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The Effect of Device When Using Smartphones and Computers to Answer Multiple-Choice and Open-Response Questions in Distance Education

Thomas Royce Wilson
Old Dominion University

THE EFFECT OF DEVICE WHEN USING SMARTPHONES AND COMPUTERS TO ANSWER MULTIPLE-CHOICE AND OPEN-RESPONSE QUESTIONS IN DISTANCE EDUCATION

by

Thomas Royce Wilson
B.S. May 1982, University of Southern Colorado
M.S. May 2009, California State University, Fullerton

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Approved by:

Ginger S. Watson (Co-Director)

John W. Baaki (Co-Director)

Cherng-Jyh Yen (Member)

ABSTRACT

THE EFFECT OF DEVICE WHEN USING SMARTPHONES AND COMPUTERS TO ANSWER MULTIPLE-CHOICE AND OPEN-RESPONSE QUESTIONS IN DISTANCE EDUCATION

Thomas Royce Wilson
Old Dominion University, 2017
Co-Directors: Dr. Ginger S. Watson
Dr. John W. Baaki

Traditionally in higher education, online courses have been designed for computer users. However, the advent of mobile learning (m-learning) and the proliferation of smartphones have created two challenges for online students and instructional designers. First, instruction designed for a larger computer screen often loses its effectiveness when displayed on a smaller smartphone screen. Second, requiring students to write remains a hallmark of higher education, but miniature keyboards might restrict how thoroughly smartphone users respond to open-response test questions. The present study addressed both challenges by featuring m-learning's greatest strength (multimedia) and by investigating its greatest weakness (text input).

The purpose of the current study was to extend previous research associated with m-learning. The first goal was to determine the effect of device (computer vs. smartphone) on performance when answering multiple-choice and open-response questions. The second goal was to determine whether computers and smartphones would receive significantly different usability ratings when used by participants to answer multiple-choice and open-response questions. The construct of usability was defined as a composite score based on ratings of effectiveness, efficiency, and satisfaction.

This comparative study used a between-subjects, posttest, experimental design. The study randomly assigned 70 adults to either the computer treatment group or the smartphone treatment group. Both treatment groups received the same narrated multimedia lesson on how a solar cell works. Participants accessed the lesson using either their personal computers (computer treatment group) or their personal smartphones (smartphone treatment group) at the time and location of their choice. After viewing the multimedia lesson, all participants answered the same multiple-choice and open-response posttest questions. In the current study, computer users and smartphone users had no significant difference in their scores on multiple-choice recall questions. On open-response questions, smartphone users performed better than predicted, which resulted in no significant difference between scores of the two treatment groups. Regarding usability, participants gave computers and smartphones high usability ratings when answering multiple-choice items. However, for answering open-response items, smartphones received significantly lower usability ratings than computers.

This dissertation is dedicated to those who have supported me. My deep gratitude goes to my wife who has lovingly supported me through all of my endeavors. This is for my daughters of whom I am most proud. To my mom and sister, I thank you for your continuous and prayerful support during this process.

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NOMENCLATURE

4G network: the most current generation of cell phone network coverage and speeds.

Android: open-source operating system used for smartphones and tablet computers. Introduced by Google.

App: self-contained program or software designed to fulfill a specific purpose; an application, especially as downloaded by a user to a mobile device.

Cell phone: telephone with access to a cellular radio system so it can be used over a wide area, without a physical connection to a network.

Cloud computing: the practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than using a local server, personal computer, or mobile device.

Distance education: the education of students who may not always be physically present at a school. Commonly conducted through courses held on the Internet. Also called distance learning, online education, and online learning.

Finger-swiping: virtual keyboard for touchscreen smartphones and tablets allows users to compose words by dragging a finger across letters on a touchscreen keyboard rather than tapping keys one-by-one.

iPhone: smartphones designed and marketed by Apple Inc.

M-learning: short for mobile learning; a form of distance education whereby students use personal mobile devices to access and engage with educational content anywhere, anytime.

Mobile phone: See *cell phone*.

Multimedia: the simultaneous presentation of audio and video in a computer-based format such as narrated animation or video (Kozma, 1991).

Online learning: method of delivering educational information via the Internet instead of in a physical classroom. A form of distance education. E-learning.

Personal digital assistant (PDA): handheld computer that functions as a personal organizer but also provides email and Internet access.

Responsive web design: approach to web design and development that suggests a webpage should respond to a user's behavior and environment based on screen size and platform.

Smartphone: a cellular phone, such as iPhone or Android, that performs many of the functions of a computer, typically having a touchscreen interface, Internet access, and an operating system capable of running downloaded applications.

Tablet computer: commonly called *tablet*; a wireless, portable personal computer with a touchscreen interface; typically, smaller than a notebook computer but larger than a smartphone.

Touchscreen keyboard: a visual keyboard on the display screen of a mobile device that can be used in place of a physical keyboard.

Universal Instructional Design (UID): A process that considers the potential needs of all learners when designing and delivering instruction; the process of identifying and eliminating unnecessary barriers to teaching and learning while maintaining academic rigor.

Usability: "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (International Organization of Standards, Part 2.13).

YouTube: a video-sharing site where more than a billion Internet users upload and share videos with a worldwide audience.

Virtual keyboard: See *touchscreen keyboard*.

Video: see *multimedia*.

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CHAPTER I

Introduction

Traditionally in higher education, online courses have been designed for computer users. However, the advent of mobile learning (m-learning) and the proliferation of smartphones have created two challenges for online students and instructional designers. First, information designed for a larger computer screen often loses its effectiveness when displayed on a smaller smartphone screen (Elias, 2011). Second, requiring students to write remains a hallmark of higher education, but miniature keyboards might restrict how thoroughly smartphone users respond to open-response test questions. The current study addressed both challenges by featuring m-learning's greatest strength, multimedia, and by investigating its greatest weakness, text input (Cheung & Hew, 2009; Hopper & Palmer, 2012).

In a 2015 survey, nearly half of respondents claimed they could not live without their smartphones (Anderson, 2015a), and smartphone usage patterns seem to support those claims. Daily, millions of Americans use their smartphones for phone calls, social networking, texting, booking appointments, viewing videos, navigation, playing games, visiting websites, video chats, taking pictures, playing music, and more (Anderson, 2015b; Facebook, 2017; Terras & Ramsay, 2012; Youtube, 2017). In higher education, students now expect anytime, anywhere access to mobile learning, and Americans' strong bond to their smartphones presents an opportunity for educators to fulfill that expectation (Ally, 2009; Vasquez-Cano, 2014).

The literature has identified numerous challenges associated with handheld devices in m-learning, but recent technological advances have mitigated many of those issues. Thanks to improved technology, today's smartphones have greater processing power, storage, battery life, connectivity, and download speeds than the handheld devices featured in past studies

(Bonnington, 2015; Hashemi, Azizinezhad, Najafi, & Nesari, 2011; Kukulska-Hulme, 2007; OpenSignal.Com, 2016; Yousafzai, Chang, Gani, & Noor, 2016). Although technology has resolved or minimized most problems associated with handheld devices in the past, the literature indicates that smartphones still pose two lingering challenges, that of screen size and text input (Crescente & Lee, 2011; Yousafzai et al., 2016).

Complaints about the small size and poor resolution of screens on personal digital assistants (PDA) and mobile phones have persisted throughout m-learning literature (e.g., Ting, 2012; Waycott, 2002,). Smartphone screens have become bigger, better, and brighter than past displays (Crescente & Lee, 2011), but screen size continues to present a potential barrier to the acceptance of m-learning in higher education (Cheung & Hew, 2009; Yousafzai et al., 2016). Small screens make reading text difficult (Churchill & Hedberg, 2008), yet text remains the predominant content format within mobile learning (Shen, Gao, Novak, & Tang, 2009). Due to the problems associated with text on small screens, some scholars have suggested that the most effective instructional modality for m-learning is multimedia (Cheung & Hew, 2009; Gregson & Jordaan, 2009; Hopper & Palmer, 2012). This current study featured multimedia instruction. In this document, the terms multimedia and video are used interchangeably to denote the simultaneous presentation of audio and video in a computer-based format, such as a narrated slideshow (Kozma, 1991).

The popularity of online videos among mobile device owners seems to indicate that users consider small screens acceptable for viewing multimedia. For example, YouTube is a video-sharing site where more than a billion Internet users upload and share videos. Of YouTube’s billions of daily views, more than half occur on mobile devices (Youtube, 2017). The popularity of online videos presents an opportunity for higher education. However, when implemented in an educational context, multimedia presents challenges for learners and for instructional designers (Low & Sweller, 2014; Mayer & Moreno, 2003).

When used for instruction, the fast pace of multimedia can make learning difficult. To minimize the problems inherent with multimedia instruction, several instructional design strategies have been developed, two of which are segmenting and signaling (Mayer & Pilegard, 2014; Van Gog, 2014). Regarding segmenting, research indicates that dividing multimedia instruction into learner-controlled segments can improve performance by giving learners time to process information between segments (Mayer & Pilegard, 2014). Regarding signaling (or cueing), research has found that when multimedia instruction contains cues about the organization of instructional content in the form of headings, learners perform significantly better than when cues are absent. Scholars presume that signaling the structure of the information might enhance learner understanding (Van Gog, 2014). The current study presented multimedia instruction in segments rather than as one uninterrupted presentation (segmenting), and each segment contained a heading (signaling).

In higher education, assessments usually require writing, which may be difficult to do on a smartphone. While smartphones seem well suited for playing multimedia instruction, the restrictive text input options on smartphones remain a weakness that might inhibit the widespread acceptance of m-learning in higher education (Cui & Viripi, 2008; Hopper & Palmer, 2012). At the time of this research, no peer-reviewed studies had investigated the effect of smartphones when answering open-response test questions in distance education.

The purpose of the present study was to extend previous research associated with m-learning. The first goal was to determine the effect of device (computer vs. smartphone) on performance when answering multiple-choice and open-response recall questions. The second goal was to determine whether computers and smartphones would receive significantly different usability ratings when used by participants to answer multiple-choice and open-response questions. The construct of usability was defined as a composite score based on ratings of effectiveness, efficiency, and satisfaction (International, 2010).

Literature Review

This literature review begins with an exploration of the theoretical frameworks and prior research that inform this study. The theoretical frameworks were based primarily in theories of cognitive learning, cognitive load, and multimedia learning. This review also examines the history, devices, research trends, and challenges of m-learning. It concludes with a review of research that has focused on multimedia instruction.

Theoretical Framework

Cognitive learning theories. The instruction in the current study was designed with the following assumptions taken from several theories about how humans learn. First, individuals process incoming information using working memory*,* which is the temporary storage system that consciously works to process information. Second, working memory has limits on the amount of information that can be processed at one time, and those limits affect learning (Baddeley, 2007; Paas & Sweller, 2014). Another assumption describes the human mind as processing verbal and non-verbal information in different cognitive channels as suggested in Paivio's (1990) dual-coding theory and Baddeley's (1986, 2007) working memory and working-component models. It is presumed that, working memory transfers incoming information to long-term memory (Paas & Sweller, 2014). Schema theory and assimilation theory both assume that long-term memory stores prior knowledge in the form of abstract cognitive structures called schemas (Anderson, Rand, & Anderson, 1978; Ausubel, 1968). Individuals use their stored knowledge to shape their perception of incoming information and ascribe meaning to it (Wittrock, 1989).

Cognitive load theory. Cognitive load theory is an instructional theory that addresses the burden placed on working memory during learning (Paas & Sweller, 2014). That burden is called cognitive load. According to cognitive load theory, cognitive load occurs in three forms: intrinsic, extraneous, and germane. The multimedia instruction in this current study featured strategies that address intrinsic cognitive load. Intrinsic cognitive load results from the mental processing of information that must be learned. Unfamiliar or complex information generates higher intrinsic load than familiar or simple information (Paas & Sweller, 2014; Sweller & Chandler, 1994). For example, for most college freshmen, a tutorial on how to calculate the gravitational force between two objects would contain more difficulty (i.e. intrinsic load) than a tutorial explaining how to make a cup of instant coffee. If the intrinsic load exceeds the capacity of the learner's working memory, the cognitive overload will diminish learning (Kalyuga, 2007; Paas & Sweller, 2014).

Multimedia instruction increases cognitive load due to the transient information effect, which occurs where dynamic visualizations such as animation convey information, but the information disappears before the learner can process it. The learner has no permanent record to reference when trying to cognitively process the fleeting information. Transitory information generates a higher cognitive load than information that is presented in a permanent form (Low & Sweller, 2014). When complex information is presented through multimedia, the combination of difficult subject matter and fleeting information can overwhelm the capacity of working memory. That cognitive overload inhibits the transfer of information into long-term memory (Mayer & Pilegard, 2014). Researchers have developed several strategies for managing the intrinsic cognitive load that learners encounter during instruction from multimedia. This current study employed two such strategies, segmenting and signaling, that are associated with the cognitive theory of multimedia learning (Mayer, 2014; Mayer & Pilegard, 2014; Van Gog, 2014).

Cognitive theory of multimedia learning. The cognitive theory of multimedia learning maintains three assumptions derived from cognitive learning theories and cognitive load theory (Mayer, 2005a; Mayer & Moreno, 2003). First, the dual-channel assumption states that humans process information in two separate cognitive channels, visual and auditory. The dual-channel assumption stems from Paivio's (1990) dual-coding theory and Baddeley's (1986, 2007) working memory and working-component models. Second, the limited-capacity assumption presumes that humans can process only limited amounts of information at a time (Mayer & Moreno, 2003), an assumption derived from working memory research (Baddeley & Logie, 1999; Kalyuga, 2007; Mayer & Chandler, 2001). Finally, in accord with Wittrock (1989), the active-processing assumption considers learning an active process that requires learners to engage in cognitive processing in order to build a coherent representation of their experiences (Mayer, 2005a).

Segmenting principle. The segmenting principle suggests that individuals learn better when they control playback of multimedia that has been divided into learner-controlled segments rather than watching a continuous, non-stop presentation (Mayer, 2005b). According to the segmenting principle, segmenting can help manage the extra cognitive load created by the rapid delivery of fleeting information. The pause between segments gives learners time to process information from one segment and transfer it from working memory to long-term memory. When ready, the learner can start the next segment. An analysis of numerous segmenting studies has indicated that learners who engaged with segmented multimedia scored significantly higher on test questions than learners who viewed continuous, non-stop presentations (e.g., Mayer & Chandler, 2001). Researchers have attributed participants' superior test performance to the management of cognitive load through the application of the segmenting principle (Mayer & Pilegard, 2014). To maximize the content recall of participants, the current study employed the segmenting principle in the instructional design of its learner-paced multimedia segments.

Signaling theories. In addition to segmenting, the multimedia instruction in the present study featured the signaling strategy of headings. In paper-based instruction, extensive text-processing research and psychological theories of comprehension have supported the use of signaling devices such as headings (Rouet & Potelle, 2005). However, few studies have investigated the effects of headings in multimedia instruction (e.g., Harp & Mayer, 1998). Headings serve as a road map that directs readers' attention to the top levels of the information's structure. That guidance helps readers select the most important information for encoding (Meyer & Poon, 2001).

Automaticity theories. Psychology studies dating back to the 19th century have found that a learner can practice a task enough to develop automaticity, which is the ability to execute functions automatically with no conscious effort (Ericsson, 2006; Moors & De Houwer, 2006). For tasks such as driving or typing, individuals can usually reach proficiency with less than 50 hours of practice. Practice beyond that threshold begins to develop automaticity (Ericsson, 2006). Most Internet users have probably logged more than 50 practice hours on their devices doing the two activities required for the current study, which were watching online videos and composing messages (Gebb & Young, 2014; Lunden, 2015; Youtube, 2017).

ISO usability standard. Considering usability in addition to performance can provide a more complete picture of the effect of device when answering multiple-choice and open-response questions. Usability has been recognized as an important factor in the design of products, but definitions of usability differ (Seffah, Donyaee, Kline, & Padda, 2006; International, 2010). A widely accepted definition (Bevan, Carter, & Harker, 2015) comes from the International Organization of Standardization (International, 2010), known as ISO. ISO defines usability as the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (Part 210). This current study used the ISO definition to analyze the usability of computers and smartphones when answering multiple-choice and open-answer test questions.

In a distance education context, good usability typically means that students can learn without hindrances (Kukulska-Hulme, 2007). The ISO usability standard helps measure the effect of hindrances, should they occur. The following hypothetical example illustrates the importance of assessing the three ISO usability criteria when designing instruction for online courses. If online students viewed a videotaped lecture and performed well on a subsequent test, the recorded lecture would be considered effective. Effectiveness is the first criterion of usability, but effectiveness alone is not a good measure of whether a tool or learning object should be used or modified for use in instruction. In this hypothetical example, the recorded lecture had low, distorted audio that required students to stop and replay the video every few seconds to decipher what the instructor said. When the lecture was recorded, the camera was placed in the back row of a large lecture hall, and students continually walked back and forth in front of the camera causing distractions. Efficiency ratings are based on ease and speed. When asked about the ease and speed of viewing the recorded lecture, students would likely give the recording a low efficiency rating. Likewise, when asked about satisfaction with the recording, students would likely express dissatisfaction. In such cases, when features of a distance education course are difficult to use, learning performance can suffer (Parlangeli, Marchigiani, & Bagnara, 1999). Therefore, the current study applied the ISO standard to assess the usability of computers and smartphones when answering multiple-choice and open-response questions in distance education.

