Learning on the open road: examining the effect of non-sequential user choice on learning from OERs

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LEARNING ON THE OPEN ROAD: EXAMINING THE EFFECT OF NON-SEQUENTIAL USER CHOICE ON LEARNING FROM OERS

by

Ethan Philip Valentine

A thesis submitted in partial fulfillment of the requirements for the Doctor of Philosophy degree in Psychological and Quantitative Foundations in the Graduate College of The University of Iowa

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Thesis Supervisor: Assistant Professor Benjamin DeVane
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ABSTRACT

In recent decades, open, online learning environments have become progressively more popular and well-funded. An integral aspect of this open learning movement is the transition of a substantial amount of control of the learning process from designers and instructors to the users engaging with the environment. With heavy investments coming from both the public and private sectors, and an ever-growing market of online learners, it is crucial that we better understand how the provision of user control over the learning process affects the quality of that learning process.

The purpose of this study was to investigate the effects of one aspect of open learning environments that has yet to be fully understood: user choice of learning sequence, or non-sequential user choice. Building on previous research with open educational resources (OERs) designed to help drivers learn about adaptive cruise control (ACC), an advanced car safety system, this research compared the learning process of subjects with (N = 42) and without (N = 42) control of the learning sequence. Specifically, this study sought to investigate two core issues: 1) the effect(s), positive or negative, that non-sequential user choice has on the development of mental models of ACC, as measured by a post-test assessment; and 2) the relationship among post-test performance, chosen order of resources, and time spent engaging with individual learning resources.

To examine these issues, two primary analyses were completed. To address the effect of non-sequential user choice, subjects’ performance on scenario problems and a declarative knowledge post-test was compared using independent sample t-tests (α = .05). A multiple regression analysis was conducted to investigate the relationship among post-test performance, chosen order of resources, and time spent on each of three learning resources (α = .05). Subjects
in the experimental (choice) condition scored significantly worse on the post-test assessment than subjects in the control (non-choice) condition ($t[82] = -2.116, p < .05, d = -0.462$). The regression analysis found a significant regression equation ($F(4,37) = 3.930, p < .05$) with an $R^2$ of 0.298 (Adjusted $R^2 = 0.222$). Surprisingly, however, only one of the resource time predictor variables was an individually significant predictor of post-test performance.

Possible explanations for these findings are explored based on the available research literature. These explanations include the possibility of choice overload, poor decision-making by subjects, confusion due to a lack of instructional guidance, and the development of choice apathy. However, further research is necessary to determine why non-sequential user choice had a negative effect, as well as to expand research on non-sequential user choice to other contexts and content areas.
PUBLIC ABSTRACT

We are living in an era of social media, search engines, and free, online encyclopedias. The way we learn is no exception to this trend, with freely-accessible, online learning seeing rapid growth in the last few years. Online, open learning materials are becoming more and more common, from badge systems providing specialized certifications to open educational resources (OERs) that give learners access to information wherever and whenever they wish.

Built into this larger open education movement is a focus on providing learners with more control over their own learning process and allowing them to discover important ideas for themselves. Using a set of OERs created to help drivers learn about new car safety systems, this study focuses on just one aspect of the control that open learning provides: choice of learning sequence. Very little research has examined the effects of giving learners the opportunity to choose the order in which they use a set of learning resources, despite the fact that this choice is almost always present in everyday life.

In this study, one group of subjects was able to choose the order in which they used three OERs, while another followed a pre-planned sequence. Surprisingly, considering the focus on learner control in modern education, subjects who could choose learning sequence performed significantly worse on a test of learning than those who followed the pre-made sequence. Possible explanations are explored, but further research is needed to determine why choice of sequence had a negative effect.
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CHAPTER 1: INTRODUCTION

Over the last few decades, open, online learning has grown significantly, with one major goal being to improve our educational system and reduce costs. From open educational resources (OERs) that anyone can access on their own time to social games in which players group together to achieve common goals, online and open learning technologies have produced large-scale changes in our education system. Both public and private organizations are pushing to make strides in the era of digital learning and open education. This is reflected in both wide public policy initiatives and individual private grants. The U.S. federal government, for example, has spent billions of dollars to develop open learning materials (The William and Flora Hewlett Foundation, 2015). Such large-scale investment in open education also reflects a general trend of increased use of openly-sourced media and technologies. In a single decade from 2006 to 2015, the number of Creative Commons-licensed works ballooned from 50 million works to over one billion works (The William and Flora Hewlett Foundation, 2015). This dissertation seeks to examine just one aspect of open learning environments which has not yet been adequately addressed in the research literature: user choice of learning sequence. In this chapter, I briefly discuss the state of the open learning movement and the relevance of that movement to the present research.

Public and Private Investment in Open Learning

In the United States, both individual states and the federal government have implemented initiatives in recent years to develop new open learning technologies and to expand competency-based education (CBE) approaches in the educational system. CBE is an approach to education that involves teaching and assessing students based on specific skills, or competencies, with each individual skill being a student’s primary focus until they are proficient (Pearson Education,
This approach allows students to self-pace their learning based on the specific skills they are developing. In 2012, for example, the State of Iowa created the Iowa CBE Collaborative, a multi-district initiative designed to spark a statewide shift towards a CBE system. The Collaborative has developed a set of principles for districts to follow, distributed resources for districts and teachers, and awarded grants for CBE projects (Iowa Department of Education, 2013). Additional efforts are underway in New Hampshire, Michigan, Colorado, Ohio, and elsewhere (Office of Educational Technology, 2017).

On a national scale, the Department of Education’s National Education Technology Plan emphasizes the value of assessing competency in our nation’s schools. As part of that goal, the plan encourages the use of OERs, massive open online courses (MOOCs), and other digital technologies as a path to developing important competencies. This includes peer-to-peer interaction, both in face-to-face settings and via online collaboration, as well as the creation and distribution of educational tools (Office of Educational Technology, 2017). This plan’s recommendations reflect a national shift towards the use of digital technologies, including online learning resources, to further our education system.

