**The Evolution of Mobile Application Development**

*YI-CHEN, CHEN*
*N11564628*
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With the popularity of smart cellular telephones and the rapid advancement of information technology (IT), mobile applications seem to have taken on a more and more important role globally. Indeed, the evolution is intergrading applications into people's daily lives, as well as challenging data security and user experience technology.

During the past 40 years of development, from the 1st generation of mobile networks to the 5th generation, a lot of changes have been made to handheld computer technology and its highly common use in people's daily lives. A note-taking application is an example of a productive application that students can use for their university work. Traditionally, people just took notes in the simplest way, such as with a pen and paper, a highlighter, and an eraser; nowadays, the young generation tends to more and less find it hard to leave the various digital tools for keeping their ideas, while its data security may become a serious challenge.

Note-taking in lectures can be seen as the most critical skill for students to achieve academic success since time immemorial, helping students absorb knowledge correctly and effectively. According to Raney's experiment result (2015), the statement "Notability improved my note-taking skills." got a score of 4 on a five-point Likert scale, which shows that the participants somewhat agree that the Notability application does indeed improve their study performance. Due to the fact that Notability offers useful features such as recording lectures and synchronising audio with handwritten notes (Raney, 2015), based on official statistics, it has accumulated over five million users across 53 countries, including kindergarten through 12th grade, since it was first published 11 years ago (Notability, 2023).

However, the increasing number of users who use the app results in a large amount of stored data, which may raise security concerns. Unlike traditional ink on paper, application users may store any type of note on the software, for instance, text, picture, voice, or even media files that are not intended to be shown to the public except the file owner. Therefore, in order to prevent user data exposure to the risk of external threats, access control and data encryption technologies are becoming more and more important in both note-taking applications (Park et al., 2020). Additionally, it is not only applications that tend to integrate into people's lives, but also interaction between users and applications, which has been recognised as a significant area of research in the field of mobile application design. As the use of mobile devices expands, and systems become more embedded in various contexts, designing applications that meet the specific needs and preferences of users becomes challenging (Arhippainen & Tähti, 2003). Hence, it is necessary for individuals to contribute further advances regarding addressing challenges, whether in a work or educational environment.

In conclusion, from the first generation of mobile networks to the advent of 5G, mobile applications have significantly impacted improving people's productivity, yet the potential risks have come to the fore, which could be in terms of two ways: security of keeping user data and user experience design.

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RESEARCH REPORT

A careful experiment and a detailed statistical analysis of the data, using the most common opinion measuring scale, the Likert scale, support the statements I cited in my essay. Also, provide a survey result with specific discussion, condition visualisation, and a consistent limitation presentation, showing the article's testability.

ASE

# Dose- and Time-Dependent Benefits of iPad Technology in an Undergraduate Human Anatomy Course

**Marcella A. Raney***
*Department of Kinesiology, Occidental College, Los Angeles, California*

This study examined the impact of iPad integration on performance in an undergraduate gross anatomy course. Two out of six course sections were assigned to one of the following conditions: control (no iPad, $n = 61$); limited access (laboratory iPads, $n = 58$); and unlimited access (personal iPads, $n = 47$). Student knowledge was assessed over time during the semester with two practical examinations in laboratory and four multiple choice/essay examinations in lecture. The same PowerPoint presentations and examinations were utilized for all conditions. Mixed ANOVA analysis identified an interaction effect between time and condition for both laboratory ($F_{2,153} = 16.12$; $P < 0.05$) and lecture ($F_{6,462} = 5.47$; $P < 0.05$) performance. Between laboratory examinations, student performance was lower by 4.2% and higher by 3.0% in control and unlimited access conditions, respectively. Unlimited access students scored higher than control and limited access ($82.8 \pm 2.2$ vs $71.5 \pm 2.6$ and $74.3 \pm 1.7\%$; $P < 0.05$) and higher than control students ($78.7 \pm 2.1$ vs $70.6 \pm 2.0\%$; $P < 0.05$) on the third and fourth lecture examination, respectively. Post-semester surveys completed by experimental students (89.5% response rate) indicated that a greater percentage of unlimited vs limited access students agreed that laboratory (84.8 vs 56.3%, $P < 0.05$) and lecture (58.7 vs 14.6%, $P < 0.05$) performance was enhanced with the iPad. Results suggest that if students are given the opportunity to overcome the technology learning curve, tablet devices and relevant applications can be useful tools in human anatomy courses. Anat Sci Educ 9: 367–377. © 2015 American Association of Anatomists.

*Key words:* gross anatomy education; undergraduate education; mobile learning; mobile technology; anatomy apps; iPad technology; e-learning; digital anatomy

## INTRODUCTION

Mobile technology currently plays a significant role in education. For example, tablet sales to educational institutions doubled from 2011 to 2012 (Brustein, 2013). This has coincided with widespread availability of touch screen technology at the primary and secondary education level. Institutions of higher education are slowly, but surely following suit (Hargis et al., 2014; Ferdousi and Bari, 2015). Results from pilot studies suggest that mobile technology integration succeeds in creating an environment that is less teacher centered and more student centered and collaborative (Looi et al., 2010; Sheng et al., 2010; Hahn and Bussell, 2012; Wakefield, 2012; Fisher et al., 2013; Toh et al., 2013; Hwang and Wu, 2014). Indeed, mobile technology can positively impact a student's interest in learning when compared to traditional instruction (Hwang and Wu, 2014). Outside the classroom, tablets with wireless capabilities encourage course content exploration and the development of life-long learning styles/techniques that are specific to the individual (Looi et al., 2010; Morris et al., 2012; Shepherd and Reeves, 2012; Song et al., 2012; Wakefield, 2012; Martin and Ertzberger, 2013; Toh et al., 2013). In addition, mobile technology has the potential to support an environmentally friendly and paperless course.