M-learning

Often m-learning definitions have centered on the type of device used in learning, including laptops (e.g., Wurst & Gaffney, 2008), PDAs (e.g., Chen, Kao, & Sheu, 2003), tablets (e.g., Sung & Mayer, 2013), cell phones (e.g., Thornton & Houser, 2005), and smartphones (e.g., Vasquez-Cano, 2014). Most m-learning studies have featured PDAs and cell phones (e.g., Chen et al., 2003; Thornton & Houser, 2005;). However, those outdated devices have diminished relevance when defining or discussing contemporary m-learning. Cell phones (also called mobile phones) cannot access web-based instruction, and smartphones have replaced PDAs as personal technology (Johnson, 2016). Some m-learning definitions have excluded laptops, limiting the definition to handheld devices (e.g., Seppålå & Alamäki, 2003). Other definitions have omitted tablets along with laptops because, unlike smartphones, tablets do not fit in a palm and are seldom carried without a premeditated purpose (Cheung & Hew, 2009; Traxler, 2009). Tablet ownership rates have declined among U.S. adults under 30 (Global, 2016), while smartphones have become ubiquitous (Anderson, 2015a). Unlike tablets, smartphones have an intimate role in their owners' daily lives (Smith, 2015; Traxler, 2009).

Rather than focusing on device, m-learning definitions sometimes emphasize where the learning takes place. Some researchers consider m-learning the use of handheld devices in a traditional classroom (e.g., Shin, Shin, Choo, & Beom, 2011). Others emphasize the anytime, anywhere potential of mobile devices in distance education (e.g., Vasquez-Cano, 2014). When m-learning emerged in the 1990's, many researchers classified it as a subset of e-learning (e.g., Crescent & Lee, 2011). Distance educators have always sought to provide learning at a student's convenience. Now m-learning allows educators to offer anytime, anywhere access (Ally, 2009; Gebb & Young, 2014) to interactive learning objects (Churchill, 2011) and assessments (Alden, 2013) through a learning management system, which is known as an LMS (Crescente & Lee, 2011). Some researchers have suggested that m-learning has emerged as a discipline of its own (e.g., Sung & Mayer, 2013). However, the current study considered m-learning a subset of e-learning because the research conditions resembled those found in traditional online distance education. For example, the lesson was housed within an LMS, and the multimedia elements of the lesson were presented sequentially, followed by a summative quiz.

Smartphones. Although the term smartphone has been used to describe mobile devices dating back to the 1990's (Cecere, Corrocher, & Battaglia, 2015), the current smartphone era began with the introduction of Apple's iPhone in 2007 followed by Google's Android the following year (Arthur, 2014). In recent years, smartphones have become ubiquitous (Anderson, 2015b), and they now influence our daily lives (Gebb & Young, 2014). More than three-quarters of Americans own smartphones, and ownership has reached near saturation (92%) among ages 18-29 (Smith, 2017).

Smartphone apps now account for half of the total time Americans spend online (Lella, 2016). Combined, iPhone and Android users have 4.2 million mobile apps available to them. Mobile users have conducted more than 165 billion app downloads (Statista, 2016a, 2016b). Facebook, the world's largest social networking site, currently hosts more than one billion mobile users each day (Facebook, 2017). The ubiquity of smartphones, coupled with Americans' strong bond to their devices, presents an opportunity for universities and colleges to reach students through m-learning (Vasquez-Cano, 2014).

Today's students consider smartphones their first point of reference for information access. Therefore, to remain relevant, universities must implement m-learning to accommodate current and future generations who will not know life without their personal, elaborate technology (Crescente & Lee, 2011; Wang & Shen, 2012). However, despite the enthusiasm surrounding the promise of m-learning (e.g., Crescente & Lee, 2011), smartphones may not be able to completely replace computers in conventional distance education anytime soon. When smartphone users attempt to access online courses or resources that are not designed for mobile devices, the potentially frustrating experience could undermine students' acceptance of m-learning as a viable form of education (Liu, Li, & Carlsson, 2010). The present study investigated one potential source of that frustration, online questions.

Research trends. Many m-learning studies took place prior to the current smartphone era when researchers and participants considered handheld devices novel (e.g., cell phones and PDAs). Therefore, much of the m-learning literature discusses outdated technology and problems that are now moot (e.g., Waycott, 2002). Typically, education research lags behind the newest technological developments (Kurubacak, 2007). However, recent research trends have begun to align more closely with the contemporary m-learning environment, specifically regarding the choice of devices and research settings used to study m-learners.

Personal devices. In past m-learning studies, researchers typically developed instruction for a specific platform, issued specific devices to participants, and trained participants how to use the issued equipment (e.g., Darroch, Goodman, Brewster, & Gray, 2005). In contrast, now that smartphones are ubiquitous, studies have begun to allow participants to use their own mobile devices (e.g., Gedik, Hanci-Karademirci, Kursun, & Cagiltay, 2012; Jubien, 2013). This current study allowed participants to use their own smartphones for two reasons. First, students generally want to learn on their own mobile devices (Bradley, Haynes, Cook, Boyle, & Smith, 2009). Participants likely had considerable comfort and experience with their smartphones. With practice, experience becomes proficiency, and proficiency can eventually translate into automaticity (Clawson, Rudnick, Lyons, & Starner, 2008; Ericsson, 2006). Second, having participants use their own smartphones may make these study results more generalizable (Gedik et al., 2012). Studying proficient smartphone users who operated their own devices to learn and take assessments may provide more meaningful data than studying participants who were trained to use borrowed, unfamiliar devices.

Personalized setting. Distance education literature has discussed two types of research, field and laboratory-based. Both types have made important contributions to methods and evaluation techniques (Kjeldskov & Stage, 2004; Terras & Ramsay, 2012). Considering the variety of locations where distance education takes place, a field-based study seemed appropriate for this current research. However, allowing individuals to participate in a study anytime, anywhere presents potential challenges for researchers. In everyday life, students commonly use their electronic devices to multitask, dividing their attention among texting, tweeting, emailing, checking social networks, listening to music, and other activities (Carrier, Rosen, & Cheever, 2015; Grinols, 2014). Research has produced mixed results regarding the affect that electronic multitasking has on academic performance (Clayson & Haley, 2012; Lui & Wong, 2012). Beyond the potential challenges presented by participants multitasking during the experiment, interruptions and environmental conditions had the potential to negatively affect their performance (McDaniel, Einstein, Graham, & Rall, 2004; Page, 2013).

Implementation challenges. From its early days, m-learning has encountered several barriers to wide-spread implementation (Cheung & Hew, 2009). Fortunately, recent technological advancements have minimized or eliminated many of those past concerns. Calls for greater processing power (Koole, 2009; Pieri & Diamantini, 2009) have been answered by smartphones with power that rivals that of laptops (Bonnington, 2015). Mobile cloud computing has yielded multiple improvements in smartphone performance by facilitating faster processing, increased storage, and longer battery life (Hashemi et al., 2011; Kukulska-Hulme, 2007; Yousafzai et al., 2016). Cloud computing can reduce institutions' dependence on expensive, device-specific operating systems while offering heterogeneity, availability, and scalability (Crescente & Lee, 2011; Yousafzai et al., 2016). In addition to addressing security and privacy concerns (Kukulska-Hulme, 2007), cloud computing has become a conduit for multimedia providers to deliver content that requires no downloading (Yousafzai et al., 2016). When downloading is desired, download speeds and connectivity have improved thanks to 4G networks that now reach 81% of U.S. mobile subscribers. Today, 4G networks represent the latest, most powerful generation of mobile device networks (OpenSignal.Com, 2016; Rekkedal & Dye, 2009). Although technological advances have resolved or minimized many past problems, some challenges from the early days of m-learning remain.

Text Input. Attempts to balance portability and functionality in mobile devices have produced various text-input methods (Smith & Chaparro, 2015). On smartphones, the two most commonly used input methods (see Figure 1) are a virtual, touchscreen keyboard and a mini, physical keyboard (Cannon, Strawderman, & Burch, 2015; Silfverberg, 2007). In studies that compared the two input methods, users performed better and had higher satisfaction with the mini, physical keyboard (Arif & Stuerzlinger, 2009; Hoggan, Brewster, & Johnston, 2008).

Despite the apparent higher satisfaction and better performance offered by mini, physical keyboards, smartphone manufacturers seem to be phasing them out in favor of touchscreen versions (Smith & Chaparro, 2015).

a. b.

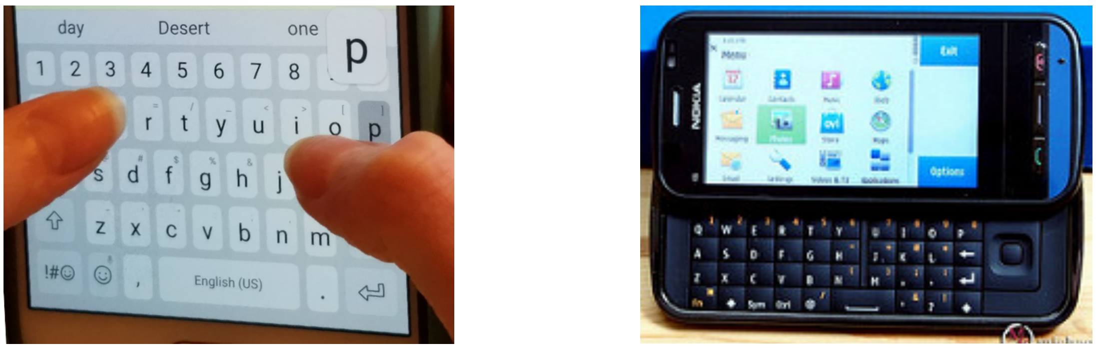

Figure 1. Photo of a smartphone touchscreen keyboard (a) and a smartphone with a mini physical keyboard (b). Touchscreen photo by Thomas Royce Wilson, copyright 2017. Mini physical keyboard photo by Michael Kwan is licensed under Creative Commons BY 2.0. Cropped from original. (See Appendix K for permission information.)

Alternatives to standard smartphone keyboards continue to emerge and improve. Finger swiping software like Swype® (see Figure 2) allows users to compose words by dragging a finger across letters on a touchscreen keyboard rather than tapping keys one-by-one (Han & Kwangtaek, 2015; Kim & Ko, 2014). Recent advancements in voice recognition technology (e.g., Dragon Diction®) have made smartphone dictation a viable input option that can be faster, but slightly less accurate than other input methods. Voice technology may be exceptionally slow for inexperienced users due to time spent correcting transcription errors (Pogue, 2013; Silfverberg, 2007). In a comparison of a mini physical keyboard, a touchscreen keyboard, finger swiping, and voice dictation, one study found that smartphone users had the best experience entering text with the voice input method, followed by a mini-physical keyboard (Smith & Chaparro, 2015).

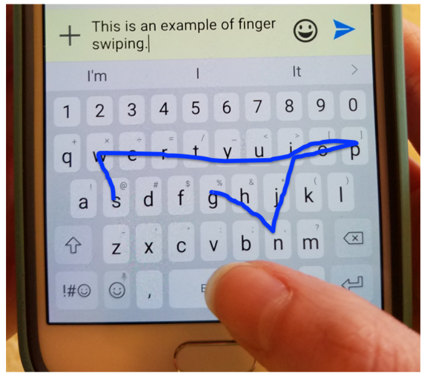

Figure 2. Photo of a smartphone keyboard that features finger-swiping software. The line across the keys indicates the path of the finger that dragged from letter to letter to compose a word within a message. Copyright 2017 by Thomas Royce Wilson.

For decades, researchers have studied typing on a standard keyboard, but little is known about typing on smartphones (Cerni, Marieke, & Remo, 2016). Comparing smartphone text entry speeds to the typing speeds obtainable on a conventional keyboard can provide context for the current study. Modest speeds for hunt and peck typing on a conventional keyboard can range from 20-40 words per minute (WPM). Proficient touch typists type 40–60 wpm, and skilled typists exceed 60 wpm (Mackenzie & Soukoreff, 2002). A study of average text input speeds on smartphones produced the following results for young adults: touchscreen keyboard - 17 wpm, finger swiping - 20 wpm, mini physical keyboard - 28 wpm, and voice dictation - 45 wpm (Smith & Chaparro, 2015). Although the past study can provide a general reference for different text input speeds, two points require consideration. First, the past study featured inexperienced users who were issued devices and given brief practice time, which is a contrast to the current study that featured experienced smartphone owners using their own devices. Second, text entry evaluations usually focus on speed and accuracy when transcribing preselected information (Wobbrock, 2007), unlike the present study that required participants to compose original ideas. Formulating original ideas and inputting them takes longer and is less efficient than transcription due to the thinking, typing, and editing required to arrive at final wording (Pogue, 2013; Silfverberg, 2007).

For brief tweeting or texting on a smartphone, thumb-typing or finger-swiping may suffice (Seppålå & Alamäki, 2003). However, for longer typing tasks, using a larger, physical keyboard is usually faster and more accurate than tapping on a smartphone (Wei & Chen, 2006). Bluetooth® technology allows users to wirelessly connect a smartphone to a computer keyboard. External Bluetooth® keyboards can range from portable, foldable, and relatively small, to standard, full-size (see Figure 3). Although more comfortable and efficient than a smartphone's native text input methods, an external keyboard compromises the handheld convenience of an all-in-one pocket device (Dern, 2015; Phin, 2016).

Figure 3. Photo of Bluetooth® keyboard for iPhone® by Miki Yoshihito is licensed under Creative Commons BY 2.0. (See Appendix K for permission information.)

Learner assessments. In higher education, learning is not enough. A student must also be able to communicate acquired understanding through assessments. Among other types of assessment, distance education students take online tests and quizzes that require text entry. Test questions fall into two categories, closed-ended and open-response. Typically, closed-ended questions are multiple-choice that a student can complete by tapping a finger on a smartphone keyboard. Online educators like the automated grading and objectivity of multiple-choice questions (Hift, 2014; Pyc & Rawson, 2009; Yeh & Park, 2015).

The second type of test question, open-response, includes short-answer and essay questions. Unlike multiple-choice questions, open-response questions can require students to write multiple paragraphs that contain complete, proper sentences. Such questions measure students' ability to analyze, synthesize, evaluate, think logically, solve problems, and hypothesize. Contrary to the belief that open-response questions test higher-order cognitive processes better than multiple-choice questions, the literature indicates that when written well, either format can effectively assess higher cognitive functions (Hift, 2014; Ornstein, 1992). However, unlike multiple-choice questions, open-response questions enable students to demonstrate their writing skills and their ability to organize thoughts, support a point of view, and create ideas, methods, and solutions (Ornstein, 1992). The ability of the open-response question to elicit original thoughts through student writing seems to suggest that multiple-choice questions might not always qualify as an equal replacement of open-response questions.

The current study tested the effect of device (computer vs. smartphone) on performance when answering multiple-choice and open-response recall questions. At the time of this writing, no peer-reviewed study had investigated the effect of device, specifically smartphone versus computer, when answering multiple-choice questions in distance education. Past studies have compared PDA and paper-and-pencil examinations (e.g., Segall, Doolen, & Porter, 2005), satisfaction with PDAs for testing (Ganger & Jackson, 2003), and computerized adaptive testing (CAT) on PDAs (e.g., Triantafillou, Georgiadou, & Economides, 2008). One team of researchers (Bradley et al., 2009) posited that multiple-choice tests are ideal for m-learning because they are simple, quick, and easy to take with a mobile phone interface, but the literature has not empirically substantiated that assumption.

In contrast to multiple-choice questions being considered optimal for smartphones, essay questions have been characterized as too tedious to complete on the small devices (Elias, 2011), but no empirical evidence has been offered to support that claim. A past PDA study (Rekkedal & Dye, 2009) unintentionally discovered that handheld devices seemed to inhibit the composition of long messages. During the first trial of the study, participants used their assigned devices to accomplish a variety of tasks, but they had difficulty using the small PDA keyboard to take notes. Therefore, in a second trial, participants received full-size keyboards that operated with the PDAs. The full-size keyboards resolved participants' note taking problems. When using the larger keyboards instead of the PDA onboard keyboards, participants also wrote longer messages in the study's discussion forums.

Due to the lack of m-learning literature regarding assessments for smartphones, the current study turned to smartphone research outside of education. In a survey about personal habits with mobile technology (Kaikkonen, 2009), respondents reported a tendency to avoid answering e-mails on their mobile devices. They would send only short replies when a response was absolutely necessary, but preferred to wait until they could use a standard computer keyboard for writing longer email messages. Like open-response answers on a test, emailing usually requires longer, more formal written messages than texting; therefore, emailing tendencies seemed relevant for the present study.