This shift in our education system is not based purely in the public sector, however. Private organizations, including charitable foundations and for-profit corporations are deeply invested in new educational technologies and the promise of open, online, competency-based education. Pearson Education, for example, provides a handbook for developing CBE programs, as well as other resources for the process (Pearson Education, 2016). The Gates Foundation, a perennial source of education grants and funding, has contributed millions of dollars in grants to such projects as the Learning Games Network (http://learninggamesnetwork.org/), a network of teachers and designers creating digital games for learning, and the University of the People
Amongst these reform campaigns, one significant movement calls for the development and distribution of open educational resources (OERs). OERs are “teaching, learning, and research resources” that are freely available to the public and may include “full courses, course materials, modules, textbooks, streaming videos, tests, software, and any other tools, materials, or techniques used to support access to knowledge” (Atkins, Brown, & Hammond, 2007, pg. 4). In fact, it has been argued that they are “becoming a primary agent of change” in our education system, toward a more open, learner-centric model of teaching and learning (Lane & McAndrew, 2010, pg. 952). Atkins, Brown, and Hammond (2007) echoed this sentiment, noting that “At the heart of the movement toward Open Educational Resources is the simple and powerful idea that the world’s knowledge is a public good,” continuing to argue that “OER are the parts of that knowledge that comprise the fundamental components of education—content and tools for teaching, learning, and research” (pg. 5). OERs provide designers of learning environments a way to reach a large audience with a single piece of design, while also providing users a large amount of flexibility in terms of timing, location, and goal of use. When OERs are published online, users mostly have the freedom to engage with them in the time, manner, and order that they wish. In terms of when they can be accessed, online OERs are persistent and available regardless of the presence of a teacher or designer. Similarly, the learner is able to access learning material from anywhere in the world that has a stable internet connection. Just as when
using a search engine (or, in fact, much of the internet on the whole), users can also access these materials in any order they wish, including ignoring those resources that do not appear helpful.

These aspects of user control in OERs are often associated with a user’s ability to select a mode of, or approach to, learning in a domain and at a time of their choosing. As learners are able to choose individual resources, so too are they able to tailor their own learning to the type of tools that they prefer, whether those tools are primarily visual, auditory, or otherwise. OERs often cater to just-in-time and customizable learning experiences, which is representative of the overall educational trend of increasing the amount of control that users have over their own learning process. This representativeness allows OERs to serve, in some ways, as a litmus test for the open learning movement on the whole. In other words, what works in OERs may well apply to other open learning tools.

Khan Academy: An OER Exemplar

Open educational resources (OERs) have a unique place in the larger open learning movement, as discussed in the previous section. However, the wide variability among OERs can make it difficult to define what actually qualifies as such as resource. This section, then, seeks to elaborate on that definition by providing a concrete example of a prominent OER: Khan Academy (https://khanacademy.org/)

Khan Academy is a freely accessible, online learning platform which learners from around the world can use to develop a better understanding of a wide array of topics. The site’s courses range from kindergarten-level math to high school physics, history, and economics. Resources available through Khan Academy include instructional videos, practice problems, and a community of learners that asks and answers questions about these varied topics around the clock, often completely for free. Learners can track progress through the site’s courses by
creating an account, which provides access to suggestions for new learning and feedback on the work completed so far.

All of the learning resources provided through Khan Academy can be accessed with or without an account on the site, however, and a learner can find highly varied topics within just a few seconds. For example, from the home page (https://khanacademy.org/), I was able to access an instructional video comparing the role of women in early Roman and Chinese societies in just three mouse clicks. Another three clicks brought me to a section on hedge funds and whether they are good or bad. In each of these courses, and in fact all of the courses on Khan Academy, learners can skip over any sections that they are uninterested in, whether they have engaged with that content or not. The comparison of the roles of women in early societies, for instance, was the 16th topic in the second section of the World History course, but accessing it was just as simple as if I had started at the beginning of the course.

With all of this in mind, it is easy to see how Khan Academy is an exemplar, of sorts, of OER design paradigms. It provides an array of learning materials that can be accessed at any time, from any location, and by any learner. The resources Khan Academy offers do not restrict learners to a particular content area or level regardless of those learners’ previous experiences. Learners may engage with – or skip – any content that does not interest them, and they have complete control over the sequence and timing of their learning. Khan academy exemplifies the type of choice of learning experience that the open learning movement has advocated for, and that this research seeks to address.

**User Choice and Mental Models in Open Learning: A Gap in the Research**

The question at hand, then, is why the shift toward open learning really matters in the context of the present research. Open learning advocates present a simple but ambitious
premise: that anyone should be able to learn whatever they want to learn, whenever and wherever they want to learn it. In other words, each learner should have as much control over their own learning as possible. This goal of extensive learner choice has become ingrained in how we think about education, ranging from free online tools to traditional classrooms. Unfortunately, like most incipient big ideas at the outset, detailed and grounded understandings are missing. Despite support from businesses, foundations, governments, and individuals, the effects of this extensive learner control are not clear. For all of its supposed benefits, there is not a robust body of empirical support for providing learners with as much control over their learning as possible.

This research, then, sought to address one aspect of that problem, by assessing the effect of user choice of sequence on the development of mental models from the OER learning experience. As defined by Norman (1983), mental models are applicable, practical mental frameworks that can be applied to physical systems in the real world. Such an operationalization of mental models is distinct from conceptual models which contain primarily declarative knowledge of a system or topic. In the case of physical systems like adaptive cruise control (ACC), the car safety system examined in this study, mental model formation is often related to the issue of trust in the system. In past research, for example, the extent to which users trusted ACC in various scenarios was used as an indicator for the accuracy of those users’ mental models (Beggiato & Krems, 2013). In other words, if a user trusts the system in the situations in which it will perform well, but not in the situations in which it will struggle, that user appears to have an accurate mental model. However, very little research has examined the effects of providing choice of learning sequence on the development of mental models of physical systems
like ACC, and even less research has considered OERs as a genre of learning experiences in this regard.