While the use of mobile technology has increased on College and University campuses, the use of cadaver dissection in anatomy courses has decreased (McLachlan and Patten, 2006). Previous studies have indicated that tablets and relevant software applications (apps) can be a strong compliment to cadaver specimens (Mayfield et al., 2013; Lewis et al., 2014). However, faculty have been reluctant to replace live dissection with three-dimensional (3D) models and/or virtual dissection software like that available on mobile devices. Part of this reluctance may be related to the lack of an app

*Correspondence to: Dr. Marcella A. Raney; Department of Kinesiology, Occidental College, 1600 Campus Road, Los Angeles, California 90041, USA. E-mail: raney@oxy.edu

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database that includes a professional review of app content and accuracy. Although 3D4 Medical (2015), (3D4Medical.-com, LLC, San Diego, CA) and Visible Body (2015) (Argosy Publishing, Newton, MA) apps may be appropriate for undergraduate anatomy courses in health science curriculums, the apps do not provide adequate realistic detail for advanced anatomy courses like those instructed in medical school (Lewis et al., 2014). Nevertheless, a well-designed anatomy course that uses tablet technology can provide students with a multimodal educational experience independent of anatomy-specific apps, an approach which has been shown to improve student performance (Johnson et al., 2012; Rossing et al., 2012; Stewart and Choudhury, 2015).

Despite the proposed benefits of mobile technology for learning, in practice, faculty and students often disagree both within and between cohorts on the degree to which mobile technology can be a useful learning tool or a distraction in the classroom (Baker et al., 2012; Ifenthaler and Schweinbenz, 2013; Langmia and Glass, 2014; Stowell, 2015). It has been argued that the teaching and learning techniques achieved with mobile apps are effectively no different than those that can be achieved with alternative methods (Murray and Olcese, 2011). In addition, even though the prevalence of mobile technology is high among the 18–35-year-old demographic, a significant gap exists between access to devices for school-age children depending on income and school district which may negatively impact the learning experience of some students who are required to use devices for the first time (Rossing et al., 2012; Hesser and Schwartz, 2013; Purcell et al., 2013). Faculty who did not grow up using the devices may lack the appropriate training needed to effectively implement mobile technology into the classroom setting (Armstrong, 2011; Johnson et al., 2014). However, with adequate support, there is evidence that social constructive pedagogy is enhanced beyond what is possible without mobile tablet technology (Cochrane et al., 2013). Furthermore, adoption of an undergraduate curriculum designed to improve tablet technology competencies is likely to make students more competitive in the job market (Johnson et al., 2014; Fuller and Joynes, 2015).

A majority of previous studies conducted on tablet use in the classroom have primarily focused on student and faculty perception (Rossing et al., 2012; Wakefield, 2012; George et al., 2013; Nguyen et al., 2015). Few studies have directly measured the impact of tablet technology on classroom performance. Additionally, in a majority of pilot programs for anatomy education, students have been given devices to use for specific assignments or projects or as tools in laboratory for short durations as opposed to full classroom integration (Coulby et al., 2011; Hahn and Bussell, 2012; Hesser and Schwartz, 2013; Lewis et al., 2014; Shoepe et al., 2015). Therefore, the purpose of this comparative study was to determine the impact of tablet technology integration with the use of the iPad at varying doses and durations on student performance in an undergraduate human anatomy course. Based on previous studies, it was hypothesized that student performance would be positively related to iPad exposure.

# METHODS

## Study Design

All procedures used in this study were approved by the Occidental College Institutional Review Board (HSRRC #Rane-D12012). Over the course of three years, six different undergraduate gross anatomy course sections using the same curriculum (Human Anatomy II) participated in this study as an extension of an iPad faculty learning community and College-wide iPad pilot program. Two of the six course sections were assigned to one of the three conditions: no iPad control (CTL), limited iPad access (LTD), and unlimited iPad access (UNL). In the limited access condition, students had access to the device during scheduled laboratory times only. In the unlimited access condition, students had access to the device during laboratory, lecture, and outside of class. Condition assignment was determined prior to the beginning of each semester based on the availability of College-owned pilot iPads and the number of classes that had previously completed the study for a given condition. Throughout the three years of data collection, condition assignment was distributed as follows: year 1: CTL and LTD; year 2: LTD and UNL; year 3: CTL and UNL.

Immediately following iPad distribution, a comprehensive iPad tablet and app training was provided by staff from the Center for Digital Liberal Arts (CDLA). The instructor, who participated in a two-semester iPad faculty learning community prior to the first class, was available for the complete duration of all laboratory meetings and during office hours to provide additional technological assistance. Tablets used in the LTD condition were preloaded with anatomy-specific apps including 3D4 Medical (2015) Pro Series (3D4Medical.-com, LLC San Diego, CA); Visible Body (2015) (Argosy Publishing, Newton, MA); 3D Brain (2015) (Cold Spring Harbor Laboratory, Cold Spring Harbor, NY); Upper Respiratory Virtual Lab (URVL, 2013) (Georgia Regents University, Augusta, GA); and EyeDecide (2015) (Orca Health, Inc., Sandy, UT). Unlimited access tablets were temporarily registered to individual students using a unique Apple ID allowing these students to configure the device and purchase apps according to their personal preference. Unlimited access students were provided vouchers for the same anatomy-specific apps used in the LTD condition as well as apps for note-taking, student response, and creative/collaborative purposes. The specific apps included Notability (2015) (Ginger Labs, Inc, San Francisco, CA), Socrative Student (2015) (Socrative, Inc., Cambridge, MA), Educreations (2015) (Educreations, Inc., Palo Alto, CA), and DisplayNote (2015) (DisplayNote Technologies, Belfast, Ireland). When possible, the free version of the app was installed. Paid-for apps such as 3D4 Medical Pro Series (2015), Visible Body (2015), and Notability (2015) ranged in price from $2.99 (Notability) to $29.99 (Visible Body) on the app store. However, as a result of mass purchase, these costs were cut by approximately 50%. Specific apps were selected after consultation with CDLA staff, review of previous studies, and self-guided experimentation by the course instructor.

