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Learning Thermodynamics with iPad: Adaptation and Learning Opportunities for both Instructor and Students*

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The use of technology in education is rising today. In such a scenario, it is important to discuss the results and the merits or demerits of using technology by both educators and learners. The aim of this paper is to present the adaptation and lessons learned from using iPads in an introductory thermodynamics course in a large engineering school in the USA. The discussion has been supported by results from a study conducted by the authors, accounting for students' learning. Findings are presented to provide evidence of students' conceptual understanding of thermodynamics concepts from two groups (a class using iPads and a traditional class with no use of iPads). For further understanding of the benefits of integrating technology in the engineering classroom, students' perspective is presented in this study as well. The paper concludes with suggested implications for renovating engineering education.

Keywords: iPad; technology; engineering education; thermodynamics

1. Introduction

In today's world, technology has been intrusive in almost every aspect of life and education has not been an exception. The use of technology is gradually on the rise at all levels of education which presents learning opportunities for both instructors and students. Collective adaptation to novel user interfaces and technologies is vital to create effective learning environments and promote active participation, while creating interactive and collaborative learning methods. Science and Engineering educators nowadays are interested in applying pedagogies of engagement relying on technology in multiple ways while aiming to achieve effective ways of teaching. In the everlasting effort to enhance students' learning, educators are adapting to new ways of communicating and representing foundational knowledge. In such collective adaptation, instructors and students are creators of new knowledge—this unique symbiosis naturally paves the road for potential learning not only of the subject matter but also by building a special relationship between educators, students, technology, and the learning environment.

In this paper, we present the adaptation and lessons learned from using iPads in an Introductory Thermodynamics course in a large engineering school in the USA. We discuss the study results, accounting for students' conceptual understanding of thermodynamics, and provide students' perspective on what they think is the effect of iPad class implementation on their learning.

2. Background

2.1 The use of technology in education

The use of technology in education has been increasing in the 21st century and it is now becoming an integral and inseparable component of education. One of the main reasons for this is that the aim of education is to increase the amount of learning during the duration of a course without increasing the level of stress on students. Studies have shown that the traditional lecture format is an ineffective learning environment, whereas active participation as well as interactive and collaborative learning methods are more effective in various areas of science and engineering including chemistry [1], physics [2], engineering [3] and computer science [4]. In today's teaching scene, technology is being used in multiple ways to achieve more effective ways of teaching.

Technology today is applied in many higher education institutions in a variety of courses and in a number of ways (iPad, Tablet PC's or other multimedia features or devices). iPad/Tablet PC's are used for course content development as intense graphic material and equations can be easily captured electronically and multimedia content like internet links, simulation videos, audios, and images can be incorporated [5]. Interactive classroom environments are created using wireless tablet PC's and software applications like NetSupport School [6]. iPads are used by faculty to create lecture presentations, enhance the quality of lectures and for course assignments [7]. E-books applications are

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in rise as well, allowing for easy, quick, and free access to knowledge by hyperlinks and annotations [8]. Tablet-PC-based classroom collaboration systems such as Classroom presenter [9], and the Ubiquitous Presenter [10] are used that can enhance learning and engagement. Virtual reality is used to create interactive learning environments where learners can visualize new concepts, test them and receive feedback to build new knowledge and understanding [11], which is almost similar to project based learning. An important work highlights an interesting use of technology that is, a small fraction of class time devoted to student-selected videos related to course topics and students solve homework problems based on events in the video, which helps increase interest in the class and increases student attendance [12]. Interactive textbooks are used which provide significant features that traditional textbooks cannot. Some of the more important interactive features include: picture galleries, rotating 3D drawings, real-time simulations controlled by the user, interactive charts, and embedded videos [13]. Flipped classrooms are another technology supported instructional strategy that reverses the traditional learning environment by giving students access to the lectures outside the classroom, often online. Class time is spent on activities like problem solving which have traditionally been homework [14]. Technology is being used in a number of universities to support class engagement in various ways ranging from e-books and presentations to simulation tools in which engineering students can test models [15, 16].