In addressing that gap in the research, this study found a significant, negative effect of non-sequential user choice on subjects’ learning of declarative knowledge about adaptive cruise control (ACC) when learning from OERs. In addition, time spent on one of the three learning resources was a significant predictor of post-test performance, but chosen sequential order and time spent on other resources were not significant predictors. As discussed further in subsequent chapters, these results were surprising to the author, but they have important implications for future research and the design of guided instruction in open, online learning environments.

**Research Objectives**

Capitalizing on the flexibility of OERs, this study examined the effect(s), positive or negative, that a user’s choice over learning sequence has on learning. Using existing OERs developed for a public information campaign aimed at teaching drivers about new car safety systems, this study sought to compare learning gains by individuals who followed a linear, prescribed path with those who chose the sequence in which they used available resources. The materials used for the present research were designed for drivers seeking to learn about adaptive cruise control (ACC), an enhancement of conventional cruise control systems. The materials include three resources: 1) Understand, a text- and image-based description of ACC systems and how to use them; 2) Challenge, a set of text- and image-based scenario problems emphasizing the limitations of ACC systems; and 3) Play (plAyCC), a low-fidelity ACC simulation and accompanying scenario problems. The Understand, Challenge, and Play resources are included in Appendices I, II, and III, respectively. These OERs were developed as part of a larger public
information campaign, My Car Does What (http://mycardoeswhat.org), which is focused on educating drivers about advanced car safety systems.

This research addressed two major questions:

1. What effect, if any, does user choice of sequence through OERs have on their development of mental models, as compared to a pre-determined path?
   a. What effect does this choice of path have on performance on scenario- and simulation-based problems distributed throughout the learning process?

2. What relationship, if any, is there among time spent on individual resources, order of viewed resources, and performance on an assessment of declarative and conceptual knowledge?

The first question, regarding the effect of user choice of sequence on learning, was assessed based on performance on a summative post-test, as well as formative assessments taken throughout the learning process. Most modern literature on user choice in learning environments points to choice being beneficial, and so with regard to the first question, I hypothesized that providing non-sequential user choice would positively impact learning, as reflected in the post-test and scenario scores for subjects able to make choices about learning sequence. The second question was examined using multiple linear regression techniques, as discussed in more detail in the Methodology chapter. This regression analysis used timing and ordering data collected via Qualtrics from subjects in the experimental condition, as well as learner performance on the summative post-test. In previous research (Valentine, Zhou, Moore, & DeVane, 2018), collaborative pairs who spent a larger time solving problems tended to perform better than those who spent a smaller amount of time. With those results and an expected positive effect of non-sequential user choice, I hypothesized that both chosen order of resources and time spent on
individual resources would be significant predictors of post-test performance. In the following literature review, I provide an examination of the research literature on learning about adaptive cruise control, mental models, OERs, and various perspectives on non-sequential user choice for educational games, badge systems, and other forms of instruction.
CHAPTER 2: BACKGROUND LITERATURE

Open learning environments in general, and open educational resources (OERs) in particular, have brought with them a renewed focus on providing the ability for users to control their own learning process. The choices provided to learners in these environments may take a number of different forms, and the amount of choice provided can vary greatly. As Brown (2001) describes it, user choice in learning environments can be generally conceptualized as how individuals purposefully engage with instruction and how much control the learner has over instruction. With the advent of computer-based learning, user choice is both easier to provide to learners and more easily studied, as it allows researchers to directly measure user data. Important aspects of user choice that can be built into online learning environments include control of pacing, sequencing, and specific learning resources used (Andreu & Jáuregui, 2005; Brown, 2001). The present research specifically examines the effects of non-sequential user choice, which is defined by Chou (2003) as the ability for users to engage with content in a non-linear way. In other words, this research examines the effects of providing learners the control over the sequence in which they engage with open, online learning materials. In 2001, Brown pointed out that there had been little research that explicitly examined specific user choice behaviors in online learning environments. Unfortunately, since then the same appears to have been true, with few works added to the research literature. Outside of the speculative conceptions of user choice of content or timing in the OER literature, there exists little empirical research that directly addresses the topic. In addition, there is little research on how user choice can impact active, online development of mental models of how systems function in real-world contexts. However, significant scholarship exists in the related area of designing learning environments to leverage learners’ sense of autonomy.
Keeping in mind the proponents’ argument that open learning environments can provide more choice to learners, the present research sought to examine the effect of just one type of choice (non-sequential user choice) on the formation of adaptive cruise control (ACC) mental models when learning from OERs. Norman (1983) argues that mental models are naturally-evolving internal structures that “provide predictive and explanatory power for understanding the interaction” that an individual has with a physical system (pg. 7). While often inaccurate, these models must always be functional, because “the purpose of a mental model is to allow the person to understand and to anticipate the behavior of a physical system” (Norman, 1983, pg. 12). These models emerge and evolve through interaction with a target system, producing a more viable working model of that system with each interaction. In Norman’s view, then, mental models are inherently practical, and applicable to actual interactions with a system, as opposed to a purely abstract, conceptual understanding of that system. In other words, conceptual models are “tools for understanding or teaching,” while mental models “are what people really have in their heads and what guides their use of things” (Norman, 1983, pg. 12). As Norman further points out, there should be a direct relationship between the conceptual model of a system that a designer has and the mental model that the learner should develop as a result of the learning process.

Greeno (1989) presents a similar view of mental models as applicable to real, physical systems, as opposed to purely symbolic. In particular, he argues against a traditional view of mental models as based purely on cognitive symbols, noting that “reasoning is situated, in that it uses resources in the situation rather than computation on symbols to arrive at conclusions” (Greeno, 1989, pg. 286). In other words, models of physical systems are often based more upon actual interactions than an abstract conceptualization of those actions. Greeno (1989) goes on to
argue that one option for leveraging the importance of system interactions is to produce learning environments that involve “reasoning in the space of a mental or physical model that represents a situation that the person needs to reason about” (pg. 296).