## Cohort Characteristics

A total of 166 undergraduate students ranging in age from 19 to 22 years and representing multiple class ranks (sophomores = 47.6%, juniors = 34.3%, seniors = 17.1%) completed all quantitative aspects of the study. A majority of students were kinesiology majors (68.5%) followed by Biology (11.3%), and Biochemistry (6.5%). The remaining students majored in a variety of departments representing all three academic divisions: sciences, social sciences, and arts and humanities. Due to the inconsistent course enrollment from semester to semester, a greater number of students participated in the CTL and LTD conditions (CTL = 61; LTD = 58; UNL = 47). There was no difference between groups in the distribution of sex (males = 63; females = 103; $\chi^2_{2,166} = 0.47$; $P = 0.791$) or learner type as assessed at the beginning of the semester with the online VARK learning style questionnaire (multimodal = 90 (54.2%); visual = 18 (10.8%); aural = 15 (9.0%); read/write = 10 (6.0%); kinesthetic = 33 (19.9%); $\chi^2_{8,166} = 2.70$; $P = 0.610$) (VARK, 2015). Previous iPad experience was also not different between experimental groups (none = 89; used iPad in another course = 4; own a personal device = 12; $\chi^2_{2,105} = 5.14$; $P = 0.077$). The data from 12 additional students (CTL = 3; LTD = 6; UNL = 3) who dropped the course prior to the final examination was not included in the analysis.

## Gross Anatomy Course Description

Human Anatomy II includes three 55-minute lectures and one three-hour laboratory meeting per week during a 15-week semester. Two laboratory sections are offered for each lecture class. In this study, the same faculty member instructed all lecture and laboratory sections. Due to College breaks and holidays, the course meets for a total of 73 hours (37 lectures and 13 laboratories). Enrollment is restricted to sophomores, juniors, and seniors. Curriculum includes a structural survey of the human body covering the nervous, endocrine, cardiovascular, lymphatic, respiratory, digestive, urinary, reproductive, and integumentary systems. The material for each system is covered in one to two weeks with the exception of the nervous system which is covered over a period of five weeks. The course is designed as a prerequisite to the human physiology course required for pre-health students. Three specific course objectives are listed in the syllabus: (1) to identify the location and function of important body landmarks in each of the systems covered from a variety of subsection views; (2) to understand how specific anatomical features confer specific functions in the human body; (3) to develop a basic understanding of how and where systems of the body work together for optimal performance. Traditionally, this course is instructed using the techniques described for the control condition.

**Lecture.** Course lecture material was delivered by the same instructor via PowerPoint® (Microsoft Corp., Redmond, WA) for all three conditions. Lecture slides were made available to all students on the course management system Moodle, version 2.6 (Moodle Pty Ltd, Perth, Australia) one week prior to lecture. In addition to traditional lectures, each class period began with the presentation of review questions from the previous lecture in sample examination formats. In the CTL and LTD conditions, students raised their hands to provide answers while in the UNL condition, every student responded to the question using the Socrative app on the iPad. The Socrative app allowed the instructor to create a database of questions and to present appropriate questions at-will using the internet. In the CTL and LTD conditions, the correct answer to sample examination questions was provided orally by the instructor and in the UNL condition, the Socrative app informed students of whether or not they had selected the correct answer as soon as it was submitted. Anonymous live results were also visible on the projector screen. At least once per week, all students were required to participate in collaborative small group activities such as comparative drawing and labeling of anatomical structures, preparation of their own mini lectures, or case studies. In the CTL and LTD condition, students frequently came to the board while students in the UNL condition completed group assignments and then projected them from their seat.

**Laboratory.** The instructor did not lecture during laboratory sessions. Rather, students were assigned a given number of landmark terms each week. Laboratory time was devoted to independent and collaborative learning of the location and function of each structure by consulting the textbook (CTL) and/or apps and the internet (LTD and UNL) while interacting with life-size and bigger than life-size 3D anatomical models. Due to budget and space limitations, students did not have access to cadaver or prosected specimens. In all conditions, each student was required to orally present the location and function of a subset of the week's terms to the rest of the laboratory section. All students earned participation points through the completion of an independent out-the-door identification quiz covering the assigned terms. The number of correct responses did not impact course grade and was not used to compare knowledge between groups. Out-the-door quizzes were administered orally in the CTL condition while students in the LTD and UNL conditions completed the out-the-door quizzes within the Moodle website on the iPad. In addition to practice with the 3D models and/or iPad apps available in laboratory, students were required to complete assignments using virtual dissection software (CTL only) or the 3D4 Medical apps (LTD and UNL) outside of scheduled laboratory time.

**Assessment.** All students completed the online VARK learning style questionnaire (2015) at the beginning of the semester. The VARK questionnaire developed by Fleming et al. (2015) poses a series of questions related to the sensory modalities one prefers to use to take in information (V = visual; A = aural; R = read/write; K = kinesthetic) and then creates a profile and suggestions for more personalized learning methods.

Student knowledge in lecture was assessed with four examinations including multiple choice and short essay-style questions. Each examination was cumulative spanning material from the beginning of the semester to the examination date. Student knowledge in laboratory was assessed via traditional landmark identification practical examinations using 3D anatomical models. Practical examinations were not cumulative; however, the second practical covered ~20% more anatomical landmarks. The same examinations were distributed in all three conditions. In an attempt to minimize the impact of examination content sharing between students in different course sections, the instructor did not return examinations and did not post answer keys. The data collected from students who did not complete all six assessments was eliminated from the analysis.

In addition to student knowledge, every LTD and UNL student who took the final examination was given a link to a 36- and 42-item online postsemester survey, respectively, to assess personal practice and attitudes about the use of the iPad as a supplemental instructional and study tool for the anatomy laboratory and/or lecture. The survey contained questions related to (1) student demographics (sex, class year, major, learner-type, previous iPad exposure), (2) traditional classroom practices (note-taking, use of textbook, incorporation of technology), and (3) student perceptions related to

