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iPads in the Engineering Classroom – Boon or Bane?

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iPads in the Engineering Classroom – Boon or Bane?

Introduction

As iPads and similar touch-screen devices continue to flood the market, engineering programs are seeking to integrate these platforms into student education. With total market penetration of perhaps 125 million iPads sold to date and nearly half a billion smartphones (all brands) shipped in 2011 alone[1] for a total of just over 1 billion smartphone users currently holding active accounts worldwide[2], the transition to highly-mobile touch screen computing is upon us. Further, the Pew Internet and American Life Project estimates that 66% of those between 18 and 29 years old own smartphones, with the likelihood of ownership increasing with higher incomes[3]. Engaging the current technology-hungry college student is thus promising, possible and necessary; but with over 100,000 applications available for the iPad alone, critical questions remain. What applications, tools and methods truly enhance the learning environment and what educational benefit, if any, do the students receive through the use of these devices? How do we integrate these devices in a way that appeals to our students, Prensky's "digital natives"[4], when most of our professors are "digital immigrants", without placing unmanageable burdens on the instructional team?

The current literature examines the use of tablet devices in the college classroom but no study focuses on the use of iPads in the engineering classroom. An interdisciplinary team of educators from Indiana University – Purdue University Indianapolis (IUPUI) conducted a study using iPads as part of a Faculty Learning Community (FLC)[5]. This study specifically took a look at student perceptions based on learning with the iPad as a supplemental learning tool in the college classroom. The team used iPads for learning activities and assessment, for communication, and research support. This study shows that most students perceived a high learning value while using the iPad. This study used the iPad in courses like English, journalism, and music. With very little data collected about iPad use in the engineering classroom, we could shift our focus to the use of e-text books. A study conducted at the University of Mary Hardin-Baylor on the student's preference for hard copy books versus an e-text book shows a preference for hard copy books[6]. This study also outlines the large amount of conflicting literature showing no consensus on the preference for hard copy books versus e-text books. The preponderance of literature gets varying results and does not prove conclusively if students prefer hard copy text books or e-text books.

To examine these questions, the authors collected and analyzed data pertaining to the college classroom application of the Apple iPad and the effects on student outcomes. Data considered includes a 3-year longitudinal study of student technology adoption preferences and attitudes that took place during academic years 2010-2012, focus group results as well a one-semester in-depth look at adoption in a junior-level thermo-fluids course, including evolution of student attitudes and student accomplishment. This paper then considers the effect of iPad adoption in the college classroom, including student outcomes and attitudes, with the goal of assessing whether the technology enhances the learning environment. Commentary on instructor efficiency and observations on best practices are also included.

Background

This study has been conducted as part of a larger, longitudinal study of the use of technology in engineering education. The longitudinal study began with the collection of data in the fall of 2009 in the Thermal Fluids I Course. This course was selected because its use of a locally authored text afforded the team the flexibility to present the course text to the students in a variety of formats and contexts. Over seven semesters, the team has polled the students in the course with regard to their textbook preference: printed, electronic, or indifferent. The results of this polling are shown in figure 1. The question posed to the student was, "If there were no difference in price, I prefer an e-text (electronic text) over a printed text for this course." The response options were 'Yes', 'No' and 'Indifferent' and the number of respondents in any semester varied from 81 to 200.