Norman goes on to note out that mental models are often incomplete, and we therefore depend upon “superstitious” beliefs, or “rules that ‘seem to work,’ even if they make no sense,” in part because these models need to be as simple as possible to allow complex action with little added mental planning (Norman, 1983, pg. 8-9). Similarly, mental models are unstable and amorphous, with portions often forgotten or confused with other systems over time. While these mental models are very useful, providing individuals with the ability to interact with complex systems, inaccuracies can be dangerous. Problems can arise from such inaccuracies when drivers’ mental models depend too much on naïve or superstitious beliefs and, as a result, have limited functionality in interactions with the target system. It is therefore crucial to help ensure that learners are able to develop mental models that accurately reflect real-world systems.

Unfortunately, there is very little research examining the effects of user choice on the formation of mental models in open learning environments, which is particularly concerning given the rise in popularity of open learning. This study builds on some previous work (Valentine, Zhou, Moore, & DeVane, 2018) in assessing the use of OERs to help learners attain such accurate mental models.

The present research highlights an existing gap in the research literature related to user choice of learning sequence. Relatively little research has examined the effect of this non-sequential user choice on general aspect of learning, and even less research has discussed its design implications for open learning environments that help users form accurate mental models of complex systems. The remainder of this chapter examines the literature that is available,
including research on adaptive cruise control (ACC), mental models, user choice, and open educational resources (OERs). First, I describe ACC systems and how drivers currently learn about the system in real-world settings, and why these systems are valuable sites for research on mental model formation. Then, I describe the practical nature of mental model formation with systems like ACC in mind. Next, I discuss major topics of scholarship about learning from open educational resources (OERs), describing how proponents believe these learning environments can empower users, and detailing the types of user choice that have been examined in the research literature. Next, I examine self-determination theory (SDT) as a rationale for providing choice in open learning systems. Last, the major goals of this study are restated in light of the available literature.

**Adaptive Cruise Control and How Drivers Learn About It**

Adaptive cruise control (ACC), an enhancement of conventional cruise control, is able to automatically adjust the car’s speed based on traffic ahead. In thinking about Norman’s (1983) conceptualization of mental models, ACC is a useful system to study. It is a complex, physical system that learners (typically drivers) can, and should, learn about in an applicable way, meaning that developing accurate mental models is important. Unfortunately, a majority of owners of ACC and other new driver safety systems are unfamiliar with aspects of the systems, with as many as 72% of ACC users unaware of any limitations of the system (Jenness et al., 2008). At particular risk are those drivers who learn about ACC through driving, as they may develop incomplete understandings of system functions and therefore overtrust the system’s performance (Kazi et al., 2007). This over trusting of system capabilities can produce dangerous driving situations for both the user and others, making it crucial for drivers to understand the car safety systems they utilize.
Few resources are available to drivers to learn about ACC and other car safety systems. The main source of information about such safety systems is car manuals, which very few drivers read completely (Mehlenbacher et al., 2002). Evidence from a 2014 U.S. national survey of drivers indicates that the internet was the most common source consulted about vehicle behavior (McDonald et al., 2015). This suggests that the best opportunity to help drivers develop more appropriate mental models of adaptive cruise control, and other car safety systems, is to leverage the internet as a source of reliable, accurate information. Online resources, and open educational resources in particular, are a promising avenue to correct dangerously inaccurate mental models.

**Developing Mental Models of Adaptive Cruise Control**

Research on ACC has a similar, but distinctive, approach to Norman’s (1983) for characterizing mental models, with Beggiato and Krems (2013) arguing that “a correct mental model of system functionality acts as basis for an adequate development of acceptance and trust in the system” (pg. 48). A focus on trust of a system’s function and acceptance of its use is common in the literature surrounding ACC. Unfortunately, as the work discussed in the previous section has shown, this conceptualization of mental models does not eliminate the problems of limited models described by Norman (1983). Limited mental models may actually cause drivers to overtrust systems like ACC, producing dangerous driving situations (Kazi et al., 2007). This finding aligns with additional research indicating that a large majority of ACC users are unaware of system limitations (Jenness et al., 2008). In other words, dangerous driving may result from drivers developing incomplete, overtrusting mental models of ACC due to a lack of knowledge about system limitations. Even if drivers escape any hazardous situations unharmed, the result is typically a dramatic loss of trust that never recovers (Beggiato & Krems, 2013). Conversely,
developing an accurate understanding of ACC can result in improved trust and more appropriate use of the system in the future (Beggiato & Krems, 2013; Kazi et al., 2007).

Another potential problem for users’ mental model formation is the process of becoming too accustomed to semi-autonomous systems like ACC. ACC systems, and other adaptive driver safety systems, may be useful in reducing driver workload and improving overall safety through reducing traffic speeds and increasing time headways (the amount of time between two vehicles in motion). Unfortunately, becoming too accustomed to these semi-automated systems can result in a variety of dangerous situations. One such danger is the possibility of distracted driving. In one examination of use of ACC in a driving simulator, for example, ACC use significantly reduced situational awareness availability of mental resources (Stanton & Young, 2005). In another simulator study, users with a high level of trust in ACC tended to brake later and harder in critical driving situations. Similarly, these responded to fewer events overall and received more warnings from the system, suggesting reduced awareness due to acceptance of system automation (Xiong et al., 2012).