2.2 Recently adapted technologies in educational settings

Many current developments in technology are adapted in educational settings. The Adaptive Neuro-Fuzzy inference system for mobile learning is a mobile learning reasoning engine for learning based on the acquired learner profile. The learner profile contains the learner's preferences, knowledge, goals, plans, place and other aspects that can be used to create the personalized learning content [17]. There is also technology to validate adaptive learning algorithms like CAVIAr. This software is based on set theory and logic, which can validate adaptive courseware based on defined validation models [18]. VECAR is a technology that uses augmented reality and computer vision algorithms to create a virtual environment where users can communicate with virtual contents using hand gestures [19]. Augmented reality can be very useful in supporting education due to its inherent advantages: real world annotation, contextual visualization and vision-haptic visualization [20]. Virtual reality and motion capture technology can also be used for education. For example, students learning dance can use motion capture technology to capture their motion, which can then be analyzed by the system and the students can receive feedback [21]. Combinatorix is a technology that uses a tangible user interface to teach students concepts before they watch video lectures [22]. Work has been done to show that tangible interfaces are beneficial for improving problem solving skills [23]. Assessment of Computer-supported collaborative learning is required since computer support is being used a lot in learning today and it has to be assessed [24]. Case-based learning is a common learning method in a number of fields. Such learning methods can be supported by semantic web technologies. These technologies can give a framework capable of supporting individual and collective engagement in different learning environments [25]. Assessment of student assignments is also a major educational challenge as the inherent problem in assessment of any work by an instructor is subjectivity. Computer algorithms can be used to avoid this issue. One such example is discussed by Lamberti and colleagues, in which a computer-based tool is used to grade 3D computer animation laboratory assignments [26]. Technology enhanced learning is developed based on preferences by the users, both instructors and students. Hence, there are many recommender systems for Technology enhanced learning (TEL). Work has been done to evaluate the recommender systems for TEL [27]. The developments in technology used for education have been immense mainly due to the demand for such technologies, which shows that the acceptance of using technology for learning is increasing.

2.3 Advantages of technology being used in education

The use of technology in engineering education particularly has a number of benefits for both students and faculty. Tablet PC's offer multiple benefits to students and faculty, which has caused an increase in their usage in education. Having access to a Tablet PC may allow engineering students to utilize key learning strategies that may not have been possible otherwise, thereby motivating students to learn and apply course concepts in new ways [28]. Tablet PC's improve online and collaborative learning by improving learning experiences through virtual laboratories, simulation environment laboratories and remote laboratories via the internet [29]. With the availability of Tablet PC's, students do not have to note information which is on the white boards as the lectures can be uploaded online. In addition, instructors can face the students, which reduces chances of missing questions from students and instructor can observe the reaction of students during the lecture [30]. The use of Tablet PC's has also caused increased retention rates of STEM students in colleges [31].

iPad's too have benefits which are very similar to Tablet PC's. iTunes has multiple apps which can be used for students while taking notes, for learning or for creating interactive classroom environments. A major advantage as noted by students is the convenience, immediacy and portability of these devices [32]. Students also find it easier to visualize 3D object using the software and tools available in their iPad's [33].

Other types of technologies used in education also have significant benefits. Interactive learning networks in classrooms lead to better student performance in courses, better retention rates of material, better student engagement in courses [6]. Multimedia based classroom-learning helps in dynamic linking of verbal and visual information, which is an important factor for the learner to process, and attune to information [34]. The use of virtual reality has a number of benefits too as it supports learning in a non-linear fashion, which has been shown to be effective in teaching students how to be critical and creative thinkers [35].

Despite some disadvantages of the use of technology in education [36], the benefits are attractive and these have motivated more students and faculty to use technological aid in education. Information technology can enhance learning when the pedagogy is sound and when there is a good match of technology, techniques and objectives. The diffusion of technology into the educational community can be supported by creating communities of practice [37], so that people can share their own results and experiences. The theory of acceptance [38] shows that about 12–18% people are innovators and early adopters and about 10-12% are laggards. Thus, about 12–18% will adapt to usage of technology in education quickly and then it will diffuse slowly into the community. Technology provides pedagogical benefits from the perspective of both faculty and students, which makes a strong case for its use by the academic community.