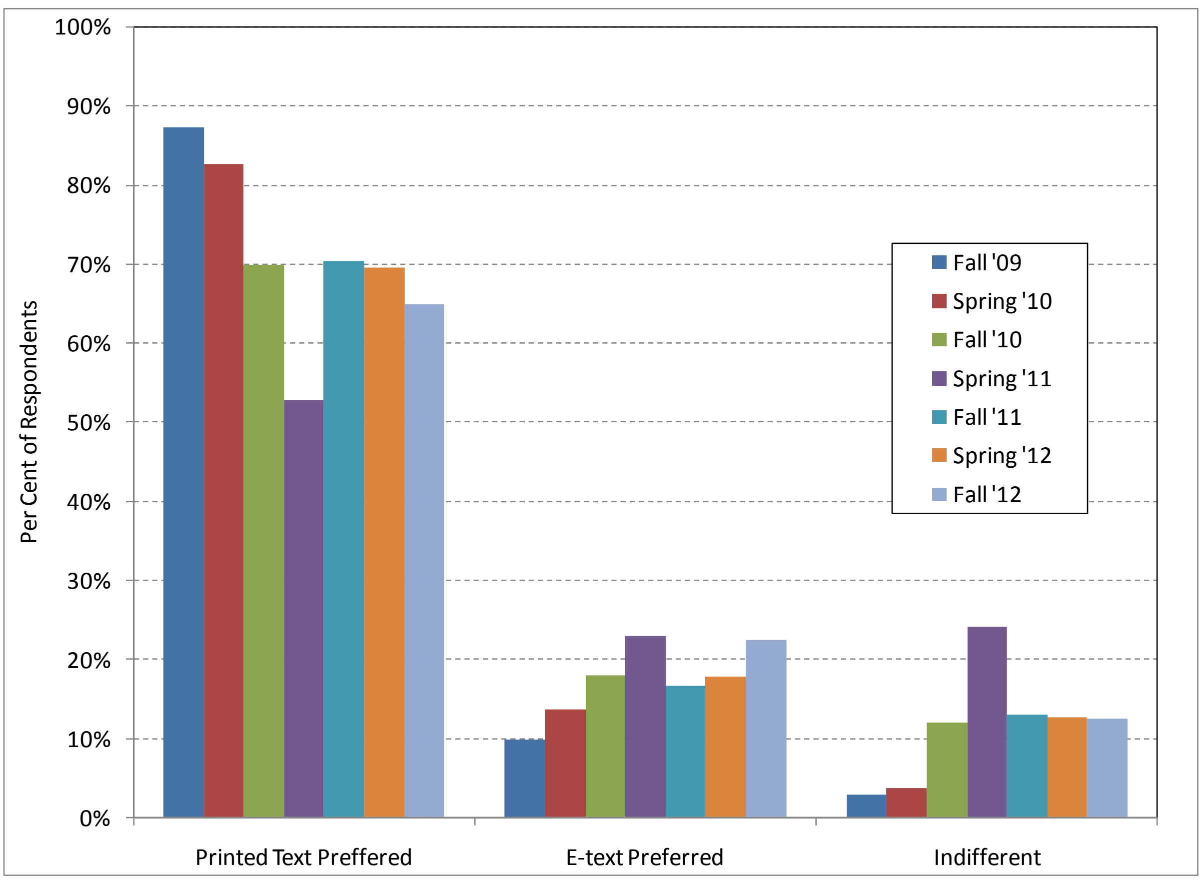

Figure 1: Longitudinal Text Preference Data for Thermal Fluids I Course

The data indicate an overall preference for a printed text for this course. There was a significant increase in student desire for the use of an e-text over the first several semesters of the survey. This seems to have stabilized over the past few semesters with the data in the spring of 2011 indicating an unusually high number of students who were indifferent to the type of text selected. After the first semester of polling students in this course, the team also added two agree/disagree questions to the survey: "I use a Kindle, Nook, iPad, or some other electronic book reading device" and "I use internet sources in doing math, science or engineering homework." Figure 2 shows the per cent of respondents who answered these questions in the affirmative. With the increasing number of students using electronic book reading devices and the increasing numbers of students who either preferred an e-text or were indifferent, the team determined that the time was right to conduct a trial with an e-text in this course.

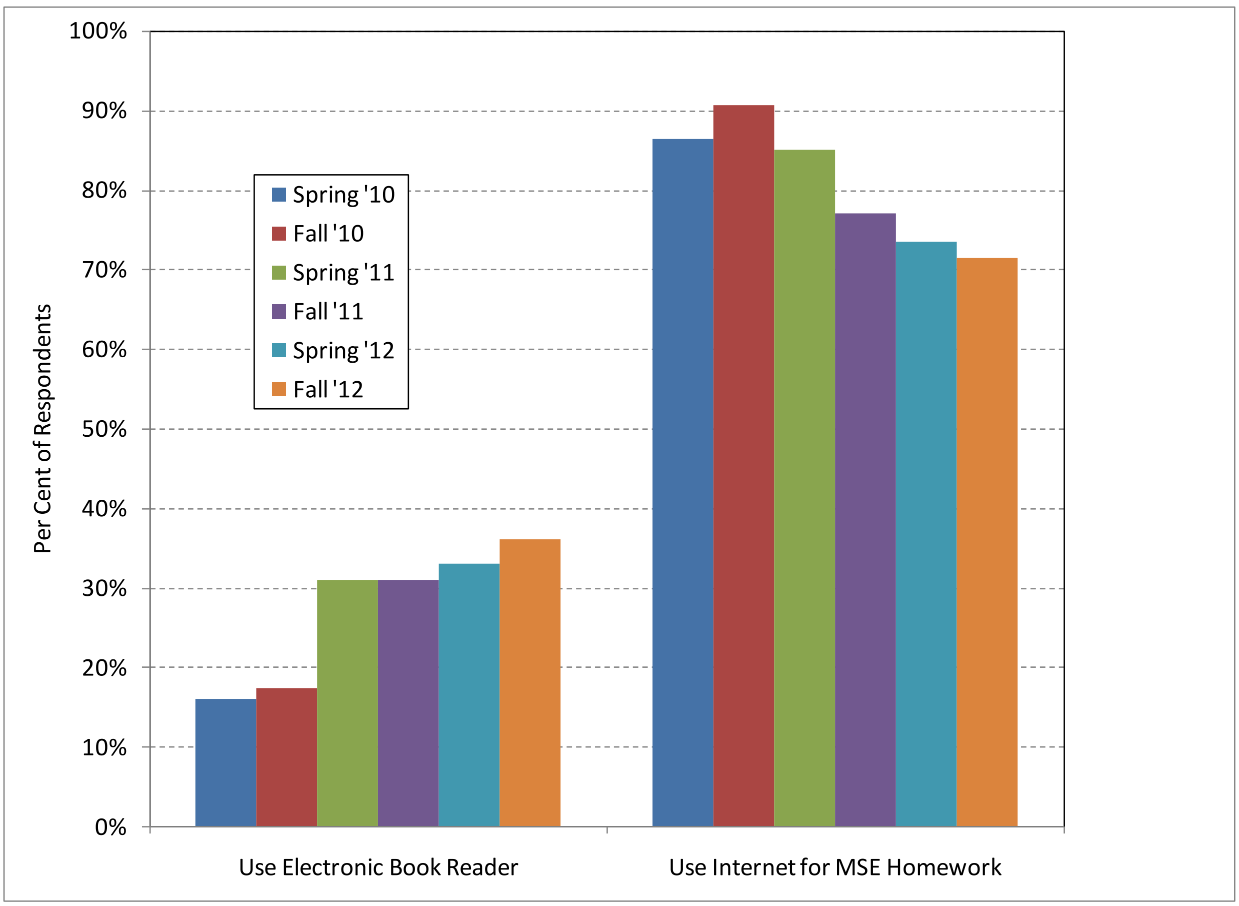

Figure 2: Electronic Book Reader and Internet Use by Students in Thermal Fluids I Course

Method

This study, with the exception of the longitudinal data described above, was conducted by issuing iPads and an electronic copy of the textbooks to one 18-student section of Thermal-

Fluid Systems I. The students given iPads represent just 18 out of 218 students taking the course during the Fall 2012 term, and the students were allowed to load applications, books and other content onto their issued iPads as they desired. Demographically, the students involved in the research consisted of three seniors, fourteen juniors, and one sophomore, and the student grade point averages (GPA) coming into this course ranged from 2.2 to 4.0 on a 4.0 scale. The students in this course were randomly assigned to a section based on others courses and schedules, minimizing preferential sorting and ensuring a broadly representative pool of students.