In addition, the effects of becoming accustomed to ACC (and other semi-automated systems) are not restricted to simulators. Evidence suggests that in real-world driving situations, users of ACC have slower reaction times and are more willing to shift their attention from the road (Rudin-Brown & Parker, 2004). Drivers using ACC tended to engage in more secondary tasks and vary lane position more than drivers not using the technology. Perhaps most concerning, simulated failures of the ACC system did not reduce user trust or reliance on the system, suggesting that learning of system limitations after use may not change how drivers use these technologies (Rudin-Brown & Parker, 2004).
These issues highlight a need for early driver awareness of system limitations, which is particularly concerning as learners are often presented with incomplete information about the limitations of ACC when viewing a sales pitch or reading only part of a manual (Beggiato & Krems, 2013). A majority of ACC owners, and at least a third of non-owners, are interested in ACC for future vehicles (Jenness et al., 2008), making appropriate mental model development around ACC increasingly important for road safety. Early, accurate instruction and understanding will be crucial to long-term, safe use of ACC (Beggiato & Krems, 2013).

The present research utilizes a set of instructional materials that were designed with accurate mental model formation in mind. These seek to address the need for accurate understanding by developing drivers’ mental models of ACC and its limitations. According to Young (1983), a user’s mental (or conceptual) model of a system should explain system performance and system design and aid the user in learning and reasoning about the system. With regard to performance, the goal of the open educational resources that are examined in this study was to provide help scaffold users’ development of mental models about how ACC works in the real world. The Understand resource used here (Appendix A) explores how an ACC system functions from a user perspective. The Challenge and Play resources (Appendices B and C) highlight the types of errors (limitations) that the system has. By exploring those limitations, users are also able to challenge common over-generalized understandings of system performance (learning about a system). Similarly, users are asked to predict how systems react, explain that reaction, and produce their own solution (reasoning about a system). Finally, the post-test assessment (Appendix F) has two sections. The first section measures primarily declarative knowledge by asking learners free-response questions about general ACC components and functioning. The second section goes on to assess how robust learners’ mental models of ACC
are by presenting questions on how well current designs work in varied real-world situations. As noted by Beggiato and Krems (2013), more appropriate mental models of ACC, which these materials can help develop, lead to higher levels of trust in ACC and safer use of the system. At the core of these materials, however, is their nature as open educational resources (OERs) that are freely available to the public, substantially increasing the amount of control that learners have over how they use the materials. Previous research on user choice in open learning environments is therefore discussed in the next section.

**Types of User Choice and Their Effects on Learning**

According to Atkins, Brown, and Hammond (2007), higher education faces “a crisis of access, cost, and flexibility” and traditional models of education “seem ill-suited to address global education needs” for a new generation of learners (pg. 33). Open educational resources (OERs) bring with them a set of promises to revolutionize education, and seek to solve this crisis by improving access to high quality education and eliminating the digital divide. OERs provide an opportunity to break down barriers for learners, allowing just-in-time access to high quality, free-to-use learning materials from anywhere in the world at any time. While OERs are of course unable to solve every problem that the field of education faces, the appropriate design and implementation of these resources can potentially bring education to a larger population than ever before in a way that is more sustainable, affordable, and flexible than traditional models of education. This promise may help us resolve the current crisis of access, cost, and flexibility.

In addition to the promise of just-in-time access for any learner in any part of the world, supporters of OERs also advocate for empowering learners to take control of their own learning. In fact, the learners’ capacity to choose is at the heart of the open learning movement, with the use of Google and other search engines as inherently “open” resources drastically changing how
people learn about any number of topics (Atkins, Brown, & Hammond, 2007). In their discussion of the changes OERs can bring about, Lane and McAndrew (2010) argue that the shift to user-centric control of learning is, “embodied in OER.” This model of teaching and learning is built upon the provision of control over learning, from timing and location to sequence and the content learned. Users can, at any point, add in an additional resource or remove an extraneous one in order to cater their learning to their own preferences and strengths. When using Codecademy, for example, a learner can skip a basic HTML module if they are familiar with it, or complete additional CSS modules to expand their knowledge base. Similarly, users can switch from resource to resource on-demand and access materials in any order they choose, even if that means abandoning a carefully-designed layout. This promise of user control over their own learning is a key component of OERs, and the open learning movement on the whole.

On the other hand, critics assert that OERs have often been unable to live up to this potential (Conole et al., 2007). Richter and McPherson (2012) note that the availability and quality of OERs do not inherently guarantee their acceptance and appropriate use, and that any learning gains made using OERs may not be permanent. OERs may, in fact, be a waste of resources in some cases, particularly if learners do not see the value in engaging with them. The issue of a lack of perceived value may be especially concerning in OERs, as the large amount of control provided to learners can result in learners believing the content is optional, leading to lower completion rates and poorer recognition of the importance of the content (Garland & Noyes, 2004). Another potential problem noted by Richter and McPherson (2012) is the issue of cultural differences. While OERs may be freely available, differences in values and language across cultures make the development of useful resources substantially more difficult than it might initially appear. As Richter and McPherson (2012) note, for example, OERs are often
provided in non-editable formats, and instructors may or may not have easy access to digital tools in their classroom, further restricting the usefulness of these resources for those instructors. These issues, combined with a need for basic skills resources in many areas, indicate that OERs may well fail to achieve their promise without significant investment, eliminating one of the major benefits.

Despite this robust debate on the value of OERs in improving access and supporting user choice, there is little empirical research investigating the effect user choice actually has on learning. The literature that is available is discussed in the following sub-sections based on the type of choice being investigated. First, I examine research on choice of content in open learning environments. Next, the value of instructionally irrelevant choice is considered. I then present the available research literature on choice of sequence and pacing. Finally, I discuss learner characteristics that can impact the value of user choice in learning environments.

**Choice of Content**

Choice over the content of learning is integral to many open learning environments. Khan Academy ([https://khanacademy.org/](https://khanacademy.org/)), for example, allows learners to engage with any content they wish to complete and skip any that they prefer to avoid. In fact, many open educational resources (OERs) have choice of content built-in, as they allow learners to access specific pieces instead of entire lessons or courses. Below, I examine the literature on the effects of choice of content on learning. It is worth noting that learning environments with complete learner choice of content also inherently contain choice of sequence. However, in the literature discussed here, non-sequential user choice was not the focus of the research.