3. This study

The alignment between content, assessment and pedagogy used in the classroom is important for successful student learning. The advantage of mobile learning has been observed at many universities and it is one of the new initiatives on our campus as well. For example, one of the authors of this study, has used an iPad in her dynamics class to record and post the lectures before class time, enabling her students to review the material prior to coming to class. She has also used iPad applications to record and solve problems that students can use as examples for class activities, quizzes or exams. Based on this experience in the Fall of 2014, the instructor fully integrated iPads in the lectures, class activities and assessment of students' learning. The instructor enabled students to also use iPads as a tool while learning the material. This integration helped the instructor to achieve alignment between the content, assessment and the pedagogy she used in the classroom. Later, the instructor and students in another engineering fundamental course (design and manufacturing processes) applied the full integration of iPads. In this study, we present and discuss the first full iPad integration in introductory thermodynamics sophomore class. The iPads were used in a variety of ways:

1. The instructor and the co-author of this paper improved student engagement in her lectures by using 'Explain Everything', an application for presenting content during a lecture that can be viewed on students' devices and embedded with interactive elements. Students could take notes during class using applications such as 'Notability'. This frees the students from having to try to write down the points from the lecture. Instead, they can focus on writing the connections they make between the lecture and other learning material in the course. To get an immediate assessment of students' understanding, the author used 'iClicker' to conduct in-class quizzes.
2. The instructor also created videos for the students using the 'Explain Everything' application. She originally used this application in her 'Dynamics' class. She recorded and posted every lecture by noon every Sunday. Since all students had iPads, she used this application in the thermodynamics class. She recorded the narrated PowerPoint-style presentations combined with recordings of her working equations by hand on the iPad (using a stylus), while lecturing in class. Using the zoom feature, she wrote long problems and still had space for notes at the side of the slides. The presentations were recorded and then posted on the course website after class using the University 'my media site'. During the semester, the instructor required students to make such videos. Firstly, she hoped they will help with the flipped classroom and secondly, to assess completely whether students read the material prior to class and understood the concepts she was teaching. Students were required to create videos and also evaluate their peers work. The videos were due on the course website before class session. Along with

learning the material, students also learned how to create videos, to use the University 'my media' products and to critically evaluate new information. With the students' permission, the instructor also used some of the created videos as course content in following semesters and uploaded them in her thermodynamics open educational resource website (http://opentext.lib.vt.edu/thermodynamics, Bairaktarova, 2014).

3. In the traditional thermodynamics classroom (with no use of iPads), the instructor used to print out between 5 and 6 problems for each student and bring them to every class. After the lecture, the remaining time of the class was used to solve problems in groups. In the Thermodynamics and Design and Manufacturing class in which students had iPads, 'BaiBoard HD' application was used for problem solving activities. Using this application helped students have collaborative experience in solving and editing similar problems together in real time, while still working individually instead of cramping on the board. The difficulty level of the problems escalated and content was added. Each one was aligned with the learning objectives for that particular lecture. This type of class pedagogy engaged students in interactive learning. For out-of-class interaction, the instructor planned to host virtual office hours the following semester, when students can join her via video chat from their iPads. Fig. 1 shows the required and recommended applications the students used.

3.1 What was the opportunity and who benefited?

Full integration of iPads in the lectures, class activities and the assessment of students' learning had the potential to provide a contemporary, interactive and supportive educational environment.

The benefits and effects of using iPads in such large classrooms were several:

(i) Alignment between content, assessment and pedagogy.
(ii) Interactive and collaborative learning.

APP REQUIREMENTS & RECOMMENDATIONS

AME 2213 - Thermodynamics

REQUIRED

Purpose	App	Use	Cost
Note Taking & Group Work	Notability	Create handwritten and typed notes and annotate PDFs	4.99
	BaiBoard HD	Write on the same digital whiteboard with peers.	Free
Quizzes	i>clicker GO	Vote in surveys/polls during class (This will require a subscription)	Subscription
Content and PPTs	Binder and D2L Website*	Access content for the course including PDF versions of PPTs to take notes on	Free

RECOMMENDED

Purpose	App	Use	Cost
Projects	iWork	Word processing, presentations, spreadsheets	Free
Communication	Mail	Connect Mail to Outlook to receive OU emails	Free
Storage	Dropbox Google Drive OneDrive Box	Save files to cloud storage or access computers files stored there	Free

Fig. 1. App Requirements and Recommendations.