The materials used for this study were nineteen 32 gigabyte Apple iPads (Wi-Fi enabled only), course text (pdf), the course reference manual (pdf), course Student Notes (pdf), the Fundamentals of Engineering Exam Reference Manual (pdf), the course reference card (pdf and hard copy), and the teaching material already used to teach the class. The teaching materials available for the students during the course consisted of: a class Blackboard site, a Powerpoint presentation for each lesson, and board notes for each lesson.

The Thermal-Fluids Systems I course, used in this study, is a face-to-face class; it met for forty-four lessons over one semester and is a 3.5-credit hour course. The attendance policy is strictly enforced, so students were present for essentially every class meeting. Thermal-Fluid Systems I is an integrated study of fundamental topics in thermodynamics and fluid mechanics, and the course introduces conservation principles for mass, energy, and linear momentum as well as the 2nd Law of Thermodynamics. Principles are applied to incompressible flow in pipes and turbo machinery, external flows, power generation systems, refrigeration cycles, and total air-conditioning focusing on the control volume approach. Laboratory exercises are integrated into the course as is a comprehensive, out-of-class design problem. This design problem provides an opportunity for students to apply engineering science and the engineering design process to a hands-on project. The course is divided up into four blocks: Introductory concepts, pipe flow and a water car case study, a steam plant case study, and a total air conditioning case study. One written in-class exam was given after each block and a comprehensive final exam was given to all students.

Each student was allowed to use their issued iPad for out-of-class reading assignments, homework assignments, engineering design problems, and lab exercises. During the exams, the students in this study were required to use the following references loaded onto their iPad: the textbook, the course reference manual, the Fundamentals of Engineering Exam Reference Manual, and the course reference card. The students were allowed to use a hard copy of the course reference card (See Appendix A for a sample of the reference card) and a separate calculator. Each exam was a paper-based exam and students in this study could not use hard copies of the course texts during the exams (except for the reference card).

Prior to using the iPad, each student uploaded the required course materials. This process required the use of a computer and Apple iTunes. The student's had no problems uploading the texts or using iTunes with the iPad. The real challenges came when the students had to choose an e-reader for the course text. No mechanism was in place to pay for application for each student. The students paid for the applications themselves. The iPad comes with a free application to view the e-text; however, this does not have the capability to alter the e-text for note-taking or highlighting. The most popular application for note-taking and highlighting was iAnnotate. This application costs $9.99 from the Apps store within iTunes. 89% of the students used iAnnotate and all of the students in the study used some type of application to alter their e-text.

Access to the internet was the largest inhibitor to more wide-spread use by the students. The wireless infrastructure available for iPad use during this study was limited to 4 select locations across campus. The students had to be within wireless signal range of one of these 4 locations to use the iPad's wireless connection capability. This limitation minimized the effective use of the iPad as an internet capable mobile device. Each iPad had the ability to connect to the 3G network, but no student paid the subscription fee for this service. Therefore, the use as an e-reader was fine, but the expanded use as an Internet-ready mobile device was limited.

The initial classroom set-up by the instructor was both minimal and tedious. The iPad can display from a classroom projector, the same as a laptop, using a VGA adapter (additional cost). This method was very easy to set-up; however, it restricts the instructor to the podium. A wireless solution is available using an Apple TV, but this requires a more tedious set-up and additional equipment. The Apple TV (additional purchase) and the iPad must be connected to the same wireless network and the Apple TV must be connected to a display, i.e. a projector or Smartboard. An additional cable may be required to connect the Apple TV's HDMI output to a projector's DVI input. This capability was used to incorporate videos, Powerpoint, and applications such as Air Chalk.

Air Chalk is an application which replicates a chalkboard on the iPad. This application was very difficult to use. It could only display one board at a time. So, referencing material from previous boards was not easy. The penmanship on the iPad is hard to keep neat. However, each board is stored on the Air Chalk server and available to the students.

Data management is more difficult with an iPad. Documents are not created on the iPad, so transferring them between a computer and an iPad is sometimes challenging. Apple products are compatible with other Apple products; however, Microsoft products are not as compatible. Transferring files from your Microsoft based laptop to your iPad is done using iTunes and a hard-wire connection. Dropbox is a good web server to upload your documents and have access to them anywhere via the Internet. Dropbox has an app for the iPad so document transfer is easy if an internet connection is available.

Results

Student perceived value

Two attitudinal surveys were administered during the length of the semester. A pre-attitudinal survey was given during the first lesson. A final post-attitudinal survey was given on the final lesson. To inspire frank responses from students, the surveys were not viewed by the instructor at any point during the semester but only after the semester ended and the final grades were assigned. The two survey instruments, pre and post, are shown in Appendix A In a general sense, the questions sought to assess familiarity, comfort and use expectations at the start of the semester, and student perceptions about these same issues as well as educational benefit at the end of the semester. Summarized results for these surveys are presented in Figures 3 through 5.