For the current study, literature regarding commercial survey behavior provided the most empirical data about the effect of device when answering different types of questions. Like academic tests and quizzes, online surveys can feature multiple-choice and open-response questions. Survey respondents in one study indicated that they disliked composing long messages on their mobile devices (Cui & Viripi, 2008). A study of survey behavior found that smartphone users spent significantly more time answering open-response survey questions than computer users did (De Bruijne & Wijnant, 2014). Survey respondents in another study usually chose blatantly implausible multiple-choice options rather than choosing the logical alternative that required text input (Peytchev & Hill, 2010). In a study of survey completion rates, smartphone users terminated their survey participation twice as often as computer users (Peterson, 2012).

Screen Size. Phone screen sizes are determined by measuring screens diagonally. Before 2011, phone screens measured between 2.5 and 4 inches. However, since 2013, sub-4-inch screens have given way to bigger, better, and brighter smartphone screens. The latest screens average slightly more than 5 inches (Apple, 2017; Crescente & Lee, 2011; Taylor, 2014b). Despite the improved quality and bigger size of smartphone screens, screen size remains a potential barrier to the acceptance of m-learning (Cheung & Hew, 2009; Yousafzai et al., 2016). In distance education, text is the dominant mode of instruction, but unfortunately, small smartphone screens make reading text difficult (Churchill & Hedberg, 2008; Shen et al., 2009).

Compounding the problem of text on small smartphone screens, most websites do not automatically adjust to fit content on a small screen. Therefore, navigating and reading their pages with a smartphone can be cumbersome and inefficient (Crescente & Lee, 2011). The problem of crowded text on small screens has prompted some scholars to call for limits on how smartphones are used in education. They contend that mobile screens are too small to comfortably read text or graphical information. Rather than trying to offer entire courses for smartphone access, those researchers have suggested limiting smartphone use to the review of key points or summaries of a course (Churchill & Hedberg, 2008; Wang & Shen, 2012).

In contrast to calls for limited use of smartphones in education, a growing movement seeks to make networks, operating systems, and information more accessible to all devices. Web developers around the world have begun to adopt the "one web" protocol championed by the Worldwide Web Consortium (W3G), a global organization that develops guidelines to support sustained growth of the Web (Worldwide, 2016). The one-web protocol emphasizes developing content and websites that can be accessed by all devices instead of following the past practice of building different operating systems for different devices. A related trend, the bring-your-own-device (BYOD) movement, has begun to take hold in higher education as institutions recognize that students always have their personal devices with them (Chen, Seilhamer, Bennett, & Bauer, 2015; Negrea, 2015). According to a 2015 study, at least 42% of U.S. institutions in higher education had implemented a BYOD strategy in which students use their personal portable devices to access their institution's network (Negrea, 2015).

Rather than requiring users to download an app, many websites now feature what is known as responsive web design. Responsive design enables webpages to automatically adapt to the screen size of any device (Worldwide, 2016). Hosting online courses in an LMS that responds to web content can help accommodate smartphone users. However, to fully utilize responsive web capabilities, instructional designers must build content with responsive design in mind (Kim, 2013). For example, graphic images will not shrink and expand responsively unless an instructional designer sets their properties appropriately.

To address the challenges of learning on small smartphone screens, scholars need to rethink course design (Elias, 2011). To that end, universal instructional design (UID) guidelines emphasize creating an inclusive learning environment that addresses the learning needs of all students (Pliner & Johnson, 2004). Ensuring a quality learning experience for one group can benefit other groups. For example, physically impaired computer users (e.g., visual, motor skills) often experience reading and input challenges that resemble the situational impairments of able-bodied smartphone users. In those cases, instructional design principles developed to support disabled computer users can benefit all smartphone users as well (Yesilada, Harper, Chen, & Trewin, 2010). UID guidelines have been adapted for computer users in e-learning (Elias, 2010) and for handheld device users in m-learning (Elias, 2011). The current study incorporated relevant UID guidelines in the design and delivery of its m-learning instruction and assessment.

As an alternative to computers, this current study researched smartphones rather than tablets because smartphone screens have approximately half the screen size of the most popular tablets, and nearly a third the average screen size of laptops (Taylor, 2014a, 2014b). Smartphones, the smallest devices, present the biggest challenge for learners and test takers. If smartphone users can successfully engage with instruction and assessment in an online course, users of larger devices would likely be able to do so as well (Worldwide, 2016; Elias, 2011).

Multimedia Instruction

In contrast to concerns about text-based instruction on smaller screens, several scholars consider multimedia the most effective use of handheld devices in education (Cheung & Hew, 2009; Gregson & Jordaan, 2009; Hopper & Palmer, 2012). Considering the challenges of learning from text-based instruction on small screens and the popularity of online videos among smartphone users, educators should emphasize the use of multimedia in m-learning (Alden, 2013; Crescente & Lee, 2011; Youtube, 2017).

Purpose

The purpose of the present study was to extend previous research associated with m-learning. The first goal was to determine the effect of device (computer vs. smartphone) on performance when answering multiple-choice and open-response recall questions. The second goal was to determine whether computers and smartphones would receive significantly different usability ratings when used by participants to answer multiple-choice and open-response questions. The construct of usability, taken from the ISO standard (International, 2010), was measured with a composite score based on ratings of effectiveness, efficiency, and satisfaction.

Research Questions and Hypotheses

The following research questions and hypotheses guided this study.

Question 1. How does device (computer vs. smartphone) affect performance on multiple-choice questions that measure recall?

Hypothesis 1: Computer users and smartphone users will have no significant difference in their scores when answering multiple-choice recall questions.

Question 2. How does device (computer vs. smartphone) affect performance on open-response questions that measure recall?

Hypothesis 2: Computer users will score significantly higher than smartphone users when answering open-response recall questions.

Question 3. Do usability ratings differ significantly between computers and smartphones when both types of devices are used to answer multiple-choice questions?

Hypothesis 3: Computers and smartphones will have no significant difference in their usability ratings when both types of devices are used to answer multiple-choice questions.

Question 4. Do usability ratings differ significantly between computers and smartphones when both types of devices are used to answer open-response questions?

Hypothesis 4: Computers will receive a significantly higher usability rating than smartphones when both types of devices are used to answer open-response questions.

CHAPTER II

Method

Participants

The present study recruited 70 online participants (43 women and 27 men) using email (see Appendix A) and social media (see Appendix B). Participant ages were 22-30 (n = 7), 31-45 (n = 27), 46-60 (n = 27), and over 60 (n = 9). Most participants had a graduate degree (n = 63). The remainder had either an undergraduate degree (n = 6) or some college experience (n = 1). Most participants had been involved with online learning as either a student or instructor within the year (n = 51), within the past three years (n = 11), or more than three years ago (n = 7). Only one participant had no online course experience. The computer treatment group contained 14 Mac users and 20 PC users. The smartphone treatment group contained 23 iPhones users and 13 Android users. Participants were registered for a one-in-four chance to win a gift card to a nationally known merchant (see Appendix A).

In a pre-study survey, of participants who reported viewing online video several times per day, 15 were from the computer treatment group, and 11 were from the smartphone treatment group. Of those who viewed several times per week, 11 were in the computer treatment group compared to 18 were in the smartphone treatment group. Of those who viewed several times per month, seven were in the computer treatment group versus five participants from the smartphone group. Of the three participants who reported that they seldom viewed online videos, the computer treatment group had two participants, and the smartphone treatment group had one.

In the pre-study survey, participants also reported which device they usually used to view online videos. Several members of the computer treatment group (n = 11) and smartphone treatment group (n = 17) reported spending an equal amount of time viewing videos on both devices. Within the computer treatment group, 15 reported viewing more on their computers, and eight viewed more often with their smartphones. In the smartphone treatment group, 12 reported viewing more on their computers, and six reported viewing more on their smartphones.

Regarding texting and emailing habits, only survey responses from the smartphone treatment group had relevance to the current study. In the pre-study survey, 75% of the smartphone treatment group reported using their smartphones to text messages at least five times per day, but only 31% sent email that often from their smartphones. The relatively low frequency of smartphone emailing aligns with past findings from research into smartphone email behavior. In one study, when participants logged their time with email, the records indicated that smartphone users spent 95% of their time reading email but only 5% of their time sending email with their devices (Cui & Viripi, 2008). Figure 4 summarizes the pre-study survey results of the current study regarding text messaging and emailing behavior of the smartphone treatment group.

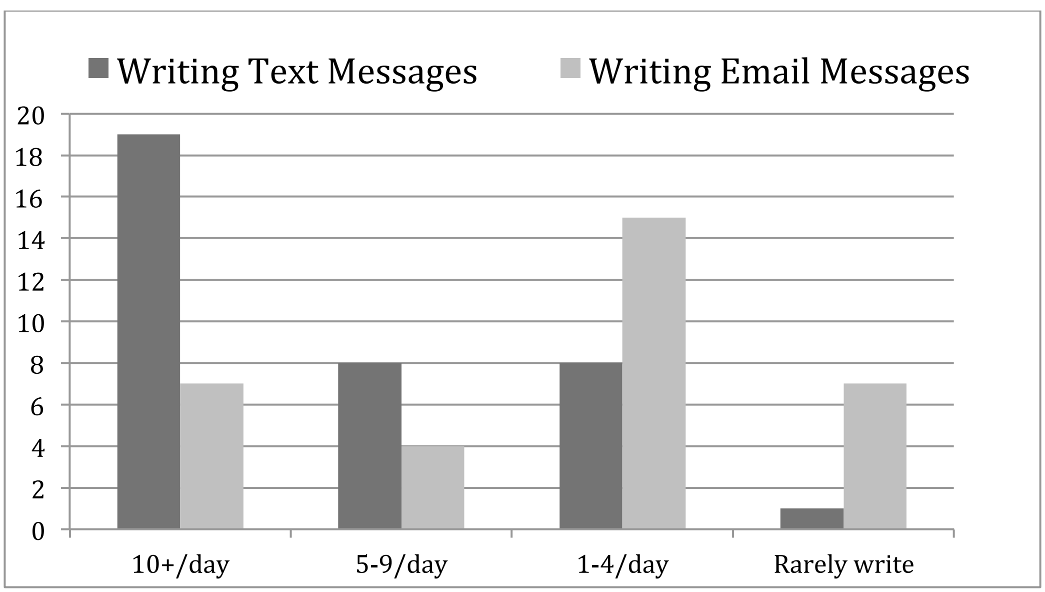

Figure 4. Frequency of writing text messages versus writing emails on a smartphone. Pre-study survey results of smartphone treatment group.

Research Design

The present research was a comparative study that featured a between-subjects, posttest, experimental design. The independent treatment was device (computer vs. smartphone). Participants were randomly assigned to either the computer treatment group or the smartphone treatment group. The four outcome variables were recall scores on multiple-choice test questions (Research Question 1), recall scores when responding to open-response test questions (Research Question 2), the usability rating of a device when used to answer multiple-choice questions (Research Question 3), and the usability rating of a device when used to answer open-response questions (Research Question 4).

Multimedia Instruction

The multimedia instruction of the current study was adapted from a script about solar cells that Sung and Mayer (2013) used in a multimedia segmenting study. For the present study, the original script was edited to remove information that did not explain the functioning of a solar cell. For example, Sung and Mayer devoted one slide, 29 words, to describing ancillary characteristics of a silicon atom that had no substantial bearing on the understanding of how a solar cell works. In the current study, removing non-essential information and jargon reduced the original 800-word script nearly 40% to 490 words. The total instruction time was reduced from six minutes to three minutes.

The published script from the Sung and Mayer (2013) study contained only two images. Therefore, the researcher conducted research to determine appropriate visuals to illustrate the main points of the narration. The researcher created original animation for the multimedia instruction using the computer-based presentation program PowerPoint®. The final instruction used in this study consisted of a three-minute lesson that contained 11 segments ranging from

10–30 seconds each (see Appendix F). Such short segments might be impractical for some instruction in actual college courses; however, for complex information, research has found that segmenting supports learning (Mayer & Chandler, 2001).

On one hand, the literature has indicated that signaling in multimedia instruction can benefit computer and tablet users (e.g., Sung & Mayer, 2013). On the other hand, UID researchers have suggested that adding text to instruction might clutter a small smartphone screen, making information difficult to read (Churchill & Hedberg, 2008). The current study attempted to strike a balance between the two concerns. Adhering to the recommendations of UID (Elias, 2011), each animated slide contained minimal text. In accordance with the signaling principle (Van Gog, 2014), the multimedia instruction strategically incorporated text two ways. First, to reinforce each step of the process and help participants understand the underlying structure of the instruction, the segment number and title remained visible throughout each segment. The title length averaged approximately three words per slide (see Figure 5). Second, key words from the posttest were strategically displayed to reinforce important information that participants would need to recall during the posttest. For example, while participants heard the narrator explain that boron atoms were added to the bottom of a solar cell, the narration was reinforced when the word “boron” appeared underneath the panel diagram with an arrow pointing to the underside of the panel (see Figure 5). The two-column multimedia script (see Appendix F) contains the narration and key frames of animation.

The PowerPoint® animations were played on a MacBook Pro® laptop, and the desktop display was captured using Camtasia® video editing software. Camtasia® was used to record narration, and then used to edit the animation and narration into 11 segments. Each narrated multimedia segment was exported as an MP4 video file. Originally, the video files were uploaded to a private YouTube channel, and each YouTube segment was embedded on its own page within the instruction. However, the Google Sites page did not consistently control YouTube's extraneous promotions for other videos. During pre-study testing, extraneous promos appeared on some smartphones but not on others. To avoid unwanted promos, the videos were uploaded to Screencast.com®, a paid video hosting site. Each multimedia lesson featured a built-in control panel that allowed participants to stop, start, and replay the lesson. The multimedia was embedded in one site for computer users and another site for smartphone users. The only difference in the sites was the instructions that specifically referenced either computers or smartphones.

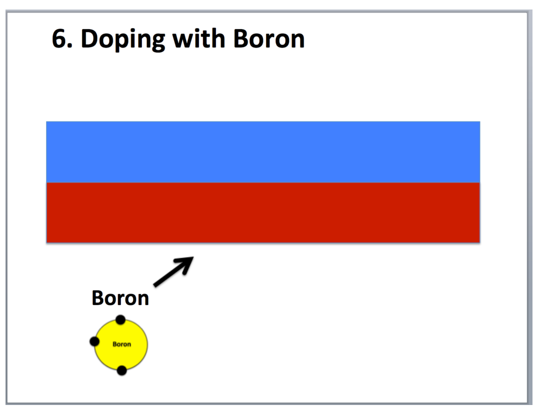

Figure 5. Sample multimedia frame that illustrates this study's signaling strategy for smartphone screens. Text signals important points that will be tested. The heading uses few words and ample white space to introduce the segment number and topic. The heading remains visible throughout each animated segment.

The difficulties encountered in the current study illustrate the challenges of designing instruction for smartphone users in higher education. The original research plan called for hosting the instruction and assessment in the LMS Canvas®. However, product testing revealed that the responsive design of the LMS would adjust only to the size of a tablet rather than reducing enough to accommodate smaller smartphone screens. As a result, smartphone users would have seen only a fraction of each page unless they manually "pinched" each page to resize and reposition it. Requiring one treatment group to manually resize and reposition every page, page-by-page, was unacceptable. The LMS had a mobile app that would have accommodated smartphone users, but requiring volunteers to download an app on their personal smartphones was deemed a potential barrier to participation.

Another barrier to participation was the password requirement of the LMS. For participants who had used Canvas® at anytime in the past, the LMS would have required the individual's Canvas® password to access the current study. Therefore, many participants would have needed to remember the password that they were issued months or years earlier, and that could have been a barrier to participation.

To avoid the limitations of the LMS, the multimedia lesson for both treatment groups was built in the classic version of Google Sites, a free webpage building site. Google Sites allowed access to the multimedia instruction without requiring a password. Having no password requirement was considered an advantage that could help facilitate participation. However, building outside of an LMS created a different challenge regarding assessment. Google Sites had no quiz tool. Therefore, the posttest was built at surveyanyplace.com®, a paid survey-hosting site. The survey site was integrated into the multimedia instruction and required no official logging in, which was deemed an advantage for participation. Participants used a simple sign-in page to enter their name and email. Another advantage was that the survey site automatically recorded the types of devices that participants used to access the posttest. One disadvantage of hosting the posttest outside of an LMS was that the survey tool did not automatically grade multiple-choice test items. Therefore, the multiple-choice items required hand grading.

Independent Treatment Groups

Computer users. The computer-user treatment group represented traditional online education with its large computer screens and full-size keyboards. After receiving their treatment group assignment, these participants used their computers to view the multimedia instruction (see Appendix F). They then answer the posttest recall questions and survey items (see Appendix G).

Smartphone users. The smartphone-user treatment group used their smartphones to view the same multimedia instruction as the computer-user treatment group (see Appendix F). They also answered the same posttest survey and recall questions (see Appendix G). Despite the ubiquity of smartphones, distance learning programs within higher education continue to focus primarily on computer users (Elias, 2011). Therefore, this treatment group had value in helping determine the effect of smartphones on student performance in m-learning.