(iii) Peer learning.
(iv) Exposure to more content was easily accomplished.
(v) Easier to flip the classroom.
(vi) Synergy between mobile learning and the open educational resource e-book.
(vii) Potential for having the course on Janux (an online interactive learning community).

The appropriateness of the iPad as an educational tool:

(i) Mobility.
(ii) It has a camera and it allows students to create, edit, and publish videos.
(iii) Has nearly free access to educational applications.
(iv) Students can use the University online platform and 'my media' products.

The benefits of Flipped Classrooms (Ryback & Sanders, 1980):

(i) Students can view material at their own convenience.
(ii) While watching the recorded lectures, students can stop, pause and fast forward material so that they can examine things at their own pace.
(iii) Class time is dedicated on problem solving instead of lectures and students can ask questions regarding problems.
(iv) Easy to address different learning styles (visual vs verbal learners).

3.2 What were the obstacles?

(i) The majority of the students in the Thermodynamics class did not watch the videos prior to class time. They complained that they do not have enough time for out-of-class class assignments/work.
(ii) Some concepts require longer explanations, which resulted in videos longer than 15 minutes.
(iii) Based on WIFI connectivity, the 'iClickers go' did not always work as fast as the physical iClickers. The classroom easily became chaotic and the instructor needed to engage the students in group activities using only the physical iClickers owned by students who requested them from other courses. This eliminated the idea of assessment and it was difficult to judge if students read the material or watched the videos before class, thus making it difficult to flip the classroom.

3.3 Study goals

(i) Successfully 'flip' the classroom by full integration of iPads, available to students through the semester to achieve objectives in (ii), (iii) and (iv) below.
(ii) Provide students with more time for problem solving as the setting for this fundamental course are only lectures, which will result in understanding of abstract course material and lower misconceptions associated with the Thermodynamics content.
(iii) Engage students in the use of contemporary technological learning tools to increase appreciation of the difficult course material and engineering in general.
(iv) Address students' different learning styles to improve learning of the course material.

3.4 How did we evaluate success?

(i) Students' self-perception of learning at the end of the semester.
(ii) Concept inventory (pre- and post-survey).
(iii) Comparing the grade distribution of the students in the final exams in both years.

4. Method

4.1 Concept inventory and Final Exam for performance gain

Using the pre-and post-concept inventory scores, the pre and post means were calculated for the two classes (with iPads and without iPads). The two scores were compared to see if there was any improvement. The gain-mean scores were also calculated for the two classes. The gain means were used to infer which class had a higher improvement in scores from the pre-test to the post-test. The grade distribution in the final exam was also considered. Other statistical information regarding the final exam were average scores, median and the mode. This data helped compare the performance of the students in the class with iPads (N = 70) and in the traditional classroom without iPads (N = 89).

4.2 Students' perception

The next aspect was the perception of students of their own learning. The intent was to understand what the students felt about the pedagogical tools implemented in the class and what personally helped them most in the learning process. We created a set of survey questions. The first five survey questions were specific in nature while the final survey question focused on the overall value of the pedagogical tools available (Action center, iPad's, clickers, flipped classroom and course project). Action centers are an avenue for free, group, walk-in academic assistance sessions staffed by an instructor and and/or peer learning assistance. These are independent of regular classes and provide additional assistance to students. The instruc-