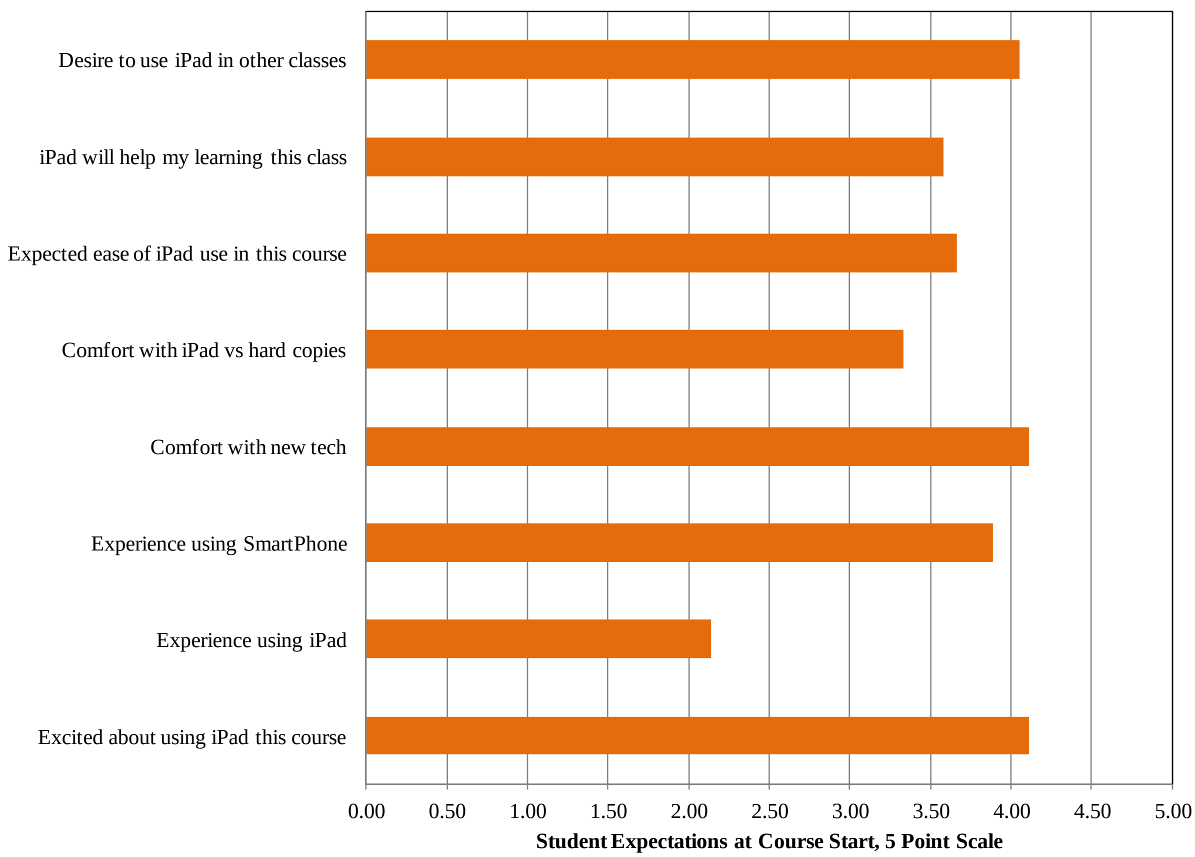

Figure 3: Student Survey Results - Expectations at Course Start

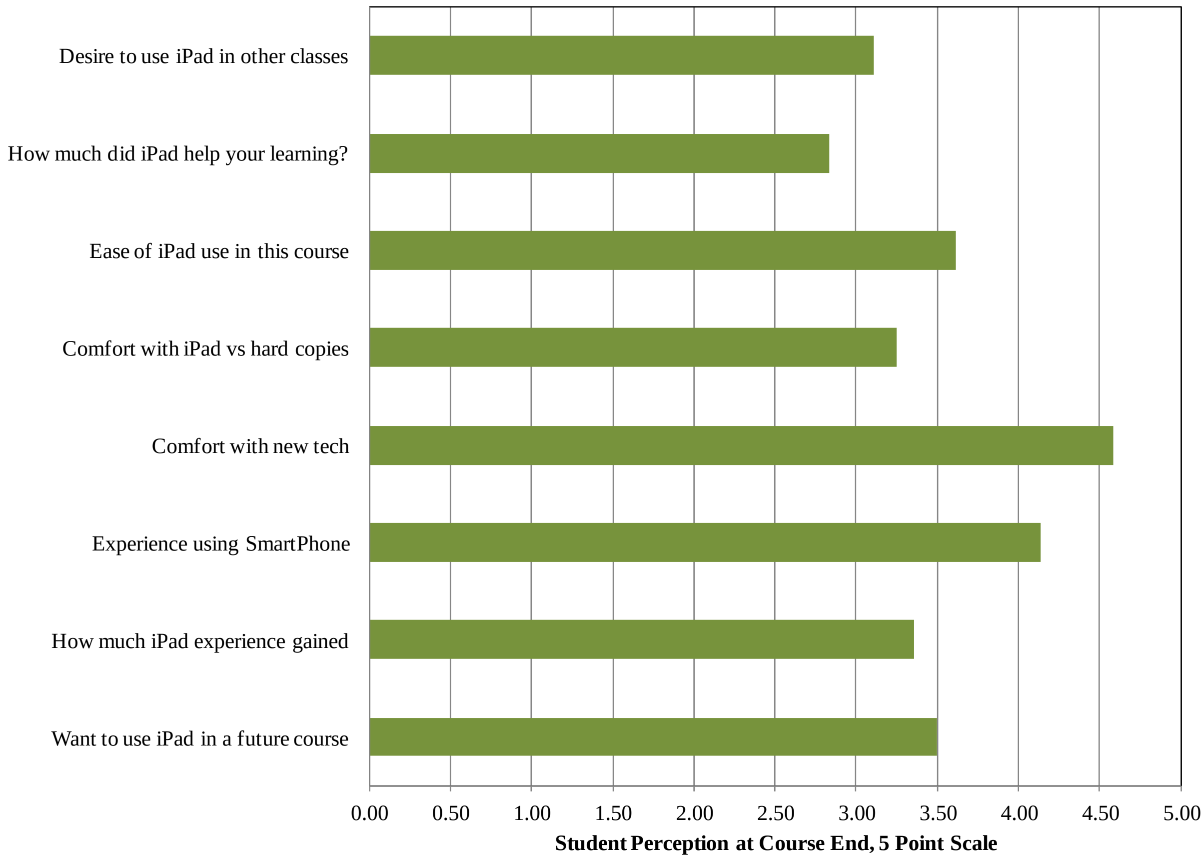

Figure 4: Student Survey Results - Perceptions at Course End

Three questions asked but not represented in the figures above were related to e-book preference, iTunes accounts and time division between the university-issued laptops and the iPads. Among these, the preference for e-books was greater prior to iPad use, with 61% of students stating a preference for e-books at the beginning and 44% preferring e-books at the end of the semester. In regards to time division between the technologies offered (laptops versus iPads), student expectations closely matched perceptions at completion, with a tiny change from 53.3% iPad time predicted by students versus 54.4% perceived at semester's end. In terms of iTunes accounts, nearly 83% had accounts at the beginning of the semester and all students had an account by the end.