## Table 1.

Student Perceptions of iPad Impact on Learning

| Survey statement | LTD Medians (IQR) | UNL Medians (IQR) | Mann–Whitney ($U_{92}$) | *z*-score | *P*-value | *r*-score | Effect size |
|---|---|---|---|---|---|---|---|
| The use of the iPad in Human Anatomy improved my ability to visualize where anatomical structures are located within the body. | 4 (3–4) | 4 (4–5) | 915 | −1.54 | 0.125 | N/A | N/A |
| The iPad is superior to the 3D anatomical models available in laboratory for learning the location of anatomical landmarks. | 2 (1–3) | 2 (1–3) | 894 | −1.66 | 0.098 | N/A | N/A |
| As a result of this course, I now prefer to study for anatomy laboratory quizzes and practicals using the iPad. | 2 (1–3) | 4 (3–4) | 425 | −5.30 | <0.001 | 0.55 | Large |
| My performance in laboratory was enhanced due to the introduction of anatomy-specific iPad apps. | 4 (3–4) | 4 (4–4) | 771 | −2.92 | 0.004 | 0.30 | Medium |
| My performance in lecture was enhanced due to the introduction of anatomy-specific iPad apps. | 3 (2–3) | 4 (3–4) | 600 | −4.01 | 0.004 | 0.41 | Medium |
| The technology component of the iPad detracted from my ability to learn material. | 2 (1–2) | 2 (2–2.25) | 915 | −1.53 | 0.125 | N/A | N/A |
| If given the opportunity, I would participate in another iPad pilot instructional program. | 4 (3–5) | 4 (4–5) | 817 | −2.15 | 0.031 | 0.22 | Small |
| If available for checkout at the library, I would checkout an iPad to help study for courses with similar instructional applications/electronic texts in lieu of a laptop. | 3 (2–4) | 3.5 (2–4) | 1055 | −0.21 | 0.837 | N/A | N/A |
| The College should increase the utilization of iPads in the classroom and laboratory. | 4 (3–4) | 4 (4–5) | 673 | −3.32 | 0.001 | 0.34 | Medium |

LTD, limited access (iPad available in laboratory only); UNL, unlimited access (personal iPad). Students asked to rate how well they agreed with a statement on a five-point Likert scale where: 1 = strongly disagree; 2 = somewhat disagree; 3 = neutral; 4=somewhat agree; 5 = strongly agree. Group results reported as medians and interquartile ranges (IQR).

iPad and iPad apps. The six additional questions in the UNL condition referred to apps not available in the LTD condition. The third section of the survey consisted of 5-point Likert-type scale statements in which students responded with a degree of agreement or disagreement (Tables 1 and 2) as well as open-ended questions related to perceived strengths and weaknesses of iPad incorporation into the laboratory and lecture. Likert-scale statements were developed as a result of previous technology perceptions presented in the literature and feedback received from a piloted version of the survey in a Musculoskeletal Anatomy course (Looi et al., 2010; Hahn and Bussell, 2012; Song et al., 2012).

## Statistical Analyses

All quantitative analyses were performed using IBM SPSS Statistics, version 22 (IBM Corp., Armonk, NY). An $\alpha$ of 0.05 was adopted as the standard for significance.

Lecture examination reliability was assessed with Cronbach's alpha as described by Wells and Wollack (2003). Multiple choice sections on all four lecture examinations were shown to be reliable indicators of classroom performance with correlational coefficients >0.70 (Examination #1: 0.777; Examination #2: 0.780; Examination #3: 0.804; Examination #4: 0.785). Validity and reliability of the final survey were tested using Kendall's tau and Cronbach's alpha, respectively. Specifically, Likert-scale questions were divided into three categories for perceived effectiveness of iPad technology: laboratory performance, lecture performance, and general learning benefits. Within each category, student agreement/disagreement to an umbrella statement ("My performance in laboratory was enhanced due to the incorporation of the iPad."; "My performance in lecture was enhanced due to the incorporation of the iPad."; and "The College should increase the utilization of iPads in the classroom and laboratory.") was compared to the mean score for specific statements related to that category (e.g., "The camera was useful for the laboratory portion of the course."; "I participated

## Table 2.

Student Perceptions of iPad Functions and Specific Apps

| Survey statement | UNL Medians (IQR) |
|---|---|
| My opinion about iPad technology changed as a result of this course. | 4 (4–5) |
| My performance in laboratory was enhanced due to the introduction of non-anatomy iPad apps | 4 (3–4) |
| My performance in lecture was enhanced due to the introduction of non-anatomy iPad apps | 4 (3–5) |
| I participated more in this class than in previous courses as a result of the Socrative quizzes | 4 (3–4) |
| I participated more in this class than in previous courses as a result of the DisplayNote activities. | 3 (2–4) |
| Notability improved my note-taking skills. | 4 (2.25–4) |
| The out-the-door Moodle identification quizzes were helpful for learning anatomical landmarks in lab. | 4.5 (4–5) |
| The camera was a useful tool for the lab portion of the course. | 4.5 (3–5) |

UNL, unlimited access (personal iPad). Students asked to rate how well they agreed with a statement on a five-point Likert scale where: 1 = strongly disagree; 2 = somewhat disagree; 3 = neutral; 4 = somewhat agree; 5 = strongly agree. Group results reported as medians and interquartile ranges (IQR).

more in this class than in previous courses as a result of the Socrative quizzes.", and "The technology component of the iPad detracted from my ability to learn material."). Kendall tau analysis demonstrated significant correlational relationships between the questions in both the lab performance ($\tau = 0.57$, $P < 0.05$) and general learning benefit categories ($\tau = 0.56$, $P < 0.05$), but not in the lecture performance category ($\tau = 0.14$, $P > 0.05$) of the survey. The entire Likert-scale section of the survey exhibited strong internal consistency as measured with Cronbach alpha ($\alpha = 0.89$, $n = 22$, $\mu = 80.2 \pm 11.3$).

Extreme outlier scores (more than three times the interquartile range from the rest of the scores) were identified for each examination using a Boxplot. Continuous data sets with extreme outliers removed were tested for normality using the Shapiro-Wilk, skewness, and kurtosis statistics. With the exception of the scores for the second laboratory practical, all data sets satisfied the assumption of normality. Additionally, although sample sizes differed, all lecture and laboratory examination scores satisfied the assumption of homogeneity of variance between the three groups as determined with Levene's test. As a result, a mixed between-within subjects ANOVA was conducted to assess the impact of the two experimental conditions on student's performance across time (Field, 2013; Laerd Statistics, 2013). Bonferroni's test for post-hoc multiple comparisons was performed when appropriate. Skewed practical scores were transformed using the Log10 function prior to ANOVA analysis and back transformed to report means and standard error (Field, 2013).

