the students to appreciation the distinction in what they saw or heard.	A set of comprehensive surveys were designed specifically for each lab. The surveys comprised of both multiple choice and open ended items aimed at collecting both quantitative and qualitative data.	Students' responses on the survey indicated an increase in their overall interest in the concepts. They also reported feeling like they had enough time to focus deeply on what they were doing in the lab. More than half of the sample reported great appreciation for being able to see and hear the change in the frequency of the waves they were working with. This they reported made the abstract concept not so grasp.	The concept of music was the focus of the application used in the lab but since the sample was made up of students from various engineering disciplines music might not have been an area that interested them.	Constructive

Study title	Description of activity	Description of data collection	Reported students' perceptions	Limitations	I-C-A-P
The use of enhanced guided notes in an electric circuit class: An exploratory study *(Lawanto, 2012)*	Students are presented with course notes before class with the intent on having the students engaged in the class discussions without being distracted by having to take verbatim notes. The instructor creates a set of note sheets that not only requires students to fill in blank spaces but to complete activities, answer conceptual questions and formulate conclusions.	Both quantitative and qualitative data was collected through the use of a circuit concept inventory (pre and posttests) and students' response to the Learning Experience Questionnaire.	Statistical results showed significant improvement in the students learning gains as well as their appreciation for the EGN. Students reported the activity helped them understand the concepts discussed in class, improved their problem solving skills and actively engaged them in the learning process.	The use of this approach could be at the expense of students feeling the need to refer to or read their required text before attending classes.	Constructive
How does Technology-Enabled active learning affect undergraduate students' understanding of electromagnetism concepts? *(Dori and Belcher, 2009)*	In a typically large introductory physics circuits course this tool TEAL utilizes a set of carefully structured min-lectures, recitations and laboratory exercises. Students work in small groups interacting with simulation software aimed at providing visualization to abstract concepts.	Both cognitive and affective data were collected through the use of pre and post testing as well as observations and surveyed focus groups at the end of the course.	Students reported an appreciation for the discussions they could have with each other while they completed lab exercises or problem sets. Their improved understanding was collectively attributed to differentiated perspectives facilitated by social interaction. Statistically there were significant improvement in students' conceptual understanding among the students in the experimental group as opposed to those in the control groups.	There is a constant concern when students are placed in groups and encouraged to learn together in that this might not sit well with their learning styles. In addition some of the students reported sometimes feeling overwhelmed as they were uncertain if their understanding of the concepts were in fact right.	Interactive

Study title	Description of activity	Description of data collection	Reported students' perceptions	Limitations	I-C-A-P
Conceptual understanding of resistive electric circuits among first-year engineering students *(Sangam and Jesiek, 2012)*	Three sections of students were tested using a concept inventory for pre and post test scores. One section however was taught the instructional module using a specially designed based on recommendations of conceptual change research.	Data was collected using pre and post concept inventory test as well as an evaluation survey. Students were tested before the module and then again after the module was completed. They were also required to complete the module evaluation survey.	Among the three sections of students, section one (the experimental group) showed the most overall increase in students' grades. Students who were taught using the conceptual change instruction rated their interest and understanding in electrical engineering to have improved after the module.	The sections were all taught by different instructors which could have had some influence on how the students rated the module. In addition there might be marked differences in how either section was taught.	Passive

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