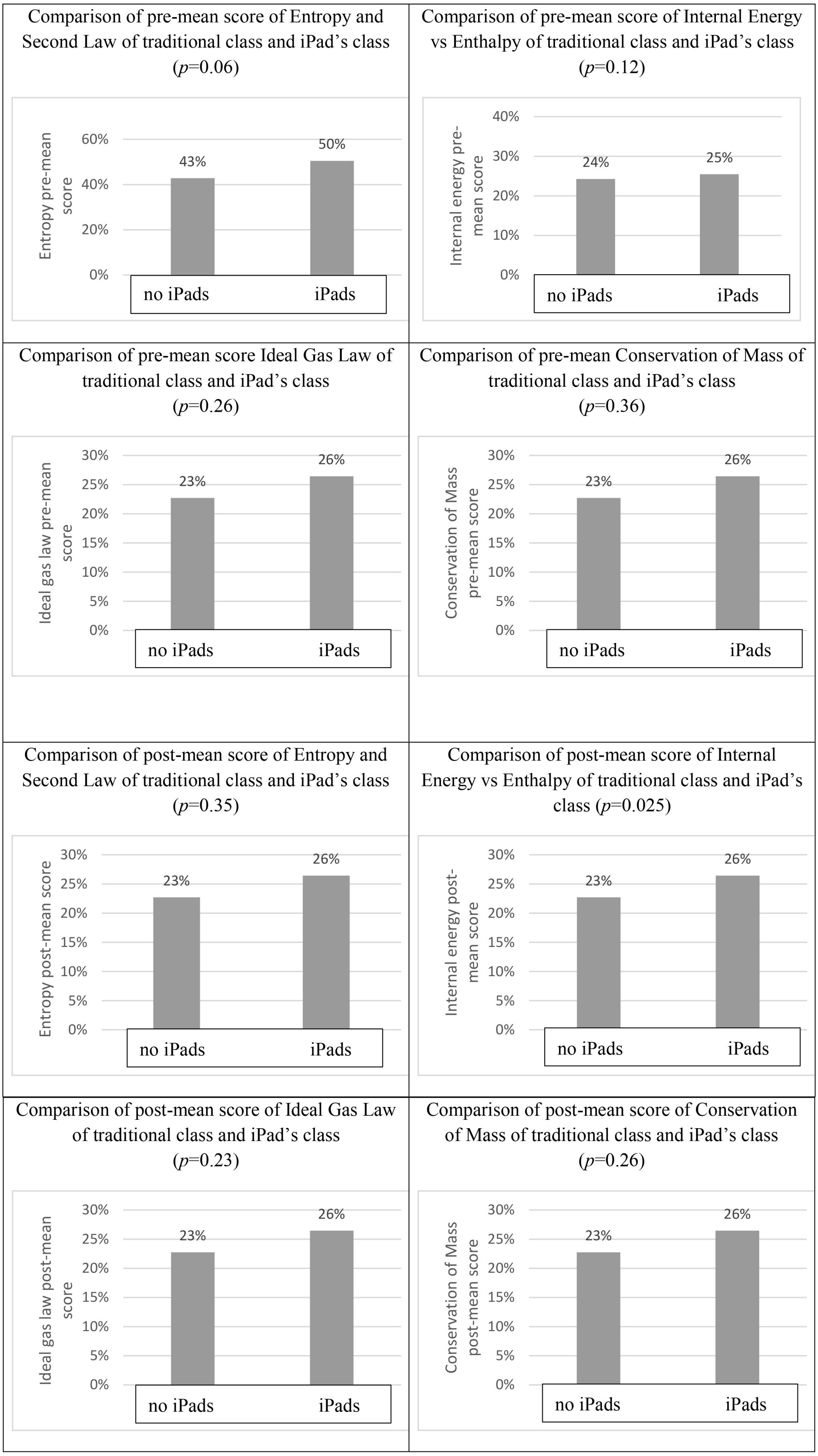

Fig. 2. Concept inventory pre- and post-scores by misconception topics.

tor of the thermodynamics class held action center hours for the whole semester, independently of lecture time. iClickers are devices that allow students to respond to the instructors' questions anonymously. This helped the instructor and the student see how well the students understood concepts. The students kept the iPads with them not only in class but also throughout the semester. This made flipping the classrooms easier than in the traditional class. Flipped classroom is a pedagogical approach where students have access to the lectures out of class and class time is used for addressing difficult parts of the new concept or solving problems. This approach was intended to increase students' interest and time spent on the course in and out of the class. iPads were used for multiple purposes like facilitating resource sharing, in-class assignments, uploading lectures to facilitate flipped classrooms, creating synergy between mobile learning and the open educational resource e-book (http://ouopentextbooks.org/thermodynamics/ (Bairaktarova, 2014)) and the potential to have the course in an online platform. The students had to rate the pedagogical tools as 'Best Help', 'Very Helpful', 'Helpful', 'Moderate Help', 'Not helpful at all'. Allowing the students to rate the different pedagogical tools helped to compare them based on the students' perspective. It also helped to understand what the students felt about the use of iPads in class, among all the other pedagogical tools used in the classroom.