Demographic survey data (categorical) and responses to five-point Likert scale questions (ordinal) were compared between groups using the Chi Square and Mann–Whitney test, respectively, as outlined in Creswell (2014). Marginal homogeneity test, an extension of McNemar for paired outcomes with more than two categories presented in an ordinal fashion, was used to compare traditional classroom practices of the same subjects at the beginning of the semester to the end of the semester (Agresti et al., 1990).

A directed content analysis approach was used to analyze responses to open-ended survey questions (Hsieh and Shannon, 2005). Specifically, based on data collected in the pilot survey, responses to open-ended questions were grouped and coded according to the five mobile tablet functionality themes previously identified in the literature: access and availability of information, sharing and collaboration, novelty, learning styles and technology design, convenience, and usability (Rossing et al., 2012). Each theme included strengths and weaknesses related to iPad technology integration into the human anatomy course. During initial coding, recurring factors related to primary themes were noted (Table 3). The investigator reread each textual response and populated each factor with frequency values.

# RESULTS

## Quantitative Performance Assessment

A large and moderate interaction effect between time and condition was found for laboratory ($F_{2,153} = 16.12$, $P < 0.001$, $\eta p^2 = 0.174$) and lecture ($F_{6,462} = 5.47$, $P < 0.001$, $\eta p^2 = 0.066$) performance, respectively (Fig. 1). Post-hoc analysis revealed that CTL student performance was significantly higher than UNL student performance on the first practical examination. Within-subject effects demonstrated that CTL student scores were lower on the second practical examination compared to the first ($-4.2\%$, $P < 0.001$) while UNL student scores were higher on the second practical examination ($3.0\%$, $P = 0.005$) in the laboratory portion of the course. Additionally, on the third lecture examination, UNL students scored significantly better than CTL and LTD students ($82.8 \pm 2.2$ vs $71.5 \pm 2.6$ and $74.3 \pm 1.7\%$; $P < 0.05$). However, on the fourth lecture examination, UNL students scored significantly better only compared to CTL students ($78.7 \pm 2.1$ vs $70.6 \pm 2.0\%$; $P < 0.05$). Limited access students also scored higher than CTL students on the fourth lecture examination ($78.8 \pm 1.9$ vs $70.6 \pm 2.0\%$; $P < 0.05$).

Neither sex (lecture: $F_{6,453} = 1.430$, $P > 0.05$; laboratory: $F_{2,150} = 1.571$, $P > 0.05$), academic rank (lecture: $F_{12,444} = 1.189$, $P > 0.05$; laboratory: $F_{4,147} = 1.861$, $P > 0.05$), major

## Table 3.

Strengths and Weakness of iPad Technology

| Themes | Access and availability of information | Sharing and collaboration | Novelty | Learning style and technology design | Convenience and usability |
|---|---|---|---|---|---|
| Related factors | - Internet<br>- Moodle/dropbox<br>- Socrative/online quizzes<br>- Notability recording<br>- Non-educational apps/email | - Note-sharing<br>- Class participation | - Technology exposure<br>- Learning curve | - Touchscreen<br>- Camera<br>- Course-specific apps | - Portability<br>- Organization<br>- Keyboard/stylus<br>- App functions/reliability |

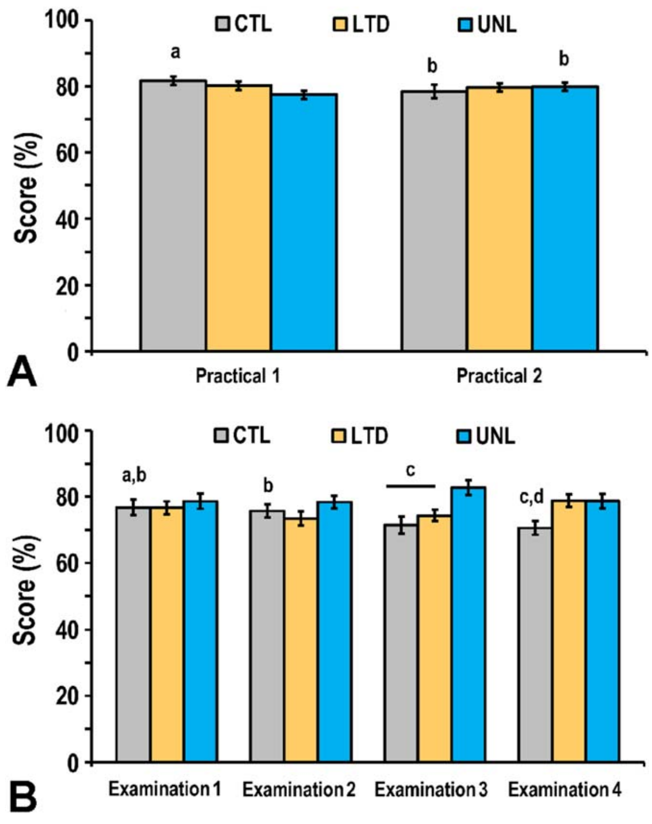
Accumulated results from open-ended survey questions asking students to indicate the biggest strengths and weaknesses of iPad technology incorporation into the Human Anatomy II course. Primary themes were adopted from results presented in Rossing et al. (2012). A minimum of four students made reference to all related factors.

(Kinesiology vs non-Kinesiology; lecture: $F_{6,453} = 2.006$, $P > 0.05$; laboratory: $F_{2,150} = 0.682$, $P > 0.05$), nor VARK learning style (lecture: $F_{24,426} = 0.671$, $P > 0.05$; laboratory: $F_{8,141} = 0.372$, $P > 0.05$) had any impact on performance changes measured over time for the three conditions.