Measures

Posttest. A 10-item posttest measured recall using a mix of six multiple-choice and four open-response items (see Appendix G). The multiple-choice questions had four response options. Before the study, three independent reviewers analyzed the posttest content for validity. The reviewers were a schoolteacher with 17 years of teaching experience in middle and elementary school, a graduate student in the final semester of an English literature master's program, and a senior in an undergraduate program for physical therapy. The three reviewers verified the content validity of the posttest items (see Appendix I), and the instrument required no changes. The posttest was then tested in a pilot study with 10 participants. In the pilot study, the multiple-choice questions had an item discrimination index of .60, which indicated strong item discrimination (Thorndike & Thorndike-Christ, 2010). When used in the present study, the multiple-choice items had a lower item discrimination index (.31) than they did in the pilot study. However, the item discrimination index value still fell within the range of what is considered good (University, 2017).

The untimed posttest contained four features designed to facilitate the writing of thorough responses to open-response questions. First, all questions were mandatory, which prevented participants from skipping the open-response questions. Second, participants had the ability to review previous questions and answers if they chose to do so. Third, multiple-choice questions about a topic were followed immediately by an open-response question that addressed that same topic. The intent was to use the information in the multiple-choice questions and answers to prime participants to answer comprehensively while the information was fresh in their minds. Finally, the posttest site prevented participants from copying the wording of a past test item or answer and pasting it into their current answer. The lack of a copy/paste function required participants to compose and enter their original answers within each question's answer box. Participants' inability to copy and paste was an unanticipated benefit of hosting the posttest on surveyanyplace.com rather than within an LMS.

Of the four open-response items, the last two items were designed to require longer answers than the first two. Questions 3 and 5 were two-part questions. Question 8 was a three-part question. Question 10, the final posttest question, asked participants to discuss everything they had learned about how a solar cell works (see Appendix G).

Two independent raters analyzed the open-response answers for accuracy and writing mechanics. Each received a rater's guide for open response answers (see Appendix H). The researcher conducted individual training sessions that defined the criteria for crediting correct answers and the guidelines for deducting points for errors in writing mechanics. The raters answered one practice question regarding recall score and one regarding point deductions. The researcher discussed the practice results with each rater and answered questions. Upon completion of the rating orientation, each independent rater received anonymous posttest data that had no identification of participants or treatment groups. Raters independently entered their scores in an online database using Google Sheets. An open-response score was calculated as a recall score minus points for errors in writing mechanics. Each open-response answer could score a maximum of 12 points. Appendix H contains the rating criteria and instructions for rating open-response answers.

To calculate inter-rater reliability, scores from each rater were analyzed using Cohen's kappa. The results indicated substantial agreement between the raters, $k = .78$, $p < .05$ (Landis & Koch, 1977). The raters agreed on 91% of the computer-user ratings and 85% on the smartphone-user ratings. On items where raters' scores did not agree, ratings were analyzed to determine how much the ratings differed. The analysis revealed that when given the choice of awarding full credit, partial credit, or no credit, raters never differed more than one level when rating an item. For example, when ratings differed and one rater gave the highest rating of full credit, the other rater never gave a rating lower than partial credit. Considering that the raters seldom disagreed, and when they did, the differences in their ratings were minimal, the researcher determined that the rater training and rating protocol had been sufficient. Therefore, no further action was necessary. Ratings differences on an item were mitigated when the scores were averaged to determine a final score.

Usability survey. The posttest recall questions were followed by eight survey items. Of the eight survey items, three addressed device usability on multiple-choice questions, and three addressed usability on open-response questions (see Appendix G). The usability survey items required participants to use a 6-point scale to rate their agreement with an affirmative statement about their experience during the study. The rating of *strongly agree* represented the highest level of the condition being measured and the highest point value. Conversely, the rating of *strongly disagree* represented the lowest level of the condition being measured. The ISO criterion of efficiency (International 2010) was addressed by one question about perceived ease and one question about perceived speed when using a designated device. The ISO criterion of satisfaction was addressed with a question that addressed perceived satisfaction when using a designated device.

Usability ratings for open-response items were calculated the same way for both treatment groups. A device's usability rating was calculated by averaging the ratings of the three usability components: effectiveness, efficiency, and satisfaction. The three components had equal weighting of 12 points each. The first component, effectiveness, was based on open-response test scores; therefore, it had no item on the usability survey. The usability component of efficiency had two criteria, ease and speed. The survey had one question about ease and one about speed. A participant's ratings of ease (6-points possible) and speed (6-points possible) were added to determine a final efficiency rating (12 points possible). The final usability component, satisfaction, was based on a participant's response to a 6-point scale. To calculate a final satisfaction rating, a participant's satisfaction points were doubled to fit this study's 12-point scale of usability. The final usability ratings from the treatment groups were then compared.

For multiple-choice questions, the first component of usability, effectiveness, was based on multiple-choice test scores. Otherwise, the process for calculating the usability of computers and smartphones when answering multiple-choice questions was the same as the process used for open-response scores. The final usability scores were then compared to determine if computers and smartphones received significantly different usability ratings when participants used their devices to answer multiple-choice questions.

Procedures

Individuals who responded to the recruitment email (Appendix A) or social media invitation (Appendix B) landed on a study information page (see Appendix C). The page explained the study and registered informed consent. Upon providing informed consent, participants completed an online demographic survey (see Appendix D) using the device of their choice from the location of their choice. In the demographic survey, respondents reiterated their agreement to the terms of the study, and they agreed to use the device that was randomly assigned to them. Upon submission of the demographic survey, an online tool (GraphPad, 2016) was used to randomly assign respondents to either the computer treatment group or the smartphone treatment group (see Appendix E). Randomly assigning participants to groups provided reasonable assurance that, on average, the groups were similar and that any differences between them were due entirely to chance. After receiving their random assignments, more smartphone users (n = 36) participated than computer users (n = 34). However, the statistical analyses used in this current study were considered robust enough to compensate for the minor difference in group sizes.

Individuals received a link to participate in the site designated for their device. The study link was emailed to computer users, but smartphone users were not sent a traditional email due to concerns that they would open the link on their computers rather than on their smartphones. Therefore, the smartphone participation link was emailed as a text message directly to participants' smartphones. To accomplish this, a participant's phone number was entered into a website (CarrierLookup.Com, 2017) that identified the phone carrier (e.g., Verizon, ATT) associated with the phone number. Once the carrier was identified, the carrier's corresponding email suffix was retrieved from a different website (TechFAQ, 2017). Brief instructions and the study link were then emailed to a participant's smartphone using the participant's phone number and appropriate suffix. Each smartphone participant received the information as a text message on her or his smartphone. For three participants who had non-standard phone carriers, the researcher texted the information from his personal smartphone rather than following the email protocol. The different delivery method had no adverse effect on the three smartphone users' participation.

At the time and location of their choosing, participants logged into their assigned online site using their designated devices. The two treatment groups received identical, 3-minute multimedia lessons about how a solar cell works. On each page, participants viewed a brief segment (10-30 seconds) of animated multimedia instruction (see Appendix F). Learner controls enabled all participants to view, review, and advance the multimedia at their own pace. After viewing the final segment of multimedia instruction, participants completed an untimed, online posttest. Both treatment groups received the same 10 recall questions. All participants then answered eight survey items, six of which addressed device usability. The survey items were identical except for references to the device (computer vs. smartphone) that was appropriate for each group. Smartphone users answered an additional survey question regarding the text entry method(s) they used during participation (see Appendix G).

The posttest site automatically recorded the type of device participants used to access the posttest. The device identification record indicated that one participant in the smartphone group used a computer to take the posttest. Consequently, that participant's data was disqualified and deleted from the study.

Data Analysis

One-way ANOVA procedures (Gamst, Meyers, & Guarino, 2008) were conducted to answer the research questions of interest. Specifically, the Fisher's *F* test was used to analyze the difference between computer and smartphone treatment groups. For each question, eta squared (η^2) was used to measure the size of the effect that the independent variable had on the dependent variable. Levene's test was used to determine if the group scores violated the homogeneity of variances assumption. Upon violation of the assumption, the Brown-Forsythe test was conducted to correct for the bias caused by the assumption violation, and it was used to evaluate between-group difference instead of Fisher's *F* test.

Supplemental Data Analyses

In addition to analyzing data related to the research questions of interest, a series of one-way ANOVAs were conducted to examine different aspects of the open-response answers. Question-by-question, answers were evaluated for raw scores, penalty points, length of answers, and other characteristics. Likewise, one-way ANOVAs were conducted to assess survey data regarding ratings for ease, speed, and satisfaction when using computers and smartphones.

CHAPTER III

Results

This chapter begins with the results of statistical analyses associated with the hypotheses of the present study. The analyses were conducted to determine the effect of device when computer users and smartphone users answered multiple-choice and open-response questions in a distance-learning environment. Table 1 displays the variables and statistical analysis method associated with each research question. The chapter concludes with results from supplemental data analyses of items not addressed by the research questions of this study. Unless noted otherwise, all analyses were conducted with SPSS statistical analysis software, and the significance level for each analysis was .05.

Table 1

Statistical Analyses Conducted for Research Questions

Research Question	Treatment groups	Outcome variable	Analysis
1	Computer vs. Smartphone	Multiple-choice recall	One-way ANOVA
2	Computer vs. Smartphone	Open-response recall	One-way ANOVA
3	Computer vs. Smartphone	Device usability rating w/ multiple-choice	One-way ANOVA
4	Computer vs. Smartphone	Device usability rating w/ open-answer	One-way ANOVA

Hypothesis 1

The first hypothesis predicted that computer users and smartphone users would have no significant difference in their scores when answering multiple-choice recall questions. As predicted, a one-way analysis of variance (ANOVA) revealed no significant difference in test performance between computer users and smartphone users when they answered the multiple-choice recall items of the posttest, $F(1, 68) = .24$, $p = .62$, $\eta^2 < .01$. Computer user scores (M = 6.0; SD = 1.15) and smartphone user scores (M = 5.0; SD = 1.04) averaged 5 of 6 points.

Hypothesis 2

The second hypothesis predicted that computer users would score significantly higher than smartphone users when answering open-response recall questions. For open-response questions, each answer received up to 12 points for content accuracy. Points were then deducted for errors in writing mechanics such as incomplete sentences, misspelled words, and errors in capitalization and punctuation. A pair of independent raters graded each open-response answer using standardized criteria (see Appendix H). To calculate inter-rater reliability, scores from each rater were analyzed using Cohen's kappa. The results indicated substantial agreement between the raters, $k = .78$, $p < .05$ (Landis & Koch, 1977).

When aggregate scores from the four open-response questions were analyzed with a one-way ANOVA, the results indicated no significant difference between the treatment groups, $F(1, 68) = 1.76$, $p = .19$, $\eta^2 = .03$. The results did not support Hypothesis 2 predicting that recall scores of computer users on open-response questions would be higher than those of smartphone users. A Levene's test indicated a violation of the homogeneity of variances. Results from a subsequent Brown-Forsythe test agreed with the earlier finding of no significance between treatment groups regarding recall scores on open-response questions, $F(1, 38) = 1.87$, $p = .18$, $\eta^2 = .03$.

Hypothesis 3

The third hypothesis predicted that when computers and smartphones were used to answer multiple-choice test items, the usability ratings of the devices would not differ significantly. The analyses of usability ratings supported Hypothesis 3. Out of 12 possible points, the average smartphone usability rating of 10.37 was slightly higher than the computer rating of 9.95. A one-way ANOVA was conducted to compare the usability ratings of computers and smartphones when they were used to answer multiple-choice test items, and no significant difference was found, $F(1, 68) = 1.00$, $p = .31$, $\eta^2 = .01$. Levene's test of homogeneity indicated a violation of the assumption of equal variances. Therefore, a subsequent Brown-Forsythe test was conducted, and it found no significant difference in the usability ratings of the computer and smartphone groups $F(1, 54) = 1.00$, $p = .32$, $\eta^2 = .01$. Table 2 shows the mean and standard deviation for the usability ratings of each device type.

Hypothesis 4

The results of the present study supported Hypothesis 4, which predicted that computers would receive significantly higher usability ratings than smartphones when participants used the devices to answer open-response test questions. Devices could receive up to 12 points in each of the following categories: effectiveness, efficiency, and satisfaction. Ratings from the three categories were averaged to determine a device usability rating. A one-way ANOVA indicated that computers received significantly higher usability ratings than smartphones when the devices were used to answer open-response questions, $F(1, 68) = 8.67$, $p < .01$, $\eta^2 = .11$. Levene's test of homogeneity indicated a violation of the assumption of equal variances. A subsequent Brown-Forsythe test found a significant difference in the usability ratings that members of each treatment group gave their devices, $F(1, 56) = 8.92$, $p < .01$, $\eta^2 = .11$. The effect size was small to moderate (Gamst et al., 2008). Table 2 shows the mean and standard deviation of usability ratings based on device and question type.

Table 2

Mean and Standard Deviation of Usability Ratings by Question Type

		Multiple-choice questions (12-point scale)		Open-response questions (12-point scale)	
Treatment group	n	*M*	(*SD*)	*M*	(*SD*)
Computers	34	9.95	(2.1)	10.55	(2.26)
Smartphones	36	10.37	(1.30)	*7.9	(6.52)

* Significant difference

Supplemental Results

Additional data analyses were conducted beyond those that addressed the current study's research questions. The posttest scores and survey results were analyzed question-by-question to determine participant tendencies. Findings from the analyses are presented here.

Open-response scores per question. Each open-response question's dataset was analyzed separately with its own one-way ANOVA (see Table 3). With 12 points possible, Question 3 computer users averaged 9.8 points versus smartphone users' 8.4 points. On Question 5, computer users averaged 9.6 points versus 8.3 points for smartphone users. Although computer users earned higher scores than smartphone users, neither Question 3, $F(1, 68) = 3.11$, $p = .08$, $\eta^2 = .04$ nor Question 5, $F(1, 68) = 2.54$, $p = .12$, $\eta^2 = .04$ had a significant difference in the scores of the two treatment groups. For Question 3, a Levene's test indicated a violation of the homogeneity of variances. A Brown-Forsythe test was conducted to provide a more robust test of equality of means by analyzing unequal variances from the group median rather than from the group mean. The Brown-Forsythe test indicated no significance between groups, $F(1, 66) = 3.15$, $p = .08$, $\eta^2 = .04$.

In contrast to the first two open-response questions, performance results from the final two open-response questions did have a significant difference. On Question 8, computer users averaged 10.4 points versus 8.7 points for smartphone users. On Question 10, computer-user scores averaged 10.1 versus 8.0 for smartphone users. A one-way ANOVA was conducted for Question 8, $F(1, 68) = 4.18$, $p = .05$, $\eta^2 = .06$, and one was conducted for Question 10, $F(1, 68) = 5.30$, $p = .02$, $\eta^2 = .07$. In both cases, Levene's test of homogeneity indicated a violation of the assumption of equal variances. Therefore, each dataset was analyzed using the Brown-Forsythe test, which provides a more robust test of equality of means for unequal groups. The mean differences for Question 8, $F(1, 64) = 4.26$, $p = .04$, $\eta^2 = .06$ and Question 10, $F(1, 63) = 5.40$, $p = .02$, $\eta^2 = .07$ were statistically significant based on the results of the Brown-Forsythe test. The effect sizes of .06 and .07 were small (Gamst et al., 2008).

Table 3

Mean and Standard Deviation of Open-Response Scores

		12-point Scale			
		Question 3	Question 5	Question 8	Question 10
Treatment group	*n*	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Computer users	34	9.84 (3.00)	9.65 (3.50)	10.44 (2.93)	10.1 (3.12)
Smartphone users	36	8.40 (3.74)	8.28 (3.68)	*8.73 (3.96)	*9.6 (4.40)

* Significant difference

Raw recall scores. A raw recall score was based only on the accuracy of the content in an answer. Writing mechanics were not considered when calculating the raw recall score. For each open-response question, a one-way ANOVA was conducted to evaluate the raw recall scores associated with individual questions. The results indicated no significant difference in raw recall scores on Question 3, $F(1, 68) = 2.08$, $p = .15$, $\eta^2 = .03$; Question 5, $F(1, 68) = .65$, $p = .42$, $\eta^2 = .01$; Question 8, $F(1, 68) = 7.68$, $p = .39$, $\eta^2 = .01$; or Question 10, $F(1, 68) =$, $p = .12$, $\eta^2 = .04$. On Question 3, Levene's test of homogeneity indicated a violation of the assumption of homogeneity. Therefore, a Brown-Forsythe test was implemented and the results indicated no significant difference between the groups $F(1, 65) = 2.11$, $p = .15$, $\eta^2 = .03$.