5. Results

In this study, we have compared two classes. One of the classes had a curriculum with full integration of iPads, while the other class was traditional, without usage of technology. Statistical analysis was conducted using SPSS statistical package, 2016 version.

5.1 Concept inventory (pre- and post-survey)

Thermodynamics concept inventory is a tool used by faculty and students as an assessment instrument to identify misconceptions in thermodynamics concepts. The test consists of about 25 questions and it has undergone extensive psychometric analysis. It has been used widely in multiple universities [39].

The pre-mean score of the traditional class was 36% and the pre-mean score of the class with iPads was 38.8%. The post-mean scores of the two classes were 46.2% and 50.2% respectively. The data reveals that there has been a slight improvement in the pre and the post scores of the students that were exposed to the benefits of technology. The Gain-mean scores of the two classes were also calculated. The Gain-mean was 10.2% for the traditional class and 11.2% for the class with iPads. As we can see, there is an increase in the Gain mean score of the students using iPads in the class. The results of the thermodynamics concept inventory pre- and post-scores and their corresponding *p*-values are presented in the Fig. 2.

5.2 Results from final exam

Figures 3 and 4 show the grade distribution of the grades of the students in the final exam in the traditional class and the class with iPads. The average score of the traditional class was 61.9% while the class with iPads average was 74.9%. The median score also improved from 61.8% (traditional) to 75% (class with iPads). The grade mode in the traditional class was 63.2% while the grade mode of the class with iPads was 80%. The graphs represent a shift towards higher grades in the class with iPads compared to the traditional class. This can be seen from the grade distribution.

5.3 Students' self-perception of learning

To confirm the benefits of integration of technology into the curriculum, the authors also collected data from students to gain an insight into their perspective. The students' perspective is summarized in Fig. 5. We can see students' response to six survey questions. This survey represents data only for the 2014 sample. The survey was collected from 70 students.

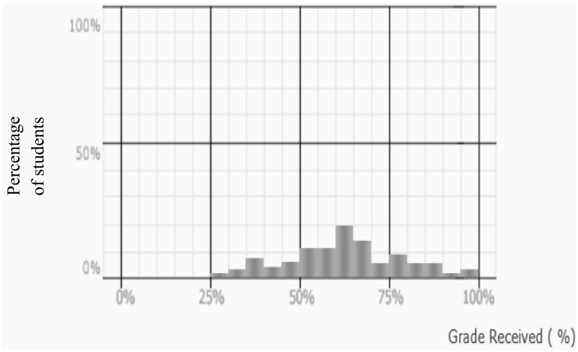

Fig. 3. Grade Distribution in Final exam (no iPads).

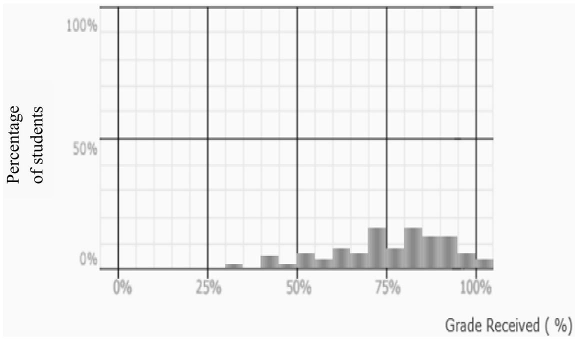

Fig. 4. Grade Distribution in Final Exam (iPads use).