In an effort to distill the survey data collected, the data presented in Figures 3 and 4 was compared and changes in student perceptions plotted in Figure 5. As seen in this summary plot, student preference for iPad use deteriorated significantly throughout the semester. The data presented is examined in greater detail in the Analysis section.

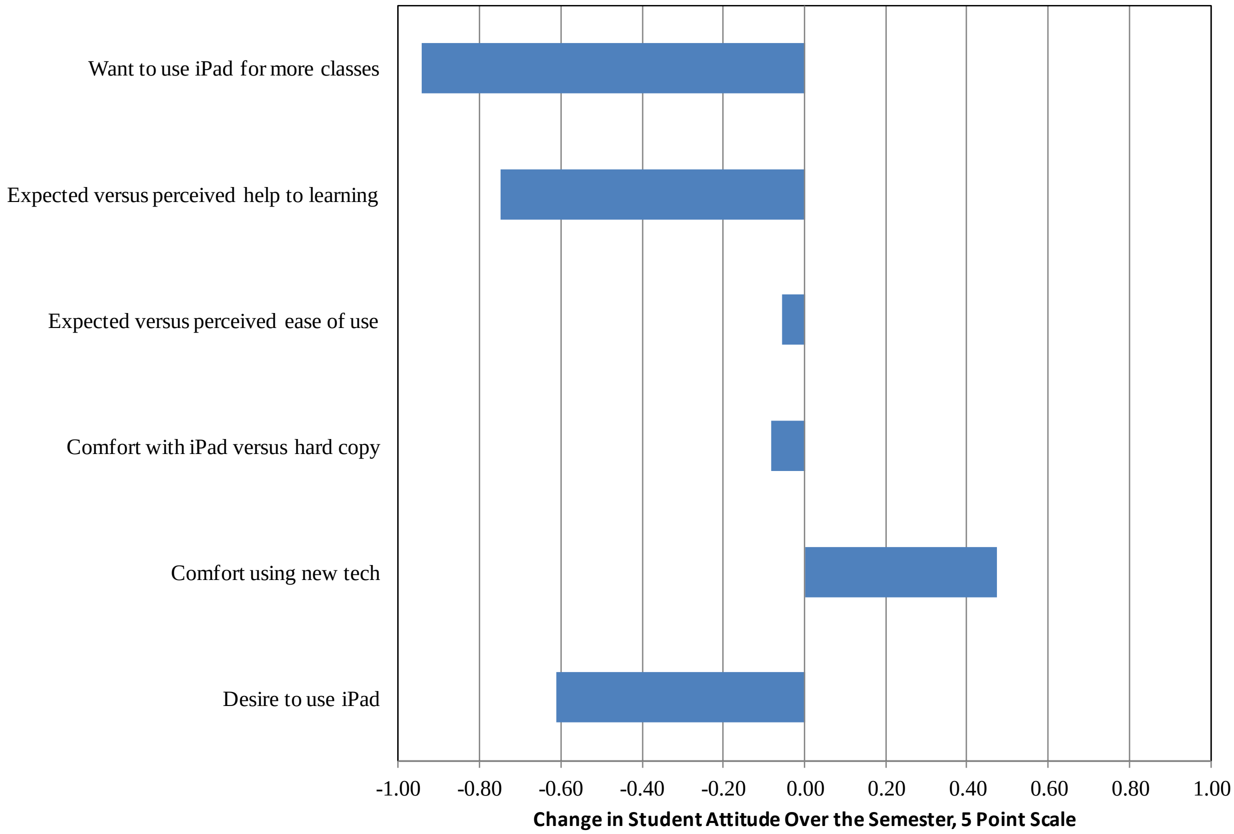

Figure 5: Change in student perception over time

To supplement the written survey instruments, two focus sessions of two groups each were conducted during the semester. The initial interviews were conducted on lesson six and the closing interviews were conducted on final lesson of the course. The instructor did not attend the focus groups to prevent the possibility of perceived or actual bias during the course. For each group, two groups of 4 students each were interviewed for about 30 minutes, using the script attached in Appendix B as a guide to the discussion. Summary observations of the interviews:

- The students presented as highly competent and sober consumers and users of technology platforms; they knew what they were getting into from the start.
- Portability and long battery life were emphasized throughout all interviews as key advantages of the iPad. Not having to carry books in the backpack was a big positive.
- Lack of easy WiFi hookup within our university was a major blow to adoption. Network security interlocks were also an obstacle.
- All interviewees thought the device was very user friendly and they were comfortable with the similarities between the iPad and their Smartphones.
- All students interviewed felt the iPad was very helpful in their humanities classes and great for personal light reading. Further, going paperless was environmentally important

to some students, inspiring greater eReader effort. No students actually bought and used the hard-copy book. Student C bought the hardcopy but then gave it away to a friend early in the semester despite her stated reluctance to using the iPad as a reader; as of the interview, she was still not in possession of the book and seemed disinterested in getting it back, evidence of a clear preference for the electronic text.