Penalty points. Writing mechanics of an open-response answer were analyzed and penalty points were assessed according to a grading protocol (see Appendix H). On open-response questions, computer users were penalized a total of 127 points compared to 237 points for smartphone users. For each open-response question, a one-way ANOVA was conducted to evaluate the penalty points assessed on individual questions. The results indicated no significant difference between groups when answering Question 3, $F(1, 68) = 1.24$, $p = .27$, $\eta^2 = .02$; Question 5, $F(1, 68) = 2.67$, $p = .11$, $\eta^2 = .04$; or Question 8 $F(1, 68) = 1.93$, $p = .17$, $\eta^2 = .03$. However, a statistical analysis found that when computer users answered Question 10, they lost significantly fewer points for writing errors than smartphone users did, $F(1, 68) = 4.38$, $p = .04$, $\eta^2 = .06$. Due to Levene's test indicating a violation of the homogeneity of variances on questions 5, 8, and 10, those questions were analyzed with a Brown-Forsythe test. The Brown-Forsythe test indicated no significant difference in Question 5, $F(1, 67) = 2.67$, $p = .11$, $\eta^2 = .04$ or Question 8 $F(1, 62) = 1.97$, $p = .17$, $\eta^2 = .03$. After the adjustment for the Brown-Forsythe test, the one-way ANOVA results for Question 10 indicated that computer users lost significantly fewer points for writing errors than smartphone users did, $F(1, 52) = 4.54$, $p = .04.$, $\eta^2 = .06$. The effect size was small.

Usability component ratings. For open-response questions, survey results related to the three components of usability (effectiveness, efficiency, and satisfaction) were analyzed separately. Each component could receive a maximum rating of 12 points. The first component, effectiveness, was based on the posttest recall scores of all open-response questions as reported in the results of Hypothesis 2 earlier in this chapter. When all open-response posttest scores were analyzed as a group using a one-way ANOVA and adjusted with a Brown-Forsythe test, participant performance did not differ significantly based on device, $F(1, 55) = .57$, $p = .46$, $\eta^2 = .01$.

Efficiency ratings. In the category of efficiency, a one-way ANOVA determined that smartphones received significantly lower efficiency ratings than computers when answering open-response questions, $F(1, 68) = 89.52$, $p < .01$, $\eta^2 = .57$. The .57 effect size was large. The component of efficiency had two criteria, ease and speed. To align the efficiency score within the 12-point scale of the other two components (effectiveness and satisfaction), the ratings for ease (maximum 6 points) and speed (maximum 6 points) were added to determine the efficiency rating. When participants were asked to rate the ease of using their devices, the average rating for smartphones was 2.61 compared to 5.82 for computers. A one-way ANOVA indicated that compared to computers, smartphones were significantly more difficult to use when composing open-response answers, $F(1, 68) = 143.52$, $p < .01$, $\eta^2 = .68$. The effect size was large. When participants rated the speed of their devices when answering open-response questions, smartphone ratings averaged 2.67 compared to 5.76 for computers. The results of a one-way ANOVA determined that smartphones received significantly lower ratings for speed than computers, $F(1, 68) = 118.73$, $p < .01$, $\eta^2 = .64$. A Levene's test determined that the satisfaction ratings violated the homogeneity of variances. Therefore, a Brown-Forsythe test was conducted, and the results indicated a significant difference between treatment groups $F(1, 39) = 101.88$, $p < .01$, $\eta^2 = .59$ This result also had a large effect size (Gamst et al., 2008).

Words per open-response answer. The number of words in each open-response answer was analyzed to provide ancillary indications of efficiency of devices for composing sentences. In an analysis of answers from all open-response items, a one-way ANOVA indicated a significant difference between treatment groups regarding the number of words in answers $F(1, 278) = 13.61$, $p < .01$, $\eta^2 = .05$. A Levene's test indicated a violation of the homogeneity of variances. Therefore, a more robust Brown-Forsythe test was conducted to compensate for the slightly unequal group sizes. The results indicated a significant difference between treatment groups regarding the number of words generated on the four open-response answers, $F(1, 278) = 13.21$, $p < .01$, $\eta^2 = .05$. On the series of open-response items, computer users produced 30, 36, 42, and 110 words per answer compared to smartphone users who produced 21, 26, 35, and 63 words. Overall, computer users produced an average of 30% more words than smartphone users when answering the four open-response questions.

Sentences per open-response answer. Sentence count was analyzed for each open-response answer to triangulate the self-reporting of device efficiency, which relates to the ease and speed of writing. For the first three open-response questions, the answers were classified using four categories: 0 complete sentences, 1 sentence, 2-3 sentences, and 4 sentences. Classification was determined not by the number of actual sentences in an answer, but by the number of relevant clauses within each sentence. For example, the three answers below communicate the same information, but each contains a different number of sentences. For the current study, the three examples would be categorized as having 2-3 sentences even though the information could be expressed in varying forms ranging from three simple sentences to one compound-complex sentence.

Three simple sentences = rating of 2-3 sentences:

Silicon, phosphorous, and boron are required for doping a solar cell.

Phosphorous has the most electrons.

Boron has the fewest electrons.

One simple sentence plus one compound sentence = rating of 2-3 sentences:

Silicon, phosphorous, and boron are required for doping a solar cell.

Phosphorous has the most electrons, and boron has the fewest electrons.

One compound-complex sentence = rating of 2-3 sentences:

Silicon, phosphorous, and boron are required for doping a solar cell, and of the three, phosphorous has the most electrons, and boron has the fewest.

In the current study, open-response scores did not depend on specific amounts of sentences or words. However, the open-response questions were designed to elicit longer answers on the last two items. That strategy had only partial success. An evaluation of participant answers indicated that for the first three open-response items, answers with 2-3 sentences could adequately address all points posed in the questions. The majority of participants in both treatment groups answered the first three open-response questions with an adequate number of sentences. For Question 3, the answers of most computer users (74%) and smartphone users (64%) contained 2-3 sentences. A one-way ANOVA found no significant difference between the treatment groups concerning how many answers contained 2-3 sentences, $F(1, 68) = .74$, $p = .39$, $\eta^2 = .01$. For Question 5, most computer users (79%) and smartphone users (67%) answered with 2-3 sentences. An additional 6% of computer users answered with four sentences. A one-way ANOVA indicated no significant difference between treatment groups regarding the number of answers that contained two sentences or more, $F(1, 68) = 1.43$, $p = .24$, $\eta^2 = .05$. A

Levene's test indicated a violation of the homogeneity of variances due to slightly unequal group sizes. Therefore, a Brown-Forsythe test was conducted, and the results indicated no significant difference between treatment groups regarding the number of participants who answered Question 5 with at least 2 sentences, $F(1, 65) = 3.42$, $p = .07$, $\eta^2 = .02$.

Question 8 elicited 2-3 sentences from 94% of computer users and 67% of smartphone users. Unlike the first two open-response questions, on Question 8, a one-way ANOVA indicated that when compared to smartphone users, computer users produced significantly more answers that contained 2-3 sentences, $F(1, 68) = 9.07$, $p < .01$, $\eta^2 = .12$. The effect size of .12 was moderate (Gamst et al., 2008). A Levene's test indicated a violation of the homogeneity of variances. However, results of the more robust Brown-Forsythe test agreed with the earlier finding. Compared to smartphone users, computer users produced significantly more answers that contained 2-3 sentences, $F(1, 52) = 9.39$, $p < .01$, $\eta^2 = .12$.

For the first three open-response questions, smartphone users answered with fewer than two sentences more frequently than computer users did. For Question 3, computer users answered with one complete sentence 26% of the time compared to 30% of smartphone users. Smartphone users answered with incomplete sentences 6% of the time compared to zero incomplete sentences for computer users. For Question 5, computer users (8%) produced fewer single-sentence answers than smartphone users (30%) and fewer incomplete sentences (5%) than smartphone users (19%) did. On Question 8, smartphone users answered with one sentence 14% of the time compared to zero single-sentence answers from computer users. Computer users (5%) produced fewer incomplete sentences than smartphone users (19%) did when answering Question 8.

An evaluation of answers to the final open-response item indicated that Question 10 required at least four sentences to adequately address the points of its longer prompt. Computer users (71%) and smartphone users (61%) had no significant difference in the number of their answers that contained at least four sentences, $F(1, 68) = 3.47$, $p = .07$, $\eta^2 = .05$. A Levene's test indicated a violation of the homogeneity of variances. Therefore, a Brown-Forsythe test was conducted. Regarding the number of answers that contained at least four sentences, the results of the Brown-Forsythe test indicated no significant difference between treatment groups, $F(1, 67) = 3.50$, $p = .07$, $\eta^2 = .05$. Among computer users, 56% of their open-response answers contained five sentences or more compared to 25% among smartphone users. Smartphone users (36%) answered with four sentences more than twice as often as computer users (15%) did. Regarding answers that were too short to adequately address all points of Question 10, 6% of computer users answered with 2-3 sentences compared with 8% of smartphone users. Computer users (12%) answered with more single sentences than smartphone users (8%) did, but smartphone users (5%) answered with more incomplete sentences than computer users (2%).

Satisfaction ratings. For satisfaction, which was the final component of usability, the average smartphone rating for open-response questions was 6.56 compared to 11.71 for computers. Results of a one-way ANOVA indicated that smartphone users reported significantly lower satisfaction with their devices than computer users when answering open-response questions, $F(1, 68) = 96.76$, $p < .01$, $\eta^2 = .59$. The Levene's test indicated a violation of the assumption of homogeneity. Therefore, a Brown-Forsythe test was conducted, and the result indicated a significant difference between the treatment groups regarding device usability ratings, $F(1, 39) = 101.88$, $p < .01$, $\eta^2 = .59$. The effect size was large (Gamst et al., 2008).

Text entry methods. In the posttest survey, smartphone users reported the text entry methods that they used to answer the posttest questions and survey. Table 4 displays the methods that smartphone participants reported. Regarding the last item in the table, the participant's comments (Appendix J) seemed to indicate that the participant became frustrated with the smartphone, quit the posttest, and came back to retake the posttest with a Bluetooth® keyboard.

Table 4

Participants' Smartphone Text Entry Methods

Entry Method	*n*
Touchscreen typing only	21
Other	
Touchscreen & finger-swiping	5
Touchscreen & mini physical keyboard	3
Touchscreen, voice dictation, & finger-swiping	3
Touchscreen & voice dictation	2
Mini physical keyboard & voice dictation	1
External Bluetooth keyboard	1

Participant comments. When asked which device they would choose for a similar study in the future, 29 computer users (85%) chose to use a computer again compared to two smartphone users (6%) who wanted to use their same device. Most smartphone users (75%) wanted to switch to a computer. Other than one computer user who wanted to use a smartphone, the balance of computer users (12%) and smartphone users (19%) said they would use either device.

In the posttest survey of the present study, no computer users reported a concern or complaint about using their devices to complete tasks in the study. In contrast, of 32 smartphone users who volunteered comments, 82% (n = 28) expressed at least one concern about using a smartphone to participate in the study. Nearly half of smartphone respondents (n = 15) in the present study used words like "difficult," "frustrating," "tired," and "stressed" to describe their experience of using a smartphone during the study. A few smartphone users expressed a slight sense of ambush, as expressed in this comment, "When I saw the free entry questions I knew this was going to take longer than anticipated" (Appendix J).

As expected, smartphone users cited physical limitations of viewing small screens, typing on miniature keyboards, and grappling with the autocorrect function of their devices. However, a few smartphone users articulated a concern that was not anticipated at the beginning of the current study. Beyond the physical and ergonomic obstacles of using miniature features on handheld devices, some smartphone users identified what might be considered a cognitive obstacle. Smartphone users suggested that the combination of a small screen and an onboard, touchscreen keyboard on their devices had a deleterious effect on their ability to think, compose, edit, and proofread when answering open-response questions (Appendix J).

When composing sentences on a smartphone, onboard, touchscreen keyboards can cover almost half of a small smartphone screen, making a small viewing area even smaller. According to some smartphone respondents in the present study, that restrictive viewing area created two obstacles to answering the open-response questions. First, the small screen space sometimes prevented smartphone users from seeing entire questions, their entire sentences, or their entire answer during composition. Respondents indicated that their inability to see everything that they were writing, in context, had an adverse effect on their ability to answer open-response questions. Second, to compensate for their smartphones' restrictive viewing area during composition, smartphone users reported that they continually scrolled up and down to see parts of questions and answers that were out of view while attempting to write. Some smartphone users deemed the scrolling disruptive to their writing process (Appendix J).

A pair of participants in the computer treatment group confirmed the observations of smartphone users regarding the potentially adverse effect of smartphones on cognition and composition when answering open-ended questions. One computer user suggested that because a computer screen provides a full view of what one is writing, one can monitor and maintain the logic of a paragraph more easily than when composing on a smartphone. Another computer user claimed that using a computer screen reduced her concerns that information would be missed (Appendix J). Table 5 contains sample comments of participants in the smartphone treatment group regarding the answering of open-response questions. Original spelling and grammar errors were intentionally left in the comments. Appendix J contains all participant comments about the present study.

Most smartphone participants did not report any technical difficulties. However, apparently on some smartphones, the multimedia instruction did not appear optimized, and participants reported the need to manually alter the image to fit their screens. For some devices, both computers and smartphones, the posttest buttons appeared out of place and they overlapped other information. For example, during multiple pre-study checks the multimedia and posttest displayed and functioned appropriately on the researcher's Samsung Galaxy S7 Android smartphone. However, in the posttest survey, a participant reported that the user interface of the posttest did not display correctly on a Samsung Galaxy S5 model of smartphone (Appendix J).

Table 5

Select Feedback from Smartphone Users

	Participant Comments
1	Multiple choice questions were fine, but I craved a keyboard and large screen for complete sentences. I became increadibly tired and stressed when I saw complete answer questions.
2	… with the full sentence answers the small screen made it impossible to see my entire answer at once so I had to keep scrolling up and down.
3	I enjoy my smart phone because I can use voice dictation. With technical terms, like phosphorus, Lauren, and silicone, I often found myself having to retype because the device is not familiar with the words. (I won't retype here so you can see what is spelled when I say the words - Lauren for boron and silicone for silicon.)
4	If I was to complete this study again, I would prefer to answer on my laptop. I found that answering and viewing the questions on my phone took more effort than if I could see the full screen and type on a normal keyboard.
5	Typing my answers on the smartphone keyboard was rather frustrating. The autocorrect feature kept changing my words and I'd have to erase and rewrite, sometimes several times, before getting the sentence finished. I also kept accidentally capitalizing things. I would much rather use a computer than a smartphone for quizzes. In regards to the video watching, I didn't have any trouble getting the videos to load or play. I'd be fine with using my phone to watch videos again.
6	I disliked the experience of using a smartphone for the following reasons: 1. It was difficult to regurgitate facts, since I was not able to write notes efficiently. 2. The questions requiring complete sentences was difficult to type on a smarrtphone, since the keyboard took up half the screen, and blocked viewability of what I was typing, and the question. 3. I received a phone call, which caused me to hit back after the call, whichcaused an error. I had to restart the quiz. 4. I had to restart the quiz twice, due to incorrectly using the browser's back button. This was frustrating.
7	I have an IPhone 6s plus, so my screen is pretty big. But even then, I still got the feeling that I was pushing my comfort level when answering questions with full sentences. I can only imagine how someone with a smaller screen would feel. I think it has to do with being able to see everything I write while writing. The phone's keyboard takes a lot of screen realestate. This is the only reason why I would rather do it on a computer the next time. …And because the section scrolls, I had to manually scroll up and reread everything hoping to find mistakes (which I found many in this response alone!).
8	My stress level has skyrocketed as a result of using my smart phone for this exercise.
9	The smartphone was convenient, but I found myself wanting to type on a physical keyboard when writing in complete sentences. It was difficult to think through the new information while writing on my phone, and it took longer to type than typing on a physical keyboard. I would rather take an assessment that requires writing on a computer every time.
10	I realized halfway through that I hadn't used complete sentences to answer questions, but made a decision NOT to go back because it was challenging to "thumb type" such long sentences! I am unable to do voice dictation at the moment because I currently share office space.

Summary of Primary Findings

The current study found that smartphone users performed as well as computer users when answering multiple-choice questions, and both treatment groups gave their devices high usability ratings regarding multiple-choice questions. On open-response questions, smartphone users scored lower than computer users, but the difference was not significant. Concerning usability when answering open-response questions, smartphone users gave their devices significantly lower usability ratings than computer users did. Several smartphone users complained about fatigue and frustration when using a smartphone to answer questions that required composition.

Summary of Supplemental Findings

Beyond the findings associated with the research questions of interest, additional analyses provided insight into the behavior of participants and their tendencies when answering open-response questions. When questions were analyzed item-by-item, the data revealed no significant difference in the raw scores of the two treatment groups. However, when word count and penalty points were assessed smartphone users were found to produce fewer words and more errors than computer users. On some of the questions, the differences were significant. Regarding usability, the survey analyses revealed that compared to computer users, smartphone users gave their devices significantly lower ratings for ease, speed, and satisfaction.

CHAPTER IV

Discussions and Conclusions

The purpose of the current study was to extend m-learning research by examining the effect of device when answering multiple-choice and open-response questions in distance education. The first goal was to determine the effect of device (computer vs. smartphone) on performance when answering multiple-choice and open-response recall questions. The second goal was to determine whether computers and smartphones would receive significantly different usability ratings when used by participants to answer multiple-choice and open-response questions.