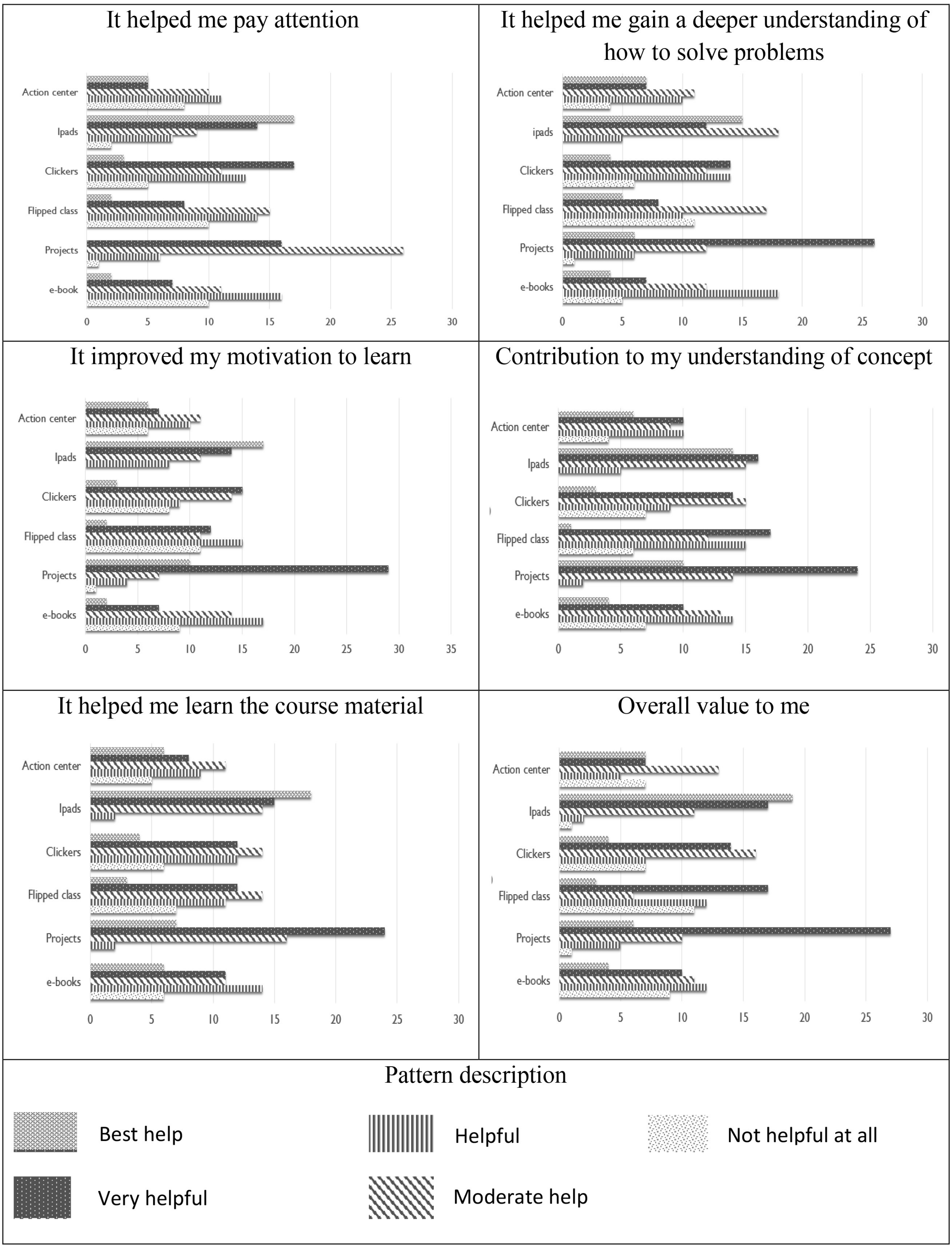

Fig. 5. Student responses to survey questions.

The students' responses to the survey questions show that iPad has been considered to be as "best help" consistently for all the survey questions. Projects have been consistently marked as "very helpful" in all survey questions except for what helped them pay attention, where most students found it "helpful". From students' perception, we can conclude that the use of iPad's added value to the course and it was one of the best pedagogical tools used.

6. Discussion

6.1 Benefits of using iPads in the classroom based on results of the study

The benefits of using technology in education have been partially observed in the results of this study. The authors employed three different indicators—the performance in the concept inventory test, the grade distribution in the final exams and the students' perspective. Based on the results, it can be seen that the grade distribution of the students in the final exam was better in the class with iPads compared to the traditional class. Also, students responses to the survey questions reveal that students themselves felt that the use of technology added value. Students' positive feedback is encouraging. Though student perception and distribution of final exam grades have shown promising results, the final exam mean scores in the two years has not reflected a significant improvement per se. Fig. 2 contains the results for the concept inventory scores and their corresponding p-values. The p-values show that there is no significant improvement in student scores in the thermodynamics concept inventory. Though the usage of technology in education has a large number of benefits, there are some disadvantages. As discussed in the literature, it has been shown that there is no statistical difference in factual knowledge acquired by students exposed to technology and students without exposure to technology [24] This is supported by the results in our study. The performance in the thermodynamics concept inventory was similar for both classes. There was no significant difference between the traditional class and the class with iPads.