- The iPad was seen as a poor tool for note taking by most students. Student A showed a strong desire to integrate the iPad into their everyday student life. That student, when interviewed at the end of the semester, attested to a 100% conversion to iPad use in preference to traditional paper notes and books. Student B wanted to use it as a "miniature instant laptop" and stated that he would take notes on the iPad. At the end of the semester, Student B reported that she had abandoned that effort. On a related note, the on-screen keyboard was sometimes mentioned as a problem; some students bought an external add-on keyboard.
- Being able to search the textbook using a text query was seen as a major advantage over traditional books, but not being able to see two pages at once was a problem.
- Students seemed more excited about the ancillary uses (communication functions, calendars, etc) than they were about course-driven uses like reading the textbook. For instance, scheduling and sharing schedules between devices and peers using the iPad was seen as a positive. Interconnectivity with their Smartphones and other devices was also very important to the students.
- 75% stated a desire to buy an iPad of their own at the end of the semester when we took the devices back.
- A protective case to allow survival in the student backpack was important to some interviewees. Students also requested that the iPads be issued with a stylus.
- In terms of educational applications, NotesPlus was popular, as was Numbers and iAnnotate. Some limited games and movie applications were also popular. Lack of a sophisticated math modeling program, MATLab, Mathematica, MathCAD and others, was seen as a problem.
- Students used it to keep inventories and track attendance in student clubs and functions.
- Inability to print seamlessly was a major problem.
- Having all course materials available in a PDF format was essential to the students. Those materials which were not digitized were a barrier for students.
- Occasional "freezes" were a problem, and students worried that the machine would crash during a testing event. None actually experienced an in-class system crash.
- Among their electronic "Triumvirate" (laptop, Smartphone and iPad) all students expressed that the iPad was their least essential item. The overall impression at the end of the semester was that the iPad was a supplement to their laptops rather than a replacement item, even for Student A (an enthusiastic early adopter).

Data Analysis

Based on the data presented, the authors offer the following conclusions, opinions and observations:

1. Overall student response to the inclusion of iPads as a primary course resource was poor. There is a clear sense that the technology's drawbacks outweigh the advantages, and some students stated that in essentially those same words in the focus groups. Further, both overall desire to use the iPad and desire to use the iPad for future academic work fell significantly over the course of the semester. Lastly, students found that the actual benefit to their learning did not meet their early-semester expectations.
2. The principle utility of the device appears to be as an e-reader for traditional books, such as those typically used in humanities classes, rather than for engineering texts, which tend to be more graphically intense.
3. Without broadly distributed and readily available WiFi connectivity, iPads are only marginally useful. Deployment of this technology without strong underlying WiFi and IT infrastructure to support it is not advised.
4. Based on the focus group results, student's actual use of and preference for the electronic textbooks was considerably greater than their perceived preference. No students really wanted or used a hard copy book when the electronic book was available. Student's stated dislike of electronic texts may be a reflection of long-observed student resistance to reading engineering textbooks and thus be totally unrelated to the platform or format of the reading assignments. Further study would be required to answer this complex question.
5. Recommending certain tools to the students, especially an application similar to iAnnotate, may help to jump-start the student's note-taking and e-text adoption process if using a .pdf version of the text. Making a course text in iAuthor and creating an e-text book for use with the iPad would make the electronic text much easier to use. iAuthor also provides so many more functions and widgets to enhance the e-text book experience for the student.
6. Each iPad user needs an iTunes account to upload the course text, buy applications, etc. So, an increase in iTunes accounts is not surprising.

Recommendations for iPads in the Engineering Classroom

- Strongly consider leaving the choice of electronic versus hard-copy in the hands of the student. There is little utility in forcing students down a single path, and as research advances in this area, it seems likely the student learning styles will have an impact on their preferred reading mode.

- Connecting the iPad in the classroom can be simple if you don't need mobility. Using a VGA adapter is an easy solution to projecting on a screen. This option ties you to a podium. The other option is using an Apple TV in conjunction with the iPad to project on a screen. This option keeps the iPad mobile.
- Applications like Air Chalk are good techniques for some academic material. This was not a good tool for the engineering classroom. We recommend an instructor experiment with different whiteboard applications or typing applications for use while projecting in the classroom.
- Microsoft PowerPoint does not display correctly from an iPad onto a screen in the classroom. I suggest using Keynote (Apple's version of PowerPoint) instead of PowerPoint.
- Access to files is not easy unless they are stored on the iPad. Document servers cannot be accessed via the iPad alone. A computer is required to access document servers and place the files on the iPad prior to class.
- Dropbox was a good web server to use to transfer files back and forth between your computer and the iPad.

Conclusion

This study yielded the net result that students do not want to use the iPads for future engineering courses. After two formal surveys and two informal focus groups over the span of one semester, student's perception of using an iPad in an engineering course changed. Students originally wanted to use the iPad in an engineering course, expected the iPad to enhance their learning, and wanted to use the iPad in other courses; however, after a semester of use the student's perceptions changed. They responded to our exit survey indicating less of a desire to use the iPad in future engineering courses, less of a perceived benefit to their learning, and less of a desire to use an iPad in an academic setting.

Many challenges identified by the students include WiFi availability, e-text usability and preference for hard copy texts. The iPad in the classroom could be a good tool but not very useful in the engineering classroom at this time. The lack of an interactive course e-text reduced the learning enhancement capability of the iPad. Powerpoint does not display correctly from the iPad when projected onto a screen. Putting documents on the iPad requires a computer or a web server. We recommend further studies with iPads in the engineering classroom using an interactive e-text and a reliable WiFi connection. A key to the iPad use in higher education seems to be the initial comfort level of the student with a similar device and their desire to learn methods of use early in a course.

For future study, the connection of memory with tactile interaction should be carefully investigated. It seems possible that the physical interaction with books and paper, including texture, smell, weight and other sensory associations helps trigger memory and perhaps routines associated with solving certain types of problems (looking at the steam tables, a pump performance curve, etc).

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APPENDIX A: Pre and Post-Course Surveys of Attitudes and Perceptions

Pre-Course Survey of Student Attitudes:

1. On a scale of 1 (not excited at all) to 5 (very excited) how excited are you about using the iPad in this course.

2. On a scale of 1 (no experience) to 5 (I own one and use it in the classroom), how much experience do you have using an iPad?