Badge systems are a prime example of learning environments that provide learners with substantial choice over learning content, as they take advantage of highly choice-dependent
learning environments. These systems are largely built around user choice, with individual
learners able to choose which badges (content) they pursue based on their own interests, goals, or
other motivations. The value of learner choice is often a crucial aspect of engagement with
badge systems and other forms of connected learning. As Davis and Fullerton (2016) point out,
many learners are far more willing to engage deeply with difficult content when they are able to
choose the content they engage with and when they engage with it. The authors go on to argue
that this highlights an important divide between school-based learning and many outside learning
opportunities: learners engage with those outside opportunities more, and therefore learn more,
*because* they are able to make their own choices about what to learn, whereas school-based
learning often involves forcing students to engage with particular content, causing them to be
less willing to engage.

In contrast, Brown (2001) notes that the individual choices of content that a learner
makes have a substantial effect on learning, raising the issue of quality of choice. As Brown
argues, poor decision-making on the part of learners has significant, negative effects on learning
and decisions about content are often relevant to success in a learning environment. This also
provides a contrast to the widely-held belief discussed by Alessi and Trollip (2001) that learners
can make their own decisions about what to learn better than educators can. While it may be true
that learners *can* make their own decisions, it may be that those decisions may not always lead to
improved learning outcomes. In fact, his study of workplace training, Brown (2001) notes that
learners with more control over content tended to engage less with the learning environment and
in an online classroom setting. Students who were given control over the content they used
(content pieces were labeled as either optional or mandatory) tended to complete learning
modules less often, spend less time on those modules, and learn less than those students who did not have choice of content.

In a now-classic, and often-replicated, examination of consumer behavior, Iyengar and Lepper (2000) demonstrated that excessive choice of purchase (analogous with choice of content) produces fewer purchases and a decrease in satisfaction with the available choices. In the original work, consumers were provided with either a small number of choices of fruit preserves or a much larger set of choices. Those consumers with more choices were less satisfied with the decisions they made. However, Iyengar and Lepper (2000) took this idea further, and applied it to educational settings. When students were given a large number of essay content topics to choose from, they tended to write essays that were shorter and of poorer quality than their peers who only had a few options. Further research has confirmed this “choice overload” effect, with only a few cases in which extensive choice is positive (Chernev, Böckenholt, & Goodman, 2015). While many of these findings are not oriented towards education, have important implications. A major argument for including high levels of choice, of any type, is that learners will experience a sense of autonomy, and therefore be more motivated to learn and satisfied with the learning process, which will then improve learning. If extensive choice instead reduces satisfaction with decisions and the learning process, we may expect a similar drop in learning gains.

**Instructionally Irrelevant Choice**

In addition to the wide-ranging instructional effects of choice of content, many learning environments are designed to provide learners with choices intended to improve engagement while leaving the instruction intact. Such choices include control over character creation in games, narrative elements in a story, and social interactions in the learning environment. This
section examines the literature focused on the effects of instructionally irrelevant choices in digital learning environments.

Cordova and Lepper (1996) directly investigated the role of instructionally irrelevant choice in promoting learning in computer-based learning and found dramatic effects. These authors present research on a game in which some players could choose some superficial, narrative elements of the game, while those elements were pre-determined for other players. In this case, choices available did not affect the actual instructional process, but rather incidental details in the program. In this way, researchers sought to eliminate the effects of any poor decision-making by the learners on the actual learning process. The data indicate that learner choice significantly improved intrinsic motivation, including an increase in perceived confidence and aspiration for future learning. The authors argue that this motivational effect is directly related to learners more deeply engaging with the material, as well as learning more content within a set amount of time. In fact, Cordova and Lepper (1996) even saw learning gains from choices that were unrelated to the instruction, implying that choice is both motivating and beneficial to learning even when it does not directly affect the learning process.

Conversely, Ross and colleagues (1986) found a highly varied effect of user choice over learning context, with benefits in some situations and detriments in others. In particular, while learner control had a positive effect for one group of undergraduates in an adaptive learning context (in which the learning context was related to student major), it provided no benefit for other groups, both in adaptive and non-adaptive contexts, suggesting that added choice may be a mixed bag. The authors note that the positive effect that was found was “not indicative of a strong or theoretically meaningful pattern,” and could potentially be questioned (Ross, McCormick, & Krisak, 1986, pg. 250). Kelly and Bishop (2014) had similarly mixed results,
finding no significant difference between guided instruction (more structure) and free choice learning (less structure). Surprisingly, these authors found that high-performing learners used guided instruction options more frequently when able, which seems to contradict the assertions (discussed in more detail in subsequent sections) by Hannafin (1984) and Alessi and Trollip (2001) that high performers benefit from more control over the learning process than low-performing learners.

Turkay and Adinolf (2015) investigated the effect of extensive in-game choice on players’ interest in playing video games for fun, including in-depth choices about their characters, the stories they pursue, and the characters they interact with. In particular, the authors argue that extensive character customization (another type of instructionally irrelevant choice) can significantly predict a greater willingness to play a game. Turkay and Adinolf (2015) also found that players’ perception of choice predicted their willingness to continue playing, another piece of evidence in favor of providing learners with that choice (or at least the illusion of choice). In another examination of choice in games, Turkay et al. (2014), while examining educational gaming in classrooms, argued that “providing students with choices can increase their enjoyment, as well as self-efficacy, intrinsic motivation, sense of control, and task persistence… [which] can lead to better performance at the task at hand” (p. 10). The resulting argument from these works is a common one in modern educational literature: extensive learner choice (even seemingly irrelevant choice) is connected to improved task performance.

**Choice of Sequence and Pacing**

While choice of content and details that do not affect instruction are of course important areas to consider, the primary focus of this study is on control of learning sequence. In this section, I discuss the available literature on choice of sequence in learning environments. Pacing
is also included in this section, as control of pace is often grouped alongside sequence in the literature.