Discussion

M-learning has been touted as the future of education (Keegan, 2002). That broad promise brings with it many unanswered questions regarding smartphones, assessment design, and higher education. The current study addressed aspects of all three elements. Researchers have lauded the smartphone as an ideal tool for answering multiple-choice questions (Bradley et al., 2009), and the results of this study have supported that portrayal. In contrast, m-learning research has characterized smartphones as unfit for composing long answers (e.g., Elias, 2011). Drawing from that prevalent theme in the literature, this study hypothesized that computer users would significantly outscore smartphone users on open-response questions. The results of this study did not support that hypothesis, and the findings contradicted the negative speculation regarding the deficiencies of smartphones when composing lengthy, formal messages.

In the present study, smartphone users might have exceeded performance expectations due to the sophistication of their contemporary smartphone technology, which was superior to much of the technology featured in m-learning literature (e.g., Waycott, 2002). In the current study, nearly 40% of participants used more than one text-input method, which included touchscreen keyboard, mini physical keyboard, finger swiping, voice dictation, and a Bluetooth external keyboard. Perhaps assessment design was another reason smartphone users exceeded performance expectations. The first three low-level recall questions could have been correctly answered with only two or three sentences. Requiring higher-level thinking and complex answers of greater length might have increased the difference in scores between computer users and smartphone users. Furthermore, the current study featured only four open-response questions, which might not have been enough to fully test the endurance of smartphone users.

On one hand, proponents of m-learning can find encouragement in the positive results of this study. In addition to supporting the use of smartphones for multiple-choice testing, the findings suggest that the smartphone may be a viable test-taking tool for open-response questions. On the other hand, m-learning proponents should exercise caution because the evidence supporting smartphone use with open-ended questions was not overwhelming. For example, the average computer-user score was 83% compared to the average smartphone user score of 72%. That difference lacked statistical significance. However, in an online classroom the scores would have represented the difference of a student earning a low B or a low C. From a student’s real-world perspective, those findings suggest that smartphones may be detrimental to one’s grade when taking tests that have open-ended questions. Compared to computer users, smartphone users rated their devices significantly lower in ease, speed, and satisfaction when answering open-response questions. Even though smartphone users and computer users had no significant difference in their performance, the usability ratings indicated that smartphone users strongly disliked using their smartphones for answering open-response questions.

Limitations

The present study had three limitations related to instructional content. First, the multimedia instruction in this study was only three-minutes, which may be shorter than instruction found in typical distance education courses. Longer instruction might produce different outcomes. Second, the instructional content was not complex. More complex content might result in different outcomes. Third, the instructional content was concept-based. Outcomes might differ for instruction focused on skills, affect, or other types of knowledge.

This study had limitations associated with assessment. The posttest featured only recall questions. Furthermore, the recall questions came in only two forms, multiple-choice and open-response. Test items that require transfer and higher-order thinking may produce different results. Likewise, different question formats (e.g., cloze testing) might result in different outcomes.

The research conditions of the current study contributed to the limitations of its findings in two ways. First, the use of convenience sampling posed a potential threat to the external validity and generalizablity of this study. The research was intended to study participants in a distance education environment. In this study, the typical graduate student population was well represented by participants age 22 and older. However, the study had no participants from the youngest age bracket of ages 18-21, which would have been more representative of a typical undergraduate population.

Second, in contrast to laboratory studies, the present online study featured remote participants, and the researcher had no way to prevent interruptions during participation. Most computer users (62%) reported at least one interruption compared to half of smartphone users. However, incoming phone calls had the potential to be more disruptive for smartphone users than for computer users. For example, one smartphone participant reported receiving a phone call while taking the posttest. When attempting to take the call, the participant accidentally exited the posttest and had to re-answer all the questions he had answered previously. On one hand, the incident suggests that some participants within the treatment groups may not have had equal research conditions. On the other hand, the incident represents an authentic learning environment and illustrates the potential hazards of taking a test on one's smartphone.

Implications

Smartphones have permeated our culture, and millions of smartphone users now expect anytime, anywhere access to their distance education courses (Ally, 2009; Crescent & Lee, 2012). However, smartphone users face two obstacles to learning, one from smartphone manufacturers and one from higher education. First, smartphone manufacturers have never and will likely never design their products for education (Traxler, 2009). The present study has highlighted two aspects of hardware design (screen size and text entry) that have hampered m-learners for years (e.g., Cheung & Hew, 2009), and those two issues will likely persist for years more. The second obstacle comes from educators who design online courses exclusively for computer users, providing no consideration for the increasing number of smartphone users who attempt to fully participate in online learning environments, but cannot. Instructional designers have no control over the obstacles presented by smartphone manufacturers, but the findings of the current study do suggest that with some rethinking and creative problem solving, obstacles to usability can be overcome through assessment design (Bradley, et al., 2009; Ting, 2012).

For example, in the present study the use of multiple-choice and open-response questions demonstrated that the same device can receive different usability ratings simply by changing the design of the assessment. For multiple-choice items, the two treatment groups had high recall scores, and smartphones received higher usability ratings than computers. For open-response questions, despite the low usability ratings that smartphone users gave their devices, their performance rivaled that of computer users. Using the findings of the current study as a foundation, educators, instructional designers, and researchers can experiment with different testing formats to determine which ones will support smartphone-user performance and facilitate high usability ratings for smartphones.

Conclusions

By investigating an area of m-learning that had not been studied at the time of the present research, this study has produced several findings that can inform instructional design in distance education. First, the results have supported the assumption that multiple-choice tests are ideal for smartphone users (Bradley et al., 2009). The findings suggest that instructional designers can include multiple-choice questions in online courses with no adverse effects for students who access online courses with their smartphones.

Second, when writing mechanics were not considered, smartphone users performed nearly as well as computer users on open-response questions. However, when penalty points were assessed for writing mistakes, the gap between the treatment groups increased. That pattern suggests that cloze testing might be a good assessment format for smartphone users. A cloze testing item omits key words in sentences and requires students to write responses that fill the blanks. An example of cloze testing to assess recall might read: “As the sun rises, more ___ hit the positive surface of the solar cell, which causes more ___ to search for available ___.” For this item, students might produce an answer similar to the following: “photons; free carriers; holes.” Such an answer is easier and faster to grade than a typical essay answer, yet cloze tests can measure comprehension and transfer as well as a standard question-answering test (Gellert & Elbro, 2013).

A third instructional design strategy calls for slightly altering the design of open-response test items to accommodate smartphone users. Research indicates that open-response test items have value in assessing students' understanding of content (Ornstein, 1992). However, the findings of the present study suggested that when smartphone users composed longer answers, they made more mistakes in writing mechanics than when they composed shorter answers for items that required less writing. One remedy could be to break multi-part prompts into a series of single-topic questions that could be answered correctly with1-2 sentences. Scaffolding the questions would elicit the desired information while alleviating the challenge of composing long answers on a smartphone.

A final instructional design strategy recognizes the dichotomy that surfaced in the results of the present study. On one hand, smartphone users performed as well as computer users on multiple-choice items, and they performed well when answering questions that required open-response. On the other hand, most smartphone users did not like answering open-response questions with their smartphones. To elicit the best performance from all students who use different devices, instructional designers and educators can build a simple notice into a course or syllabus that outlines the number and types of questions that will be on an upcoming test. Informing students would eliminate unpleasant surprises and allow all students to choose the device that they consider best for the task.

Many researchers have extolled the promise and technology of m-learning, but few have addressed the practical pedagogy that m-learning will require for its integration into higher education (Cheung & Hew, 2009; Chen, Chang, & Wang, 2008). At the time of the present study, peer-reviewed, m-learning research had not investigated the effect of device when smartphone users and computer users answer multiple-choice and open-response questions in distance education. The findings of the current study help fill that gap, and they lay a foundation for designing assessments that can help create an inclusive learning environment for all students.

Future Research

The current study featured recall questions that required brief answers, but further research is needed to explore the effects of different assessment designs on learning with smartphones. For recall questions, increasing the number of open-ended questions could test the consistency and accuracy of smartphone users when compared to computer users. Research is needed to determine how well smartphone users can perform with different levels of testing. Transfer questions that require higher-order thinking and complex responses need to be explored to determine the effect of device on participants' ability to think and compose when using smartphones.

The variety of smartphone text entry options represents another area of potential research. By testing the effectiveness of individual text input methods (e.g., finger swiping, voice dictation) as well as different combinations of methods, future studies could inform strategies for maximizing online test performance with a smartphone.

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APPENDIX A

RECRUITMENT EMAIL

Hello, __(name)__,

Do you watch videos on your smartphone and computer?

As part of my doctoral research at Old Dominion University, I am conducting an online study that may interest you (see below). Please consider participating in the study and forwarding this information to all who might be interested.

Those who have questions about this study may contact me or contact my advisor, Dr. Ginger Watson, using the information below.

Thank you,

Thomas R. Wilson
Doctoral Student
Instructional Design & Technology
Old Dominion University

Email: twils002@odu.edu
Phone: (626) 818-5039

Dr. Ginger Watson, Associate Professor
Responsible Project Investigator
STEM Education & Professional Studies
Old Dominion University
Email: gswatson@odu.edu
Phone: (757)683-3246

APPENDIX B

SOCIAL MEDIA RECRUITMENT

As part of my doctoral research at Old Dominion University, would you be willing to watch a 3-minute video and answer a few questions? You can participate at a time and location that is convenient for you. Participants have a 1-in-4 chance of winning a gift card ($5-$25). Please consider participating in the study and forward this link to all who might be interested.

If you have questions, you may contact me at twils002@odu.edu, or contact my advisor, Dr. Ginger Watson at gswatson@odu.edu.

Click for details.

APPENDIX C

STUDY INFORMATION SITE

If you choose to participate, you will…

- Be asked to use either your smartphone or your computer. Please use the device that is requested. (No tablets.)
- Set aside at least 30 minutes in one continuous session, participating at a time and place that is convenient for you.
- Watch a 3-minute online video and answer 10 questions about what you watched.
- Take a brief survey about your experience during the session.
- Be entered to win a gift card worth up to $25. (1-in-4 chance of winning.)

This study is part of the doctoral work of Thomas R. Wilson at Old Dominion University. If you have questions about the study, please contact Thomas Wilson at twils002@odu.edu. This research has been approved by the Human Subjects Committee of the Darden College of Education at Old Dominion University. If you have any questions or concerns about the research protocols or treatment in this research, you may contact Dr. Ginger Watson, Responsible Project Investigator, at gswatson@odu.edu or Dr. Petros Katsioloudis, 757-683-6309, pkatsiol@odu.edu, Chair of the Human Subjects Committee for the Darden College of Education.

Click below to indicate your understanding and agreement with the terms of participation.

Yes, I agree. Sign me up!

APPENDIX D

DEMOGRAPHIC SURVEY

The following items were delivered as a demographic survey in Google Forms. By using the link that opened this survey, individuals indicated that they had read and agreed with the terms of study.

By clicking "I agree", you indicate that you have read and understand the information provided, that you willingly agree to participate, and that you may withdraw your consent at any time. If you do not wish to participate in the study, please decline participation by selecting "I disagree" below.

__Agree
__Disagree

Your name *
Your email *

If you are asked to use either a smartphone or computer for this study, are you willing to use the device that is requested? *

- Yes, I am willing to participate using the device (my smartphone or computer) that I'm requested to use.
- No (If "no", please scroll down and click SUBMIT so we don't contact you further. Thank you.)

1. How frequently do you watch online videos? *

- Several times per day
- Several times per week
- Several times per month
- Seldom
- I don't watch online videos

2. Which sentence best describes you? *

- I watch videos on my smartphone more than on my computer (not a tablet).
- I watch videos on my computer (not a tablet) more than on my smartphone.
- I watch videos on my smartphone and computer (not a tablet) about an equal amount of time.
- I don't use a smartphone or computer to watch videos.

3. How many text messages do you usually compose with your smartphone? *

More than 10 text messages per day

- 5-9 text messages per day
- 1-4 text messages per day
- I rarely send text messages.

- I don't send text messages

4. Do you use your smartphone to read email? *
    - Yes
    - No

5. How many email messages do you usually compose on your smartphone? *
    - More than 10 emails per day
    - 5-9 emails per day
    - 1-4 emails per day
    - I rarely use my smartphone to write email messages.
    - I don't use my phone to write email.

6. Age? *
    - Under 18
    - 18-21
    - 22-30
    - 31-45
    - 46-60
    - Over 60

7. Gender? *
    - Male
    - Female

8. What is your highest level of education? *
    - Some high school
    - High school diploma
    - Some college
    - College degree
    - Graduate degree

9. When did you last participate in an online course either as a student or instructor? *
    - Within the past year
    - Within the past three years
    - More than three years ago
    - Never

Please provide your mobile phone number. (It will be used only to send you the study link in a text message.) *

APPENDIX E

DEVICE ASSIGNMENT NOTIFICATIONS

Computer Treatment Group

Subject: Your link to my study

1. Please use your COMPUTER. (No tablets or smartphones.)
2. Set aside 30 minutes to participate in one sitting.
3. Please try to participate within 3 days. Thank you!

Link: https://sites.google.com/a/odu.edu/watch-win-cm/home

Need help with access? Email me at twils002@odu.edu

Thanks!

Tom

Smartphone Treatment Group

Subject: Your link to my online study

1. Please use your SMARTPHONE. (No tablets or computers.)
2. Set aside at least 30 minutes to participate in one sitting.
3. Please try to participate within 5 days. Thank you!

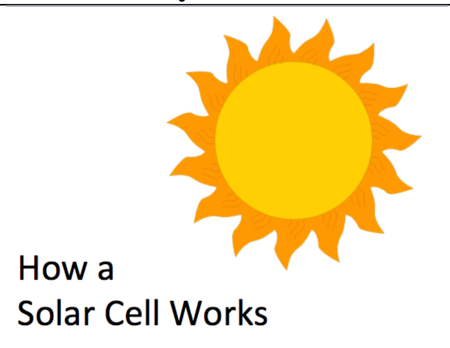
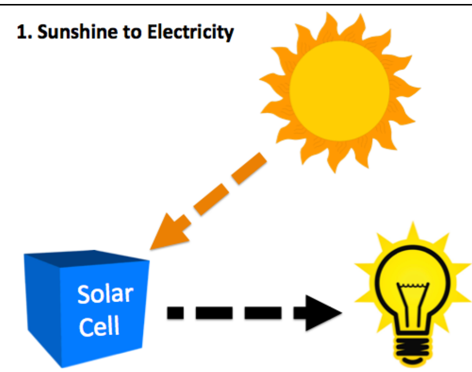
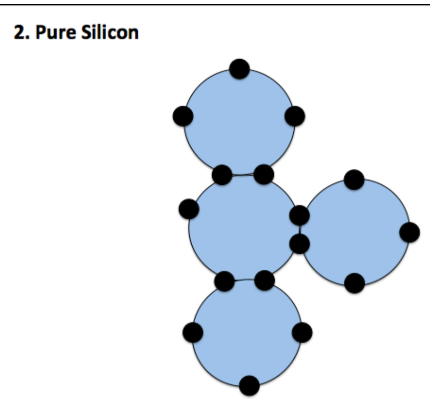
Here's your link: http://tinyurl.com/n8mv4k3

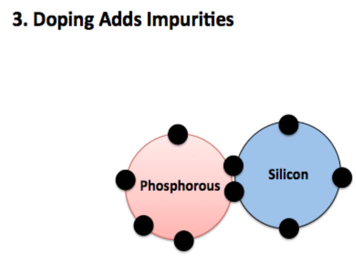
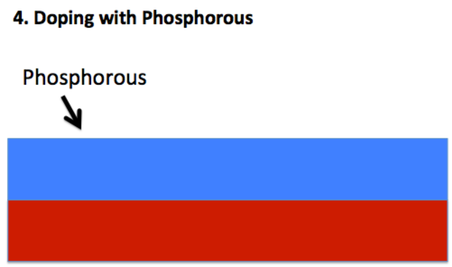
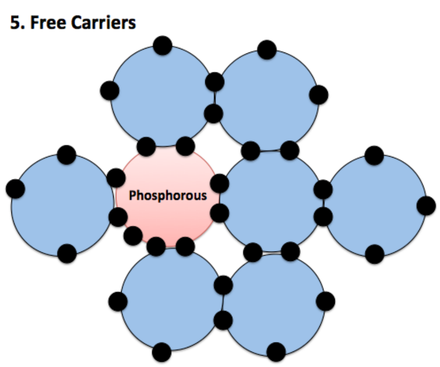
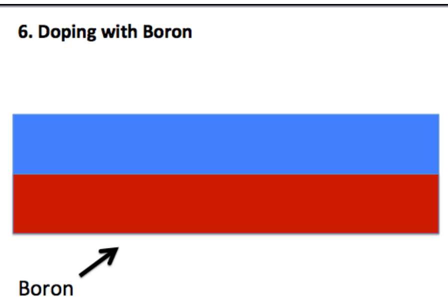
Need help with access? Email twils002@odu.edu

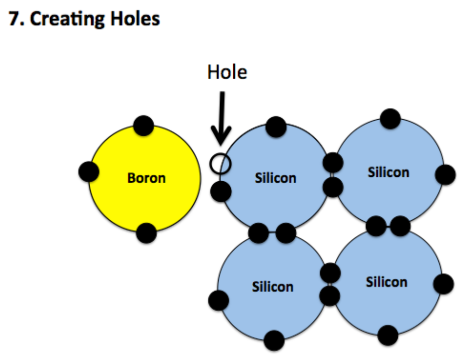
APPENDIX F

INSTRUCTIONAL MATERIAL (TRANSCRIPT)

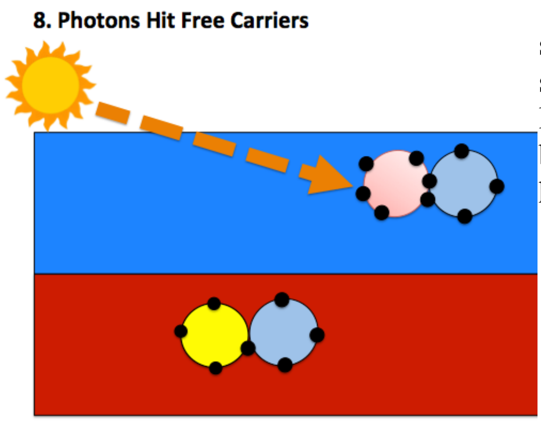
This script contains key frames of animation that occur within each segment.