## Survey Responses

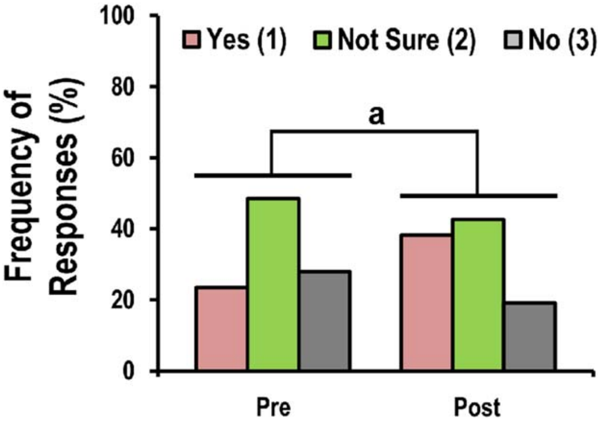
The response rate for the postsemester survey was 89.5%. Students in the LTD and UNL condition had similar perceptions about the benefits of the 3D images available on the iPad at the conclusion of the semester. Both groups also disagreed that the iPad detracted from learning (Table 1). Most students perceived that the apps were helpful for learning the location and orientation of anatomical structures in the body, but still preferred to use the iPad as a supplement rather than as a replacement to the 3D models available in laboratory. At the end of the semester, UNL students expressed a stronger desire to use the iPad over the textbook and/or internet to study for laboratory examinations outside of scheduled class time when compared to LTD students (Table 1). Indeed, 73.9% of UNL students agreed that the camera was a useful tool in laboratory. Students frequently took pictures of anatomical models, imported them into Notability and added annotations. Unlimited access students agreed more strongly than LTD students that incorporation of the iPad into the anatomy course improved their performance in laboratory and lecture. Additionally, UNL students expressed stronger support for additional College-sponsored iPad programs in the classroom (Table 1).

Students in the experimental groups who did not own an iPad prior to the study cited two primary reasons: (1) I prefer to use a laptop (34%) and (2) iPad technology is too expensive (45.7%). After one semester of unlimited iPad exposure, a majority of UNL students (78.3%) agreed that their opinion about iPad technology had changed (Table 2). This change in opinion coincided with a significant difference in student plans for purchasing a device to use for future academic purposes (std. $MH = 2.41$, $P = 0.016$, $r = 0.30$) (Fig. 2). Several students (26.5%) who were either "not sure" or had "no" plans to purchase a device before the semester began had upgraded their responses to "yes" or "not sure" by the end of the semester. Similarly, a significant number of




## Figure 1.

Impact of iPad integration on student performance in (A) laboratory and (B) lecture. CTL, control (no iPad); LTD, limited access (iPad available in laboratory only); UNL, unlimited access (personal iPad). Examination scores are reported in means ± standard error. (**A**) [a]Significant difference in score relative to UNL at the same time point; [b]significant difference in scores between the first and second practical examination, $P < 0.05$. (**B**) [a]Significant difference in score relative to Examination 3 for same condition; [b]significant difference in score relative to Examination 4 for same condition; [c]significant difference in score relative to UNL at the same time point; [d]significant difference in score relative to LTD at the same time point; $P < 0.05$.




## Figure 2.

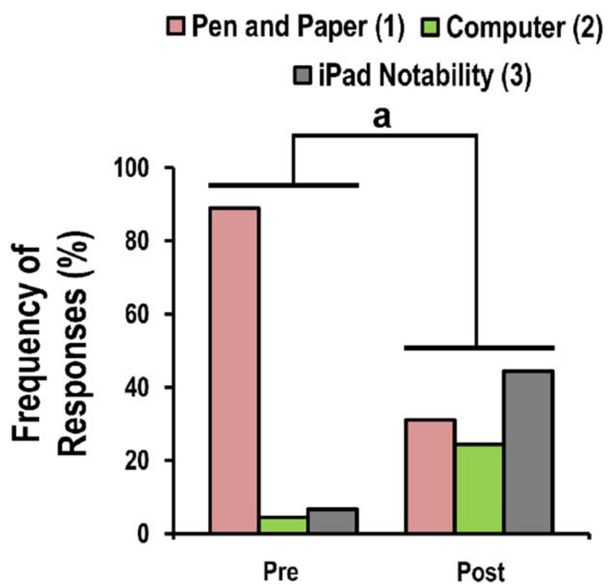
Impact of unlimited iPad access on student desire to purchase iPad for future educational purposes. Bars represent the percent of students responding "Yes," "Not Sure," or "No" to the multiple choice question "Do you plan on purchasing an iPad for educational purposes?" pre- and post-iPad integration. Responses were coded 1, 2, and 3, respectively; [a]moderate effect size for changes in response pre-post (Pre: Median (interquartile range) = 2 (2–3); Post: Median (interquartile range) = 2 (1–2), $P < 0.05$.

UNL students had changed their preferred method of note-taking from pen and paper or computer to the Notability app on the iPad (std. MH = −4.72, $P < 0.001$, $r = 0.66$) (Fig. 3). At the end of the semester, 69.6% of UNL students selected iPad Notability app as their preferred note-taking method.

In general, UNL students agreed that iPad technology improved engagement in the course (Table 2). Although 38.3% of UNL students admitted that they generally only use the textbook to complete the assigned reading and associated assignments in science courses, fewer students (10.9%) admitted that they only used the anatomy-specific apps to complete assignments for the experimental course. A majority of UNL students (80.4%) claimed that they used the apps to explore content in greater detail on a regular basis.

Out of a total of 221 responses provided on open-ended questions, 160 of the responses referred to strengths and 61 of the responses referred to weaknesses of iPad incorporation. The most commonly cited *strengths* were the ability to record lectures and synchronize the audio with handwritten notes using the Notability app (18.1%), ability to explore course content and manipulate 3D structures using 3D4 Medical apps (15.6%), the touchscreen feature (11.9%), and the camera (8.9%) (Table 3). Additionally, students often cited portability, collaborative features such as sharing notes and working with classmates during class, and organization capabilities as strengths. Students commented on the availability and accessibility of information delivered through the internet as well as with the course management system Moodle, Dropbox, and Socrative quizzes. Despite initial discomfort with anatomy app functions, students commented that it was easier to navigate between structure views and landmarks with the anatomy apps than with the textbook and that taking pictures of models during laboratory allowed them to more easily study anatomical landmarks outside of class time. One student summarized the benefits of the Notability app as follows: "*NOTABILITY WAS AMAZING... I look forward to using it to learn new material, study, using it for laboratory, and sharing notes and lecture recordings with other classmates. The Notability app also offered organization to the fullest. No more binders filled with laboratory terms, notes, and lectures. I cannot imagine taking any Kines*[iology] *courses without it now.*"