One type of learning environment with interesting parallels to the present research is museum-based learning. Just as learners using open educational resources (OERs) are able to move freely through a set of online resources, so too are learners in a museum relatively free to explore exhibits as they choose. With museum-based learning in mind, Bamberger and Tal (2005) categorize levels of choice in content and sequence of learning environments, ranging from no choice (learners follow a scripted, lecture-like path) to free choice (learners have complete freedom of learning path) environments. Between these extremes, limited choice environments involve some structure, but learner choice in both the pacing and sequencing of learning. According to Bamberger and Tal’s (2005) examination of museum-based learning, this limited choice category appears to produce deeper, more engaged learning. On the other hand, learners in both no choice and free choice environments engaged less successfully with available resources. Bamberger and Tal (2005), then, presents a more measured approach to user choice than some previous research. The focus on learning sequence (and control of that sequence) is crucial here, as it is this type of choice that is examined in the present work. In particular, this study’s consideration relates to no choice (control) and limited choice (experimental) categorizations.

Chou (2003) also discusses the importance of choice of sequence in online learning, including it as one of nine important dimensions of interactivity. According to Chou (2003), the ability to access information in a learning system in a non-linear (non-sequential) manner is part of a basic “recipe” for interaction in web-based learning. Web-based learning should therefore provide learners with search options, site maps, and other ways to make choices about
sequencing. In fact, one argument is that the control inherent in web-based learning is able to “empower individual learners,” which then improves educational outcomes (Lin & Hsieh, 2001). It is further argued that in using web-based learning, “It is no longer necessary to establish a fixed learning sequence for everyone; individual learners can make their own decisions to meet their own needs at their own pace” (Lin & Hsieh, 2001, pg. 382). The authors go on to note that expanded learner control over what content they see, and when they see it, could improve attention and help students more deeply learn. These works provide support for the notion that user choice of learning path could improve performance by promoting attention and engagement.

Work in the field of instructional design also emphasizes learner choice, with Mayer (2008) including learner control of pacing as a principle of multimedia learning design. According to Mayer, allowing learners to control the pace of their learning allows for improved learning by reducing the potential problem of overloading students. While pacing and sequencing are certainly different types of choice, this raises the issue of allowing learners to focus on the content that they deem important when they wish to, which is the essential component of non-sequential user choice.

There is also evidence to suggest that while non-sequential user choice in game-based learning may improve motivation, it does not necessarily translate into improved learning outcomes. In one case, for example, performance was assessed based on whether learners had the choice to repeat levels in a game-based learning environment or not. While this choice did appear to have some motivational benefits, it did not produce significant learning gains as compared to the non-choice condition (Nebel et al., 2016). Such results raise questions about the common argument that improved choice improves learning outcomes by enhancing learner motivation.
While learner-controlled environments have become popular, a lack of guidance may not always benefit learners. Proponents of learning environments with more learner control, and therefore little guidance provided by designers or instructors, may ignore extensive research about how people choose to learn. In fact, learners in purely discovery-oriented learning environments – in which they have substantial control of their learning – often become frustrated and confused, resulting in poor performance (Kirschner, Sweller, & Clark, 2006). Even proponents of discovery learning environments such as Brown and Campione (2004) note that, without any guidance, it is very easy for learners to develop misconceptions about important topics. Factors that influence whether more or less choice is appropriate are discussed in the next section.

**Learner and Content Characteristics that Influence Choice**

As mentioned above, extensive user choice in learning environments may not always be beneficial, regardless of the type of choice provided. A number of factors play into whether or not extensive choice should be provided for learners. These include characteristics of the learners, the type of content being learned, and the importance of success in real-world applications of the learning (i.e., how dangerous is it to fail?). Some of the issues at play are discussed below.

As a starting point, Hannafin (1984) provides a set of guidelines for the use of learner or program control for educational design, a number of which this project meets. First, Hannafin recommends high levels of user choice over sequencing and pacing when working with adult learners, who are the primary users of advanced car safety systems like ACC. In addition, user choice is seen as valuable when learning is part of a larger skill set and is generally familiar. In this case, the use of ACC fits into the larger skill of driving, which will likely be familiar for
users of these materials. Finally, Hannafin (1984) recommends substantial user choice for contextual information that requires in-depth processing or decision-making. The safe use of ACC falls into these categories as well, as drivers must make judgements on the fly about the appropriateness of using the system and the situations in which they must take back control and drive manually.

This type of learner- and content-based judgement as to whether or not to provide learner control is further discussed by Alessi and Trollip (2001). The authors note that it is a long-held belief in education that “learners may be able to make better sequencing decisions,” going on to provide specific recommendations for when learners should have more control than the learning system (Alessi & Trollip, 2001 pg. 51). These recommendations include increasing learner control for learners who are familiar with the content, those who have already completed the learning experience, and for older learners who may be able to make better decisions about their learning. Many of these recommendations echo those of Hannafin (1984), including the suggestion to give more control to adult learners and those learners who are already familiar with the content area.

Additionally, individual differences among learners may have an impact on how choice of learning strategy affects learning gains. In one examination of web-based learning, exploration-minded learners performed worse when they were unable to freely explore, while observation-minded learners performed best without such freedom (Liegle & Janicki, 2006). Brown (2001) had similar findings, noting that varied performance orientations and self-efficacy, among other individual factors, appear to be related to successful learning in high-choice learning environments. These results fit with other researchers’ findings (e.g., Ross,
McCormick, & Krisak, 1986) which suggest that substantial learner choice may be beneficial for some learners and detrimental for others.