3. On a scale of 1 (no experience) to 5 (I own one and use it regularly), how much experience do you have using a touch screen Smartphone?

4. On a scale of 1 (not comfortable) to 5 (very comfortable), how comfortable are you with new software and electronic technology?

5. On a scale of 1 (not comfortable) to 5 (very comfortable), how comfortable are you with using an iPad instead of hard copies for this course's written material?

6. On a scale of 1 (difficult) to 5 (simple), how easy do you think an iPad will be to use in this course?

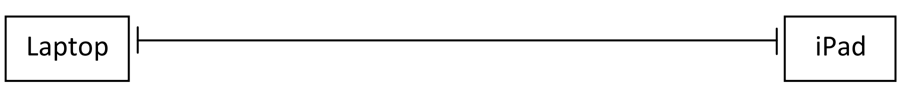
7. On a scale of 1 (not helpful) to 5 (very helpful), to what degree do you think an iPad will help your learning in this class?

8. On a scale of 1 (not at all) to 5 (every class), to what degree would you want to use iPads in other classes?

9. Would you prefer having textbooks as eBooks on the iPad rather than a printed book?(Y/N)

10. Did you have an iTunes account before this course?(Y/N)

11. On the following scale, indicate with an "X" how you anticipate dividing your time between a laptop and an iPad for this course.



Post-Course Survey of Student Perceptions:

1. On a scale of 1 (no desire) to 5 (strong desire) how much would you like to use an iPad in a future course?

2. On a scale of 1 (gained no experience) to 5 (I now own one (or plan to own one) and will use it in future classes), how much experience did you gain using an iPad?

3. On a scale of 1 (no experience) to 5 (I own one and use it regularly), how much experience do you have using a touch screen Smartphone?

4. On a scale of 1 (not comfortable) to 5 (very comfortable), how comfortable are you with new software and electronic technology?

5. On a scale of 1 (not comfortable) to 5 (very comfortable), how comfortable are you with using an iPad instead of hard copies for this course's written material?
6. On a scale of 1 (difficult) to 5 (simple), how easy was the iPad to use in this course?

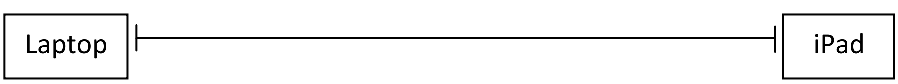
7. On a scale of 1 (not helpful) to 5 (very helpful), to what degree did the iPad help your learning in this class?

8. On a scale of 1 (not at all) to 5 (every class), to what degree would you want to use iPads in other classes?

9. Would you prefer having textbooks as eBooks on the iPad rather than a printed book?(Y/N)

10. Did you create an iTunes account during this course?(Y/N)

11. On the following scale, indicate with an "X" how you divided your time between a laptop and an iPad for this course.



APPENDIX B: Question Guide for Focus Groups

Early-semester question bank for interviewer

Have you had a chance to use your iPad yet?

What was your first impression of this tech platform? Are you fired up or panicking?

How does the iPad compare with tech you've used before?

How do you expect to use the device for class?

How do you expect to use the device for tasks other than this class?

What's the Big Payoff going to be?

What problems or barriers do you anticipate?

Do you think you'll buy one for yourself when we take this one back?

Do you see a better option that the iPad or other ways to make the iPad itself more effective in the classroom?

Any other thoughts you'd like to share?

End-semester question bank for interviewer

How much did you use your iPad?

How easy was it to use? Are you fired up or frustrated?

How does the iPad compare with tech you've used before?

How did you use the device for class?

How did use the device for tasks other than this class?

What was the Big Payoff?

What problems or barriers did you encounter?

Do you think you'll buy one for yourself when we take this one back?

Do you see a better option that the iPad or other ways to make the iPad more effective in the classroom?

Any other thoughts you'd like to share?

APPENDIX C: Reference Card for the Course (this is the only hard copy reference allowed on exams for the students in this study)

System Equations

Closed System

COM: $m = \text{constant}$

COE (1st Law of Thermo):

$Q_{12} - W_{12} = m[(u_2 - u_1) + ½(V_2^2 - V_1^2) + g(z_2 - z_1)]$

where $W_{12} = W_{bdy_{12}} + W_{sh_{12}}$ **and** $W_{bdy_{12}} = \int_1^2 PdV$

Entropy Balance (2nd Law of Thermo): $S_{prod} = m(s_2 - s_1) - \sum_j \left(\frac{Q_{12}}{T_b}\right)_j$

(Is the process possible?)

Cycles

Energy Balance: $Q_{cycle} = W_{cycle}$ **(HIP to WIN)**

$Q_H + Q_L = W_{Net}$

Reversible Cycle: $\frac{T_L}{T_H} = -\frac{Q_L}{Q_H}$

Power Cycle (Heat Engine)

Any Power Cycle: $\eta_{th} = \frac{W_{Net}}{Q_H} = 1 + \frac{Q_L}{Q_H}$

Reversible Power Cycle: $(\eta_{th})_{max} = 1 - \frac{T_L}{T_H}$

Refrigeration Cycle

Any Refrigeration Cycle: $COP_R = -\frac{Q_L}{W_{Net}} = -\frac{Q_L}{Q_H + Q_L}$

Reversible Refrigeration Cycle: $(COP_R)_{max} = \frac{T_L}{T_H - T_L}$

Heat Pump Cycle

Any Heat Pump Cycle: $COP_{HP} = \frac{Q_H}{W_{Net}} = \frac{Q_H}{Q_H + Q_L}$

Reversible Heat Pump Cycle: $(COP_{HP})_{max} = \frac{T_H}{T_H - T_L}$

Control Volume

Multiple Inlets and Exits (Steady, Uniform Flow)

COM: $\sum \dot{m}_i = \sum \dot{m}_e$

COLM: $\sum \vec{F} = \sum \dot{m}_e \vec{V}_e - \sum \dot{m}_i \vec{V}_i$

COE (1st Law of Thermo): $\dot{Q}_{ie} - \dot{W}_{ie} = \sum \dot{m}_e \left(h_e + \frac{V_e^2}{2} + gz_e\right) - \sum \dot{m}_i \left(h_i + \frac{V_i^2}{2} + gz_i\right)$

where $\dot{W}_{ie} = \dot{W}_{sh}$ **only**

Entropy Balance (2nd Law of Thermo): $\dot{S}_{prod} = \sum \dot{m}_e s_e - \sum \dot{m}_i s_i - \sum_j \left(\frac{\dot{Q}_{ie}}{T_b}\right)_j$

(Is the process possible?)