In surveys, students also highlighted the presence of a technology learning curve. Forty percent of the students who mentioned the difficulty and/or time required to learn how to use the iPad for educational purposes also indicated that this learning curve was worth it. One student wrote: "*After 2 semesters of being provided with an iPad by Occidental* [in two different departments as part of the iPad pilot program], *I have been converted from an anti-iPad/tablet person to a die-hard fan. Although I tried to be open-minded, I didn't use the iPad for note taking last semester at all. This semester I used my iPad in every class and activity and took it with me everywhere. I know that if I wasn't forced to use the iPad for both classes I wouldn't be as fond of it as I am now. It would be amazing and beneficial if everyone on campus was familiar with the iPad, however it would be very difficult to get everyone over that initial learning curve in the beginning.*" Another student who had previously taken Musculoskeletal Anatomy, a course not included in the research study, but that closely resembles the control condition with regards to the type of content delivered and the methods of instruction, commented: "*The benefit of the iPad definitely outweighs the cost of learning how to use it. I took Anatomy I and Anatomy II with Professor Raney, first without the iPad then with the iPad. My experience learning anatomy*




## Figure 3.

Impact of iPad integration on student note-taking preference. Bars represent the percent of students responding "Pen and Paper," "Computer," or "iPad Notability" to the multiple choice question "Which method do you most commonly use for taking notes in science courses?" pre- and post-iPad integration. Responses were coded 1, 2, and 3, respectively; [a]large effect size for changes in response pre-post (Pre: Median (interquartile range) = 1 (1–1); Post: Median (interquartile range) = 2 (1–3), $P < 0.05$.

*was certainly enhanced between the two courses due to the use of the iPad.*"

Similar to other studies, the most commonly cited *weakness* of the iPad was the touchscreen. In particular, students disliked that there was no keyboard and that it was difficult to write with a stylus (36.1%). Many students mentioned that specific apps suffered from obvious limitations and/or were unreliable (31.1%). Less frequently cited weaknesses included the possible distraction resulting from apps not related to the course or the email pop-up feature, the lack of a split-screen, and the inability to interact with text using the same tactile sensations one would use with printed text. Despite these weaknesses, several students expressed appreciation for the initial exposure to the general technology and educational uses of the iPad. One student wrote: "*I think having iPads in class can be very beneficial. People need to realize that they are built for much more than entertainment (Facebook, Netflix, games, etc.). I never realized how many educational apps there were, and taking the time to download and use them for a class was really eye opening.*"

## DISCUSSION

Although many previous studies have highlighted benefits and weaknesses of mobile technology in higher education, the current experiment is the first controlled study to measure and compare student outcomes throughout an academic semester. Data collected from both course examinations and postsemester surveys suggest that the apps available for the iPad and other mobile devices positively impact student performance in an undergraduate human anatomy course when integrated into course content delivery and exploration. In addition, results indicate that performance enhancement depends on the degree of tablet exposure. Quantitative and qualitative analysis confirm previous student perceptions and teaching theories that the benefits of mobile technology cannot be fully realized unless the device is available to the student for personal use inside and outside of the classroom (Rossing et al., 2012).

Fuller et al. (2015) recently argued that incorporating mobile technology into the learning environment should become compulsory. The results of this study suggest that Fuller's recommendation may be justified. Although all students owned cellular phones and had extensive experience with computers, a majority of students were exposed to a mobile tablet device for the first time in Human Anatomy II.

A closer look at the condition-specific differences in laboratory scores suggests that the technology learning curve, alluded to in many of the postsemester surveys, may have initially hurt the performance of UNL students who scored lower than CTL students on the first laboratory examination. The time that students devoted to learning how to use the technology likely detracted from the time that they would have normally spent learning course material. Subsequent examination results show that if technology did interfere with learning outcomes initially, the negative impact dissipated with time. Indeed, on the second more difficult laboratory examination, CTL student scores were significantly lower while UNL student scores were significantly higher relative to the first examination. Although scores were not significantly different between groups on the second laboratory examination, mean scores for both the LTD and UNL condition were higher than the mean score for the CTL condition. Therefore, if additional laboratory examinations had been administered, it is possible that UNL students may eventually score higher than CTL students.

Similarly, in contrast to the performance of control students, full iPad integration prevented a decrease in lecture examination score over time as examination difficulty increased. The importance of the duration of mobile technology exposure is exemplified by a lack of difference in scores between groups on the first and second lecture examinations as well as a significant difference in scores between students in the LTD and CTL condition only on the fourth lecture examination. It can be speculated, therefore, that experimental students spent time during the first half of the semester becoming familiar with tablet technology and learning how to integrate it into their personal learning strategies, a task that took longer for LTD students with limited iPad access. By the end of the semester, it appears that students in both the LTD and UNL conditions had developed and implemented effective study skills using mobile technology. Alternatively, students in the CTL condition were limited to traditional study methods which may not have been as effective for retaining the volume of information presented in the Human Anatomy II course.

It may be argued that learning outcomes in the CTL condition were affected by the awareness of CTL students that they were not being given an iPad. However, CTL condition examination scores in both year 1 and year 3 displayed a similar average and distribution as prestudy semesters for Human Anatomy II. Additionally, as reported in the results, previous iPad exposure was not different between LTD and UNL groups. Even though UNL students from the third year of the study would have had the opportunity to speak with UNL students from the second year of the study, the degree of agreement to the Likert-scale statement "My opinion about iPad technology changed as a result of this course" was not different between the two UNL courses. Anecdotally, the instructor overheard several students in both LTD and UNL classes verbally express concern related to "having to use the iPad." Therefore, together, these qualitative results suggest that it is more likely that the perceptions of students in the LTD and UNL condition rather than in the CTL condition would have negatively impacted learning outcomes at the beginning of the semester.

While students may initially resist the use of a device previously associated with entertainment, this study illustrates that student appreciation for the educational value of mobile technology changes with time. A switch in note-taking methods and increased time spent with course content resources outside of class are two prime examples of student evolution. Alternatively, the risk that mobile devices may lead to a disruptive learning environment does not appear to be supported in this study. Heavy reliance on the iPad throughout the class meeting (note-taking, student-response, and group activities) likely contributed to fewer noneducational uses than have been observed by some which is in agreement with recommendations made by Mang and Wardley (2012).