Key Frames	Narration
	
	Solar cells convert sunshine to electricity that runs electrical devices. Solar cells are made up of "silicon" atoms, the same material found in sand.
	The outer shell of a silicon atom has four electrons and four bonding sites called holes. The holes will accept the electrons of neighboring atoms. Holes are not usually shown in diagrams of atoms. The four electrons in a silicon atom can bond perfectly onto the four holes of neighboring silicon atoms. However, to create an electric current, electrons need to move. Therefore, the pure silicon must be altered somehow to get electrons moving.

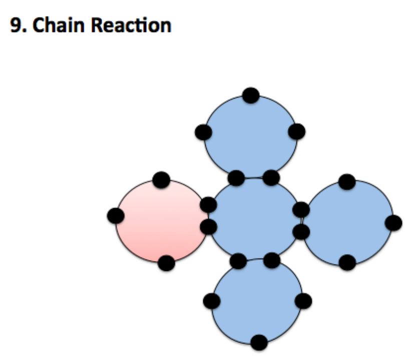
	The first step in creating a solar cell is a process known as doping. Doping is the mixing of a small amount of an impurity with the silicon.
	To dope the topside of the solar cell, phosphorus atoms are added to the silicon. A Phosphorus atom has five electrons on its outer shell, one more than a silicon atom has.
	On the doped topside of the solar cell, the extra Phosphorous electron seeks an available hole. The moving electron is called a free carrier because it can move freely about AND it carries a small electric current.
	To dope the bottom side of the cell, Boron atoms are added to the silicon. A Boron atom has only three electrons on its outer shell, one fewer electron than a silicon atom has.



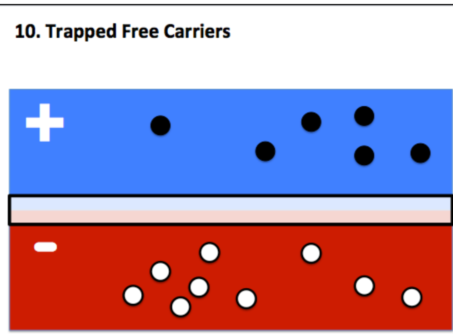
Adding boron atoms that have 3 electrons to silicon atoms that have 4 electrons creates a hole that is ready to accept a free carrier.



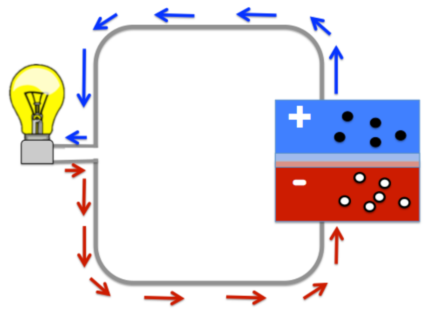
Sunlight is made up of photons. When sunlight, in the form of photons, hits the top side of the solar cell, a photon will knock loose an electron from its shell. The electron becomes a free carrier that travels to find a hole on the bottom side of the solar cell.



A chain reaction is initiated in which an incoming electron bumps one electron out of its shell and takes its place. The displaced electron bumps out an electron from a neighboring atom, and so forth.



Seeking holes, electrons travel from the topside of the cell to the bottom side. 'But the interaction quickly results in a barrier being formed between free carriers and the holes. This barrier causes the electric charge of the solar cell because excited free carriers are trapped on the positive topside, and extra holes are contained on the negative bottom side.

11. Electric Circuit 	To allow free carriers from the positive side to find holes on the negative side, an electric circuit is created. Metal wire connects the two sides to an electric device. The circuit allows free carriers to flow from the positive side of the panel to the device. As carriers pass through the device, they power it by releasing a charge. After discharging, electrons continue their journey to the negative side of the panel to find holes. The process continues as long as sunlight hits the topside of the solar cell.

APPENDIX G

POSTTEST

Instructions:

1. Use your ____ to answer these questions.
2. For each multiple-choice question, select the best answer.
3. For questions that require a written answer, please answer thoroughly with complete sentences. (No abbreviations or text language.)
4. There is no time limit.

AFTER completing the quiz, click here to exit

1. What are the three types of atoms used when doping a solar cell?
    a. Phosphorous, chromium, and boron
    b. *Silicon, phosphorous, and boron
    c. Boron, silicon, and photon
    d. Phosphorous, silicon, and chromium

2. Which statement is correct about electrons on the outer shell of atoms?
    a. *A phosphorous atom has 5 electrons, a silicon atom has 4 electrons, and a boron atom has 3 electrons.
    b. A phosphorous atom has 3 electrons, a boron atom has 4 electrons, and a silicon atom has 5 electrons.
    c. A phosphorous atom has 5 electrons, a silicon atom has 4 electrons, and a chromium atom has 3 electrons.
    d. A phosphorous atom has 3 electrons, a silicon atom has 4 electrons, and a boron atom has 5 electrons.

3. Answer this two-part question with complete sentences.
    a. What are the three types of atoms required in the doping of a solar cell?
    b. Of the three types, which atom has the most electrons on its outer shell, and which has the least?

4. Which six items must be present for an electric circuit to power a light bulb using a solar cell?
    a. *Sunshine, silicon, phosphorous, boron, a light bulb, and metal wire
    b. Sunshine, chromium, boron, aluminum, a light bulb, and metal wire
    c. Sunshine, silicon, aluminum, boron, a light bulb and metal wire
    d. Sunshine, photons, electrons, chromium, a light bulb and metal wire

5. Answer this two-part question with complete sentences.

    a. What are at least five things needed to power a light bulb with a solar cell?
    b. Which two of those items could you purchase at a hardware store?

6. When phosphorous is added to silicon on the topside of the solar cell, what is the result?

    a. *more electrons than holes
    b. more holes than electrons
    c. more electrons than free carriers
    d. more holes than free carriers

7. When boron is added to silicon on the bottom side of the solar cell, what is the result?

    a. more electrons than holes
    b. *more holes than electrons
    c. more electrons than free carriers
    d. more free carriers than holes

8. Answer this three-part question with complete sentences.

    a. Which side of a solar panel is doped with phosphorous, and which side is doped with boron?
    b. After doping, which side of the solar cell will have more free carriers than holes?
    c. After doping, which side will have more holes than free carriers?

9. Select the THREE statements that describe actions that occur when sunlight hits a solar cell.

    a. *Free carriers flow along a metal wire from the positive side to the negative side of the cell.
    b. *Photons knock electrons loose to become free carriers.
    c. *Free carriers release a charge as they pass through the electric device.
    d. Free carriers knock photons loose to create holes.

10. Discuss everything you've learned about solar cells.

Hints: sunshine, photons, electrons, holes, free carriers, barrier, electric circuit, metal wire, positive side, negative side, electric device

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(Survey Items)

(Smartphone Version of Device question)

What method(s) did you use to enter your answers on your smartphone? Check ALL that apply

a. Mini physical keyboard
b. Touchscreen keyboard
c. Voice dictation
d. Finger-swiping
e. Bluetooth external keyboard
f. Other (please describe)
g. I didn't use a smartphone

(All will receive the following questions)

1. For MULTIPLE-CHOICE questions, my _(device)_ made answering *easy*.

a. Strongly disagree
b. Disagree
c. Slightly disagree
d. Slightly agree
e. Agree
f. Strongly agree
g. I didn't use a ___

2. For MULTIPLE-CHOICE, my _(device)_ enabled me to answer *quickly*.

a. Strongly disagree
b. Disagree
c. Slightly disagree
d. Slightly agree
e. Agree
f. Strongly agree
g. I didn't use a ___

3. For MULTIPLE-CHOICE questions, my _(device)_ was satisfactory for answering questions.

a. Strongly disagree
b. Disagree
c. Slightly disagree
d. Slightly agree
e. Agree
f. Strongly agree
g. I didn't use a computer

S-4. When COMPLETE SENTENCES were required, my _(device)_ made answering *easy*.

a. Strongly disagree
b. Disagree
c. Slightly disagree
d. Slightly agree
e. Agree
f. Strongly agree
g. I didn't use a computer

S-5 When COMPLETE SENTENCES were required, my _(device)_ enabled me to answer *quickly*.

a. Strongly disagree
b. Disagree
c. Slightly disagree
d. Slightly agree
e. Agree
f. Strongly agree
g. I didn't use a ____.

S-6 When COMPLETE SENTENCES were required, my _(device)_ was satisfactory for answering questions.

a. Strongly disagree
b. Disagree
c. Slightly disagree
d. Slightly agree
e. Agree
f. Strongly agree
g. I didn't use a _____.

If you were to participate in this study again, which device would you prefer to use?

a. Smartphone
b. Computer
c. Either one; it wouldn't matter

What are your thoughts about using a _(assigned device)_ instead of a _(device)__ to participate in this study? (optional)

APPENDIX H

RATER'S GUIDE FOR OPEN-RESPONSE ANSWERS

Accuracy Instructions

1. The goal is to identify if the answer has at least one correct component. (Don't worry about incomplete sentences, grammar, or spelling errors at this point.)
2. You will access an online Scoring Spreadsheet that contains the answers that were submitted by participants.
3. Consult your Accuracy Answer Key (below) to grade each answer for accuracy using this scale:
    - 100% correct: 12 points
    - Partially correct: 6 points
    - 0% correct: 0 points
4. Enter the accuracy score in the appropriate cell of the Scoring Spreadsheet.

- **Practice:**

1. Read the sample question and its answer components (below)
2. Read the sample answer.
3. Place an X to indicate the rating you would give to Sample Answer A below?
   ___ 100% correct: 12 points
   ___ Partially correct: 6 points
   ___ 0% correct: 0 points

Sample Question: What are the three types of atoms used when doping a solar cell? Of the three types, which atom has the most electrons on its outer shell, and which has the least?

Answer Components:

- Phosphorous (5 electrons)
- Silicon (4 electrons)
- Boron (3 electrons)

Sample Answer A*:*

The three types of atoms used to create an electric current are phosphorous, silicon, and boron. Phosphorous has the most electrons and boron has the least.

Comment on Sample A Answer: The answer contains every main point of the question (they are highlighted in bold below). Therefore, this answer would receive full credit, 10 points.

The three types of atoms used to create an electric current are ***phosphorous****,* ***silicon****, and* ***boron****.* ***Phosphorous*** *has the* ***most*** *electrons and* ***boron*** *has the* ***least****.*

Here is another sample answer to the same question. Rate it:

Sample Answer B:

Silicone, photon, electron

Place an X at the rating would you give the sample answer above?

___ 100% correct: 10 points
___ Partially correct: 5 points
___ 0% correct: 0 points

Comments about the Sample Answer B:

1. The answer has at least one correct item, "Silicon"; therefore, it should receive a rating of "partially correct – 5 points" As long as an answer has at least one correct element, it is "partially correct."
2. Notice that in the answer, silicon is misspelled with an "e" at the end. The answer is not a complete sentence, and there is no ending punctuation. Issues like that are not a concern when evaluating *accuracy*. As long as you can logically conclude that at least some of the required information is present, give partial credit. Typos and other issues will be addressed in the *writing mechanics* evaluation.

Accuracy Answer Key for Open-response Questions

Question 3: What are the three types of atoms used when doping a solar cell? Of the three types, which atom has the most electrons on its outer shell, and which has the least?

Sample Correct answer: The three types of atoms used to dope a solar cell are **phosphorous**, **silicon**, and **boron**. **Phosphorous has the most** electrons and **boron has the fewest**.

Answer Components:

- Phosphorous (5 electrons)
- Silicon (4 electrons)
- Boron (3 electrons)

Question 5: What are at least five items you need to power a light bulb with a solar cell? Which two of the items could you purchase at a hardware store?

Possible Answers for the first part

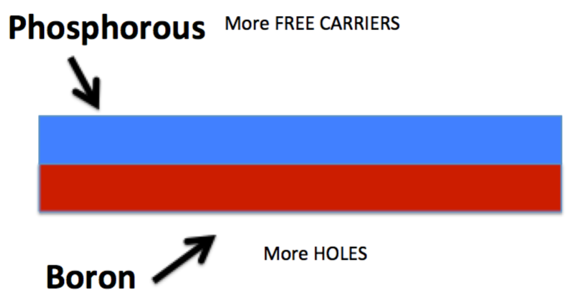
- Sunshine
- Photons
- Electrons
- Free Carriers
- Holes
- Silicon
- Phosphorous
- Boron
- Light bulb
- Metal wire

Answers for the second part: Things you could buy at the hardware store

- Light bulb
- Wire, metal wire, electrical wire

Question 8:

- Which side of a solar panel is doped with phosphorous, and which side is doped with boron?
- After doping, which side of the solar cell will have more free carriers than holes?
- After doping, which side will have more holes than free carriers?



Answers

- The topside of the panel is doped with phosphorous. (Topside can also be called the positive side.)
- The bottom side of the panel is doped with boron. (Bottom side can also be called the negative side.)
- The topside will have more free carriers than holes.
- The bottom side will have more holes than free carriers.

10. Summarize what you've learned about how a solar cell works.

Here are some key words to assist you: sunshine, photons, electrons, holes, free carriers, barrier, electric circuit, metal wire, positive side, negative side, electric device

Answer Key:
4 or more correct main points = 10 points
1-3 correct main points = 5 points
0 correct = 0 points

Main points and probable Answers:

- Sunlight in the form of photons hits the topside (positive side) of the solar cell.
- Photons knock electrons loose and make them free carriers.
- Electrons become free carriers.
- Free carriers knock other electrons loose in a chain reaction.
- A barrier forms between the positive side (topside) and the negative side (bottom side).
- Free carriers flow over a wire from the positive side (topside) to the negative side (bottom side) of the solar cell.
- Free carriers travel to a device (like a light bulb) and release a charge as they pass through it.
- Free carriers pass through the device and travel to the bottom side (negative side) of the cell looking for holes.

Word-Count Instructions

1. Paste the answer into Word.
2. Look at word count and give the answer a score based on the scale below. Do not consider grammar, spelling, or other issues when evaluating word count.

Word-Count Rating Scale

Word Count	Score
150+	10
135-149	9
120-134	8
105-119	7
90-104	6
75-89	5
60-74	4
45-59	3
30-44	2
15-29	1
0-14	0

Writing Mechanics

Overview:

1. In the online Scoring Spreadsheet, you will see answers that were submitted for each questions.
2. Some misspelled words are already highlighted due to spellcheck.
3. You will count the total of minor errors and major errors using the list below.
   - **Minor errors**
     a. No ending punctuation
     b. No internal punctuation (e.g., commas)
     c. No capitalization
     d. Misspelled words other than text language (Only count a misspelled word once per answer, not every time it appears in the answer.)
     e. Basic grammar
   - **Major errors**
   - Text language and abbreviations (e.g., "u" for "you").
   - Incomplete sentences, sentence fragments (missing verbs, articles, etc.)

4. Use the guide below to rate answers.

Writing Mechanics Rating Scale

Rating	Number and type of Errors	Deduction
Good	0-1 minor errors	0
Marginal	2-3 minor errors	-2.5
Poor	4+ minor errors or 1 major error	-5

5. In the Scoring Spreadsheet, select the correct *Mechanics* score from the dropdown menu.

Practice:

1. Review this sample answer below and rate it using the Writing Mechanics Rating Scale (above):

   Sample Answer B to Question 3:

   Silicone, photon, electron

   Sample Answer B rating: Point deductions for:
   - Incomplete sentence (-4 points)
   - There are also two minor errors (misspelled silicon and no punctuation), but they are not counted because the 4-point is the maximum.

2. Review this sample answer and rate it.

   U use phosphorous for the top & boron for the bottom. The top has more free carriers than the bottom.

How did you rate it? The text-messaging slang "U" and the use of "&" are both major errors. The rest of the sentence has no issues regarding writing mechanics. The two major errors make this answer *poor*. Therefore, it is a 4-point deduction.

APPENDIX I

POSTTEST RELIABILITY SCORECARD

For each posttest question, answer the appropriate list of questions.