Despite there being no significant difference in students' conceptual understanding in this particular study, the benefits of using technology in education must not be understated and students' perception of the pedagogical tools used in the classroom must not be ignored. The results show that students found that the use of iPads added value to the course, showing that the use of technology received positive feedback from students. In addition, there is other evidence of positive results in the class which used iPads, like better distribution of grades in the final exam. Another interesting point to note is that one particular question in concept inventory, which was on "internal energy vs. enthalpy" shows a significant difference between students in the traditional class and students with iPads. This shows that the use of technology might have had some influence on the concepts that are considered by the literature to be difficult and to provoke students' misconceptions. Further research is needed to confirm and underline the reasons for this particular finding.

6.2 Benefits of using iPads in the classroom based on Instructor's perception

An important aspect of this study is the instructor's perspective in using iPads as a pedagogical tool in the classroom. This requires a discussion of two topics which are, the benefits of using technology for the instructor and the benefits for the students which were observed by the instructor.

The use of such technology is encouraging for the instructor since it offers multiple benefits. This type of technology presents new opportunities to enhance learning in a unique way that may not be possible with other devices. Some of the benefits of this tool from the instructor's perspective have been discussed here. The implementation of this technology in education was a solution for one-to-one learning in the instructor's large class. The instructor did not need to be concerned about the visibility or readability of anything written on the board. The use of iPad's allowed the instructor to experiment with technology easily and develop innovative activities specifically for the Thermodynamics class. The iPad also offered the portability that traditional laptops and desktop computers do not offer. The use of the iPads allowed different forms of communication and representation of students' solutions to course related problems. These opportunities are fertile terrain for the natural drift of potential learning that can be developed in the classroom by knowledgeable instructors and learners. Such learning is not limited to Thermodynamics formulae, but also include the use of iPads for data analysis, representation and visualization. It also helped with the communication of students' thoughts with the instructor which helped pedagogy.

As mentioned earlier, the instructor observed multiple benefits for the students while using iPads in the classroom. With the use of the iPads, students were able to see the progressive development of the content and were also able to follow the instructor's cognitive process. Students could take notes using digital handwriting as the instructor developed the content. Students liked that the instructor's thought process was shared with them simultaneously. Given that iPads are a common technological artifact in society, students were able to easily personalize the device. The iPads allowed students to create multiple learning streams, one of which was in the class while another was through collective learning using the iPad. This is a stance on teaching that goes well beyond repetition of procedures and perpetuation of knowledge in the classroom. It creates a new source of learning that is shaped by the tools that are used. Students who are 'digital natives', those who are comfortable with technology, participated in broader virtual learning communities to study, work and interact with their peers.

7. Conclusions

In this study, the authors presented the full integration of iPads in a sophomore Introduction to Thermodynamics course. The pedagogical approach was discussed and students' performance on the thermodynamics concept inventory and the course final exam of two classes (one with the use of iPads and one without) were discussed. The authors also consider students' perception regarding what they felt helped them learn thermodynamics most. Based on the instructor and students' experience, the authors are optimistic that the use of iPads as a learning tool can enhance learning when the pedagogy is sound and when there is a good match of technology, instructional methods and learning objectives. Based on the improvement in students' scores in their final exam and their own positive perception of using iPads, the authors advocate for adaptation and integration of technological tools for pedagogy more aggressively in the engineering classroom. More technological tools should be tested by their use in various STEM classrooms and their merits and de-merits must be analyzed. The ease of availability of technology in modern times and its effectiveness proven by several studies, including this one, shows promise for integrating technological tools widely in engineering classrooms in the near future.

This study adds another example of how current technology can be applied in education from the perspective of both instructors and learners; additionally, it shifts the conversation from the engineering educators of the future to the close reality of growing community of innovators who are dynamic and adaptable to novel technologies for the benefit of our global engineering graduates. Thus, it is no longer a question of will, but when, the entire teaching community will start using technology to improve the efficiency of teaching.

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