As reported in previous studies, it was found that immediate feedback achieved through Socrative clicker questions and Moodle quizzes increased student satisfaction and participation (Carpenter and Boh, 2008; Tremblay, 2010; Shepherd and Reeves, 2012; Martin and Ertzberger, 2013; Bogdanović et al., 2014). Immediate feedback was also possible due to wireless internet capabilities. Frequently during lecture and laboratory, students would access course content online to answer questions prior to asking the instructor. The instructor also frequently asked students to "look up" material in class in order to elevate the level of discussion. Indeed, both Likert-scale and open-ended survey results suggest that tablet-induced student engagement may at least partially explain enhanced examination performance.

Despite the limited number of studies that have examined the cognitive effects of tablet-based learning at the university level, preliminary evidence suggests that tablet technology may enhance the learning process. Tablets allow students to access and interpret information in a variety of ways which supports Fleming's (2015) Visual, Aural, Reading, Kinesthetic (VARK) learning model. This model proposes that some students may prefer one learning style while others prefer a mix of one or more styles. Prior to the introduction of the iPad, Sharples et al. (2007) proposed a theory for learning in the mobile age. In this theory, mobile learning is defined as an activity that is both personalized, learner centered as well as a collaborative. Others have claimed that technology, specifically tablets and the apps they support, should be seen as a cognitive tool that encourages higher order thinking, a device to help create knowledge as opposed to deliver content (Jonassen et al, 1998; Oldfield and Herrington, 2012). For example, in anatomy-specific apps, students are given the opportunity to position and annotate new pins on various anatomical structures and to use these pins later to quiz themselves. The ability to take pictures with the camera allowed students to take the laboratory experience outside of the laboratory space. Similar to the conclusions made by Cochrane et al. (2013), iPad use in the Human Anatomy II course resulted in greater collaboration between students both inside and outside of the classroom (e.g., simultaneous participation of multiple students in whiteboard activities with DisplayNote, seamless sharing of notes with Notability, group creation and sharing of Educreation lessons), a direct application of the social constructionist theory of learning. Furthermore, feedback from postsemester surveys support the results presented by Rockinson-Szapkiw et al. (2013) which demonstrate that students using electronic textbooks expressed higher levels of affective and perceived psychomotor learning as well as a more positive attitude toward the text than students using traditional print textbooks, learning that cannot be measured using examinations and course grades.

Many of the benefits associated with mobile technology highlighted in this study can be applied to a variety of subjects, specifically for small-to-moderate enrollment classes in the sciences that are traditionally lecture-based. It may be challenging to facilitate the group activities incorporated into Human Anatomy II for large classes hosted in auditorium style classrooms. As mentioned by several students in this study, despite a childhood shaped by technology, college students still prefer to use tablets and relevant apps as a supplemental tool rather than the sole device for content delivery. For example, in the laboratory portion of the course, the anatomy apps combined with the internet could not replace student interaction with 3D models or with the instructor. For anatomy courses instructed at institutions complete with a cadaver laboratory, the use of the iPad as a supplement rather than a replacement would be preferred due to the realistic detail that has not been replicated in anatomy apps (Lewis et al., 2014).

## Limitations

Prior knowledge which may impact course performance in specific areas was not assessed in this study. However, Human Anatomy II is taken at a similar time in the undergraduate career for pre-health students regardless of major. Typically students have taken at least one semester of general chemistry, one semester of introductory cellular biology, and calculus. The course is also a prerequisite for Human Physiology. Although kinesiology students may have taken Human Anatomy I (Musculoskeletal Anatomy) prior to Human Anatomy II, it is not required and the organ systems presented do not overlap between the two courses. Therefore, because each condition included students from various majors and class years and because performance was assessed several times throughout the semester, it is likely that the condition effects presented would persist if prior knowledge had been measured.

In order to control for the impact of the course instructor on content and teaching style, the study was spread over a duration of three years. Therefore, it is possible that communication between students enrolled in different academic semesters and/or improvements in instructor teaching effectiveness over time may have influenced performance measures. Specifically, these factors may have resulted in artificially higher scores for UNL students who participated in the second and third years of the study. However, if study year played a role in performance, both UNL and CTL students would have benefited in the third year which was not confirmed by the results.

Unfortunately due to the design of the study, it is impossible to accurately attribute the additional positive impact experienced by UNL students to either anatomy or non-anatomy app exposure. The difference in structured anatomy app exposure between LTD and UNL groups was approximately 10 hours over the course of the semester. These 10 hours include the average time students spent completing course assignments requiring use of the anatomy apps and lecture time spent navigating the apps. However, these 10 hours do not include any time that students in the UNL condition spent navigating the anatomy apps independent of assignments and lecture. Indeed, many students indicated that they used both the anatomy and non-anatomy apps to study outside of class, the degree to which likely reflects individual learning style preferences. Overall exposure differences are therefore difficult to estimate. In addition, if the study was repeated today, it would be more difficult to find cohorts of students without previous mobile technology experience and, therefore, it is unlikely that the performance enhancement would be as pronounced.

Preparation for iPad assignments and in-class activities was more time consuming than traditional pen and paper methods and both the instructor and students experienced frequent frustration with the unreliability of technology and limitations of educational apps (Hesser and Schwartz, 2013). For faculty with limited experience and/or institutional support, similar projects may not prove to be possible or as successful.

# CONCLUSION

If faculty and students are given opportunities to overcome the technology learning curve, tablet devices and relevant applications may enhance student engagement with material and subsequently objective measures of student knowledge and retention in an undergraduate human anatomy course.

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## NOTES ON CONTRIBUTOR


MARCELLA RANEY, Ph.D., is an assistant professor in the Department of Kinesiology at Occidental College, Los Angeles, California. She teaches anatomy, introduction to kinesiology, and biochemistry of exercise to pre-health undergraduate students. Her research interests include the evaluation of wellness interventions in low-income communities and technology in higher education.


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