Multiple-choice Question

1. Could this question have more than one meaning? Y/N
2. Is this question easy to understand? Y/N
3. Do previous questions give clues to the correctness of this question? Y/N
4. Are the distractors plausible and attractive to the uninformed? Y/N
5. Are there typos? Y/N
6. How difficult is this question? Easy, Moderate, Difficult?
7. Does this question have a cultural bias? Y/N

Comments/suggestions:

Open-response Questions

1. Could this question have more than one meaning?
2. Is this question easy to understand?
3. Are there typos?
4. Does this question have a cultural bias?
5. How difficult is this question? Easy, Moderate, Difficult

Comments/suggestions:

APPENDIX J

PARTICIPANT COMMENTS

Computer Treatment Group

A computer allowed me to see everything on the screen with plenty of white space surrounding. I was not concerned that I might be missing some information or a button.
As a daily user of a PC I accept that this is my default mode. During the quiz I used my mouse for the multiple choice questions and the keyboard for the sentences. I choose to believe that the multiple choice answers would be easy to replicate in a mobile app format and that frequent users of phones may have no issue with constructing complete sentences with their phone or tablet electronic keyboards. Also, I choose to believe my preference is not due to my age or technical competence, but rather my proficiency with a PC vice a mobile device.
Being an older person. Even though I use my smartphone everday in business. I am more use to typing with my keyboard than my thumbs on a smartphone. I think those that use smartphones to send email and text a lot, would be just as effective using both. But, myself,I prefer the keyboard to type in data. I learned a lot that I did not know about solar cells. Than you for allowing me to be part of your study.
Computer keyboard is easy to use when providing written responses. If a smartphone is used then I would suggest using voice generated response.
For the multiple choice part, either would have been fine. For the short answer part, I definitely prefer my computer. I do not like to send long messages with my phone.
Having to write complete sentences is far easier on a computer keyboard then a phone, much faster too.
I am a capable touch-typist. Touch typing is virtually impossible on a virtual keyboard like those found on tables or smart phones. My computer keyboard is much more preferred for this function. The difference between using a mouse versus a touch-screen for selecting a radio button or checkbox is negligible; there is no advantage either way. Thus, overall I preferred my computer keyboard given the mixed nature of the study and quiz. If the study/quiz were ALL checkboxes and

buttons, then a tablet or smart phone might have been satisfactory.

Computer Treatment Group (continued)

I do not have a preference. If I were using a smartphone, I would likely have used voice to text to answer the complete sentence questions.
I enjoy a larger space to view learning videos. Typically, I only use my smartphone to view TV or other entertainment type videos. When there is a learning video with or without a quiz, I like to watch those on my computer.
I found it much faster and easier to use a keyboard and mouse to answer questions for this quiz. I would not likely feel the same way about a smart phone in terms of answers questions with complete sentences.
I greatly prefer using a computer.
I hate typing on smartphones. Even with swype or gesturing typing, I feel as though I spent 80% of my time correcting my sentences on a smartphone. If I have to write a serious email or engage in anything that will require the generation of substantial amounts of text, I seek a computer and a keyboard. I'd really enjoy it if I was *warned* about having to type a long from a smartphone too, but that's not always the case. I wind up frustrated by getting tricked into lots of typing on my phone. I pine for the days when phone had physical keyboards too. Touchscreen keyboards are the devil. You can quote me on that. I have a Bluetooth keyboard attached to my work iPad, if that tells you anything. I'm intrigued by voice UI on more recent devices, and I've shifted to using that instead of typing (think Siri or Google Assistant). There are some social limitations to engaging with your phone / tablet in this manner though (e.g.,, talking to your phone in a library, or just before church, etc.).
I like being able to type on a full keyboard when required to type out answers. Multiple choice would be easier on a tablet/smartphone as I can just touch and go. no technical difficulties experienced other than I don't think I did very well on the quiz!
I think it would be much easier to participate using a computer than a smartphone.

Computer Treatment Group (continued)

I think they both can be used effectively, I don't think the learning effectiveness would matter. I think results could be influenced by the extraneous cognitive load of having to find the next button, click on it, then find the play button, then click on that between each video... I'd suggest a future study where all the video is together as a single element. I like the animation, very clean and without extraneous cognitive load. Is a laptop a "workstation" as defined by this study? and what is the laptop has a touchscreen, is it then a tablet? (I used an iMac with a keyboard and mouse)... include 'tablets' or anything with a touchscreen in the future? my mouse was more helpful than my keyboard... but i didn't see a question about that, maybe also for future research? in the future you could also make the content longer, those results would be interesting... If I scored a 69.9 on the quiz, do I still get entered in the drawing?!? FYI, I took notes during the videos... good luck!
I typically prefer to write on a computer using a keyboard, which, at this point, makes participating in a study like this easier than with a smartphone. However, that has begun to change as I get used to the swipe capabilities of my smartphone. That has enabled me write words and sentences much faster than when I would have to punch in each letter with my thick finger. I'm also increasingly using the voice and speech to text features of my smartphone. Conceivable that could make participating in studies like this quite easy.
I would have had a very difficult time completing the quiz. I attempted to take notes on a Word document while viewing the video because I am a kinesthetic/visual learner. I wouldn't have been able to do that if I viewed the video on my smartphone.
I wouldn't really want to type the answers on a smartphone unless I had to, because a real keyboard is always better than a phone's virtual keyboard. For very short text the phone is OK. For answering the multiple choice questions, either a computer or a phone would be equally fine.
I'm not "young" enough to feel absolutely comfortable using my smartphone. Also - this felt a bit like work and I always think of my computer as a work device ... my smart phone is a bit less of a "work" device.

Computer Treatment Group (continued)

I'm not sure because I didn't use a smartphone, so I can't compare. I used a computer, per the emailed instructions. I imagine it would be more difficult to type out complete sentences on the phone because that would be annoying to do. But it is easier on an android compared to an iOS device because of the swype keyboard.
If I had to do this again, I would prefer to take it on a computer again. A smartphone keyboard would be too cumbersome to type on. Even if my phone had auto-complete or swiping actions to speed up typing, I think I'd still be more focused on typing my answers than the actual content of the answer. Since I'm used to typing on a computer keyboard, I was able to focus more fully on the content of the answers rather than on the act of typing them out.
If the study requires typing, I would much prefer to use a computer. Typing on a smart phone is extremely difficult in my opinion. It takes a long time to delete things because it is rather difficult to highlight and delete sentences on a smart phone vs. a computer. Computers are easier to control while typing and makes things more efficient because I can also type faster on a computer than on a smartphone.
It was difficult for me to pay attention to the content of the video due to disinterest in the subject. It would probably be even more difficult if I had used a smartphone.
It was easier to type the answers out and less distractions than a phone would have due to notifications that I would receive on a phone typically during 30 minutes.
It was easy, but I messed up during the quiz and hit my browsers back button versus the back arrow within the quiz and had to start over at about questions 8. It was user error on my part, but something that is a frustration to start over.
It was much easier using a computer. I'm old (57), so entering information using a SMARTphone is tedious and error-plagued, even when using predictive spelling on Android.

Computer Treatment Group (continued)

It would have been much more difficult and taken much longer for me to complete this study on my smartphone due to an inability to type with a standard keyboard and be able to see what I had already written to make any necessary changes.
It's a lot easier to type in answers and select more than one choice.
It's was easier to type sentences on my keyboard than my smartphone. Technical difficulties: I had to press Next at least twice to advance to the next question.
Seeing what you are typing is easier on a computer than on the smaller screen of a phone. With a full view of what you are writing, it is easier to see whether the logic of a paragraph holds together and easier to detect an error in the text. The mouse on a computer provides an advantage when composing and manipulating text.
The next button stuck several times while taking. A smartphone would be ok for multiple choice but for writing answers probably not a good option. Also you could have the interruptions of text messages.
There were issues with trying to press the button (it would jump around on the screen when first clicked - the third click woud be successful in advancing to the next question)

Smartphone Treatment Group

Some what risky on cell phone. I hit the screen back button once instead of the quiz back button. Thought I had lost the whole thing. The forward button took me back to where I was. Scary
Multiple choice questions were fine, but I craved a keyboard and large screen for complete sentences. I became increadibly tired and stressed when I saw complete answer questions.

Smartphone Treatment Group (continued)

I use my smart phone to see or read information only. I seldom use it to input answers as required in this study. I prefer to use my computer or iPad with a keyboard attached. I find entering on the small screen of the phone to be difficult and cumbersome.
I think it was difficult to type in complete sentences on a smartphone because it's difficult to see the entire question while answering. As far as multiple choice, my smartphone worked well.
I think it's great for multiple choice and true/false but not for written answers.
It is easier to press something by mistake on a smart phone. I have first hand experience with this and this quiz.
For the most part it was easy. The short answer sections were harder on the smartphone. But overall it really was fine.
The quiz worked well on my smartphone. It was a little unintuitive to watch the videos on a website, rather than in an application like YouTube.
The content would have been more effective with formative knowledge checks as it seemed to impart cognitive overload.
As soon as I saw the free entry questions I knew this was going to take longer than anticipated. Typing my answers on the smartphone keyboard was rather frustrating. The autocorrect feature kept changing my words and I'd have to erase and rewrite, sometimes several times, before getting the sentence finished. I also kept accidentally capitalizing things. I would much rather use a computer than a smartphone for quizzes. In regards to the video watching, I didn't have any trouble getting the videos to load or play. I'd be fine with using my phone to watch videos again. One technical glitch I noticed was that on some questions the yellow Next button overlaid the last answer choice, making it difficult to read.

Smartphone Treatment Group (continued)

The smartphone was convenient, but I found myself wanting to type on a physical keyboard when writing in complete sentences. It was difficult to think through the new information while writing on my phone, and it took longer to type than typing on a physical keyboard. I would rather take an assessment that requires writing on a computer every time.
My initial thought and feelings regarding using a smatphone were positive. I could see how an LMS could be made much more mobile friendly, at least with quizzes, using this format. The videos were quick and to the point, helping me feel okay about watching 11 videos and attempting to remember the information. I have an IPhone 6s plus, so my screen is pretty big. But even then, I still got the feeling that I was pushing my comfort level when answering questions with full sentences. I can only imagine how someone with a smaller screen would feel. I think it has to do with being able to see everything I write while writing. The phone's keyboard takes a lot of screen realestate. This is the only reason why I would rather do it on a computer the next time. Overall, no technical difficulties or problems going through the videos. I would have loved to see a spell check feature in the written response sections. I am not the best writer, and not having some kind of check unsettled me. And because the section scrolls, I had to manually scroll up and reread everything hoping to find mistakes (which I found many in this response alone!).
My stress level has skyrocketed as a result of using my smart phone for this exercise.
I realized halfway through that I hadn't used complete sentences to answer questions, but made a decision NOT to go back because it was challenging to "thumb type" such long sentences! I am unable to do voice dictation at the moment because I currently share office space, and my office mate has a student in with her. So...incomplete sentences it is! That all said- best of luck, Tom! This is a very interesting and well-put together study.
I had to move the cell phone sideways to view the video. Because there were so many videos to watch, it was annoying. Would rather have fewer longer videos to watch.
No issues. I would have preferred though to have one continuous video which I could pause rather than having to click several times to access different clips.

Smartphone Treatment Group (continued)

Touch screen typing is difficult Would rather use computer or regular size keyboard
It was good overall but the videos at the beginning when not optimize to go full screen when playing the videos and the buttons on the bottom of the videos when not optimized for mobile phone. They were two small. Thank you for putting it together. Very interesting subject. I enjoyed it greatly.
The only technical difficulty I had was opening the link sent in the text message. I had to try several times. Otherwise, very easy to do. I like the way it all flowed. I would called micro eLearning if I were to give it some sort of name. However the subject matter pretty complex for me to synthesize quickly.
It was more difficult to use the phone. Autocorrect created both a help and miscorrections.
No technical difficulties. I enjoy my smart phone because I can use voice dictation. With technical terms, like phosphorus, Lauren, and silicone, I often found myself having to retype because the device is not familiar with the words. (I won't retype here so you can see what is spelled when I say the words - Lauren for boron and silicone for silicon.)
I had to restart the test several times. I do not know what I may have touched on the screen but it brought me back to the page to select the quiz. I had to walk away for a day! Some of the segments were slow to complete and I never knew if they were finished so I just clicked on the next segment. In one of the segments, I had to click the play button twice to view the complete segment. I would to be able to save my work so I would not have had to start over if need be. I think a start over button for viewing the segments would be helpful instead of hitting the back button for each of the 11 segments. Very good tutorial. I liked learning about solar cells.
If I was to complete this study again, I would prefer to answer on my laptop. I found that answering and viewing the questions on my phone took more effort than if I could see the full screen and type on a normal keyboard.

Smartphone Treatment Group (continued)

I found it very frustrating to use a smartphone for this exercise. First, the videos were slow to load and the sound was glitchy, cutting in and out. Second, the segments were very short, but the loading time was longer than the segments, so there were long pauses between the Snippets of information. Then when it was time to answer multiple-choice questions the next button and back arrow covered up part of the screen so I could not read all of the answer choices completely. Finally with the full sentence answers the small screen made it impossible to see my entire answer at once so I had to keep scrolling up and down. Even though the use of a tablet was not an option for this study, that would definitely be my first choice for a learning experience like this.
When watching video I had to zoom in and out to select and view next button. I prefer to type with a keyboard than on smart screen. Fat finger syndrome
I prefer using a computer to watch instructional videos and answer survey questions. I have an easier time answering questions when I can type on a keyboard. I'm not sure why but I also think it's easier for me to take notes if I'm watching a video on my computer rather than my smartphone. Since the subject matter of the video with something relatively new for me, I felt there was a learning curve trying to grasp the new information.
I disliked the experience of using a smartphone for the following reasons: 1. It was difficult to regurgitate facts, since I was not able to write notes efficiently. 2. The questions requiring complete sentences was difficult to type on a smarrtphone, since the keyboard took up half the screen, and blocked viewability of what I was typing, and the question. 3. I received a phone call, which caused me to hit back after the call, whichcaused an error. I had to restart the quiz. 4. I had to restart the quiz twice, due to incorrectly using the browser's back button. This was frustrating.
Watching videos on a phone was fine. Typing complete sentences was a pain. I don't typically text on my phone much, so maybe that's part of the reason it was difficult. A computer would be easier for open-response questions.
I would prefer the computer, because I prefer the experience of having a larger screen and not having to use a touch screen keyboard.
The next time you see me RUN!

Smartphone Treatment Group (continued)

I find it very difficult to use a smartphone for reading and answering questions involve ongoing typing. I was much slower than I am on a computer.
A short quiz would be okay using a smart phone, but with many text based answers a computer would be easier and faster.
Computer would have been better.
If I had remembered how well my phone recognizes my voice, I would have used it for the complete sentences questions

APPENDIX K

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(Uncropped version of photo used in Figure 1B)

Title: Symbian-based smartphone from Nokia with slide-out QWERTY keyboard
Author: Michael Kwan https://www.flickr.com/photos/beyondtherhetoric/
Source: flikr https://www.flickr.com/photos/beyondtherhetoric/5493198319/
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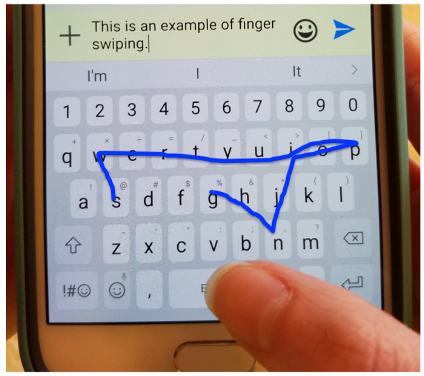

Copyright 2017 by Thomas Royce Wilson (from Figure 2)

(from Figure 3)

Title: Bluetooth keyboard for iPhone
Author: Miki Yoshihito: https://www.flickr.com/photos/mujitra/
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VITA

Thomas Royce Wilson

STEM Education and Professional Studies Department
Darden College of Education
Old Dominion University

PROFESSIONAL EXPERIENCE

Director of Online Learning, 6/2013 – Present
Azusa Pacific University, Azusa, CA

Online Instructional Designer, 6/2011 – 6/2013
Azusa Pacific University, Azusa, CA

Associate Dean, Online Learning, 2/2010 – 6/2011
Everest University Online, Santa Ana, CA (Corinthian Colleges, Inc.)

English Teacher/Department Chair, 2000 - 2010
Joshua Springs Christian School, Yucca Valley, CA

Marketing Director, 1997-2000
Marine Corps Air-Ground Combat Center, Twentynine Palms, CA

Instructional Media Producer/Consultant, 1991-1997
Royce Media, Honolulu, HI

Trainer (part-time), 1991-1997
Olelo: The Corporation for Community Television, Honolulu, HI

Television Writer/Producer, 1985-1991
Brekke Television Productions, Honolulu, HI

EDUCATION

PhD Candidate, Instructional Design and Technology; Old Dominion University; Norfolk, VA (Dissertation defense May 2017)

MS Instructional Design and Technology; 2009; California State University, Fullerton; Fullerton, CA

BS Mass Communications; 1982; University of Southern Colorado; Pueblo, CO