One Inlet/One Exit (Steady, Uniform Flow)

COM: $\dot{m}_i = \dot{m}_e = \dot{m}$ **and** $\dot{m} = \rho A V$

COLM: $\sum \vec{F} = \dot{m}(\vec{V}_e - \vec{V}_i)$

COE (1st Law of Thermo): $\dot{Q}_{ie} - \dot{W}_{ie} = \dot{m}\left[(h_e - h_i) + \left(\frac{V_e^2}{2} - \frac{V_i^2}{2}\right) + g(z_e - z_i)\right]$

COE (Energy Equation): $\frac{P_i}{\rho_i g} + \frac{V_i^2}{2g} + z_i = \frac{P_e}{\rho_e g} + \frac{V_e^2}{2g} + z_e + \frac{\dot{W}_{ie}}{\dot{m}g} + h_L$

where $h_t = \frac{(\dot{W}_{ie})_t}{\dot{m}g}$ **(turbine head) and** $h_p = \frac{(\dot{W}_{ie})_p}{\dot{m}g}$ **(pump head)**

Entropy Balance (2nd Law of Thermo): $\dot{S}_{prod} = \dot{m}(s_e - s_i) - \sum_j \left(\frac{\dot{Q}_{ie}}{T_b}\right)_j$

(Is the process possible?)

Special Case: Bernoulli Equation (COE)

Head Form

$\frac{P_i}{\rho g} + \frac{V_i^2}{2g} + z_i = \frac{P_e}{\rho g} + \frac{V_e^2}{2g} + z_e$

Pressure Form

$P_i + \frac{\rho V_i^2}{2} + \rho g z_i = P_e + \frac{\rho V_e^2}{2} + \rho g z_e$

Pitot-Static System: $P_0 = P_1 + \frac{\rho V_1^2}{2} \rightarrow V_1 = \sqrt{\frac{2(P_0 - P_1)}{\rho}}$

Internal Flow Equations

Ideal Gas

Ideal Gas Law: $PV = m\left(\frac{\bar{R}}{M}\right)T$ or $Pv = \left(\frac{\bar{R}}{M}\right)T$

Constant Specific Heats:

$u_2 - u_1 = c_v(T_2 - T_1)$

$h_2 - h_1 = c_P(T_2 - T_1)$

Psychrometrics

Humidity Ratio: $\omega = \frac{m_v}{m_a} = 0.622\frac{P_v}{P_a}$

Relative Humidity: $\phi = \frac{m_v}{m_g} = \frac{P_v}{P_g}$

Mixture Enthalpy (h): $(\dot{m}h)_{mixture} = \dot{m}_a h$

$h = h_a + \omega h_v$

Volumetric flow rate of atmospheric air: $\dot{V} = \dot{m}_a v$

Mixture volume per mass of dry air: $v = \frac{V}{\dot{m}_a}$

Pipe Flow

Reynolds Number $\text{Re}_d = \frac{\rho V_m d}{\mu} = \frac{V_m d}{\nu}$

$\text{Re}_d > 10{,}000 \rightarrow$ Turbulent
$\text{Re}_d < 2{,}000 \rightarrow$ Laminar

Head Loss $h_L = \sum h_{L,\text{minor}} + \sum h_{L,\text{major}}$

$h_{L,\text{major}} = f\left(\frac{L}{d}\right)\left(\frac{V_m^2}{2g}\right)$ $h_{L,\text{minor}} = K_L\left(\frac{V_m^2}{2g}\right)$

Static Fluid

Manometer Swim-Through Technique: $P_{\text{end}} = P_{\text{start}} + \sum_i (\pm \rho_i g h_i)$

Buoyancy: $F_B = \rho_{\text{fluid}} g V_{\text{body}} = \gamma_{\text{fluid}} V_{\text{body}}$ (V_{body} is submerged portion only)

Resultant Net Hydrostatic Force on Submerged Plane Surface:

Magnitude: $F_{R_{\text{Net}}} = (\rho_{\text{fluid}} g h_C)A = (\rho_{\text{fluid}} g y_C \sin\theta)A$

Direction: Acts inward and normal to wetted plane surface

Location (P_{atm} acting on both sides of submerged plane surface): $y_{CP} = y_C + \frac{I_{x_C}}{y_C A}$

Steady Flow Device Isentropic Efficiency

Turbine: $\eta_t = \frac{w_{ie}(\text{actual})}{w_{ie}(\text{ideal})} = \frac{h_i - h_e}{h_i - h_{e_s}}$

Compressor: $\eta_c = \frac{w_{ie}(\text{ideal})}{w_{ie}(\text{actual})} = \frac{h_i - h_{e_s}}{h_i - h_e}$

Pump: $\eta_p = \frac{w_{ie}(\text{ideal})}{w_{ie}(\text{actual})} = \frac{v_i(P_i - P_e)}{h_i - h_e}$

Nozzle: $\eta_n = \frac{\text{ke}_e(\text{actual})}{\text{ke}_e(\text{ideal})} = \frac{h_i - h_e}{h_i - h_{e_s}}$ $(V_i \approx 0)$