In the case of the present research, there are also concerns from traditionally-accepted guidelines for implementing learning environments with substantive learner choice over pacing, sequence, and content. For example, Alessi and Trollip (2001) argue that learner control should be reduced when mastery is important, and mistakes could be dangerous. The use of advanced car safety systems clearly meets this criterion, with mistakes putting the lives of road users at risk. These issues, along with empirical evidence to suggest that choice may hurt some learners, raises questions about the process of assessing whether choice should be built into learning or not. Such questions are particularly relevant in working with OERs, as the goal is to reach as many learners as possible, regardless of learning style or other personal factors. If these factors play into the effects of varied types of choice, we face a major issue: to whom do we cater our materials? As a key part of the open learning movement, and its focus on eliminating barriers to successful learning, a consensus on such a wide-reaching design decision is crucial.

**Mental Models and Choice in OERs**

Previous research presents two competing arguments around the design of open, online learning environments with regard to user choice. The claim has been made that choice of sequence, content, pacing, and even irrelevant details has a positive effect on learning outcomes (e.g., Turkay et al., 2014). Conversely, other research suggests that unguided learning experiences may have a negative effect on learners’ understanding (e.g., Kirschner, Sweller, & Clark, 2006). The present research seeks to contribute to our understanding of these issues by attempting to establish the effects of choice over sequence on learning from OERs. Educational trends would suggest that learner choice of sequence could improve learning through fostering
motivation and engagement. On the other hand, issues of choice overload or poor user choices could also produce a negative effect on learners’ acquisition of declarative knowledge and development of mental models.

Unfortunately, despite the substantial debate surrounding the benefits (or lack thereof) of extensive user choice of content, sequence, and pacing, very little research has considered how the provision of choice affects the formation of mental models of complex systems. While some instructional design literature points toward potential issues (e.g., it is very dangerous to use a car safety system incorrectly) that could influence the effect of choice in the present research, there is a significant need for additional research into the influence of user choice on the development of mental models.

**Self-Determination Theory as a Rationale for User Choice**

Many learning environments have been designed to try to support user choice, even as scholars still grapple with how and when to enhance learner autonomy in OERs. Designers’ claims about the potential of open environments to support learner autonomy, and researchers’ empirical investigations of learner autonomy in said environments, are sometimes rooted in interpretations of self-determination theory. Self-determination theory (SDT) argues that autonomy is a basic need for intrinsic motivation to learn, indicating that a lack of choice or control on the part of learners can produce poor learning gains (e.g., Ryan & Deci, 2000). In previous research describing the development of multimedia learning environments, SDT is often used as a design framework for motivation. In such design frameworks, the choice of specific content and/or the sequence of that content is seen to be closely connected with a sense of autonomy (Turkay & Adinolf, 2015). To be clear, the present research is not rooted in SDT or
motivational theory in general, but rather, the author recognizes that much of the available research on user choice has used SDT as a backdrop, making it a topic worth examining.

Boekaerts (1988) presents an even more detailed description of the relationship among choice, motivation, and learning. The author develops a motivation- and choice-oriented framework for conceptualizing learning. This framework involves the support of learner choice as a crucial component of the learning process. In particular, Boekaerts (1988) presents a view of choice that involves a learner’s ability to make specific choices about their learning strategy and about the management of their own learning process. Boekaerts notes that learners’ perceptions of control (or lack thereof) can significantly affect success in a learning environment. In fact, she explicitly argues that meaningful learning should be conceptualized, in part, as a learner’s “satisfaction with the learning opportunity,” as defined by the amount of control learners believe they have over their process of learning (pg. 277). This argument is echoed in Boekaert’s (1988) results that individuals who did not feel in control of their learning experience negative feelings towards the experience and perform worse. Alongside feelings of competence, this assertion, combined with Cordova and Lepper’s (1996) positive effect of user choice, highlight a central theme in the motivation literature: feelings of choice (of varied types) improves learning through increasing motivation to learn. Again, the present research is not primarily investigating the effects of non-sequential user choice on motivation, nor does this author seek to make the argument that the connection to motivation is appropriate. Rather, previous research has made that argument, and this author is simply discussing how that previous research might relate to the questions at hand about mental models and non-sequential user choice.
The connection to motivation is also very common in literature on educational games (e.g., Ryan, Rigby, & Przybylski, 2006; Rogers, 2017). For example, Ryan, Rigby, and Przybylski (2006) used an SDT framework to examine the effects of autonomy (partially defined as the availability of choice) and competence on game enjoyment. Provisions for user choice, in this case including control of sequencing of tasks and the specific tasks completed, were predictive of improved feelings of autonomy and performance. This sentiment and finding are echoed by Rogers (2017), who extends that SDT framework to include the types of rules and social interactions built into games. The author finds that flexible rules, those that give the player freedom to make important choices about their character and progression through the game, improve feelings of competence and enjoyment in a game. While Rogers (2017) does not make direct arguments regarding learning gains, these pieces of research together further suggest that motivation to engage with a digital system (in this case, a digital game) is improved when substantive choices are available to players, with the potential for learning gains as well.

Along similar lines, extensive choice (via this connection to autonomy) has been used to predict engagement in online learning environments, which is in turn a key predictor of success. In fact, Lee, Pate, and Cozart (2015) argue that providing substantive choices for learners is crucial to supporting autonomy and, by extension, engagement in online learning. These choices can include types of engagement with content, as well as the content being learned. The authors note that a sense of control over the learning process is directly associated with improved motivation, feelings of competence, higher rates of completion of online courses, and academic performance (Lee, Pate, & Cozart, 2015). In terms of this present research, this implies that a sense of control over their own learning could help push a driver new to ACC (or other systems)
to engage with every resource available in a meaningful, intrinsically-motivated way, producing better outcomes.

Additional research on educational badges has investigated the effects of badges as rewards and credentials on motivation and learning. One study, for example, considered how various goal orientations and ability levels interacted with achievement (as measured by the number of badged earned (Abramovich, Schunn, & Higashi, 2013). The authors note that, at least in some cases, badges as external rewards can improve motivation and achievement.

Similarly, Ahn, Pellicone, and Butler (2014) argue that badges can be powerful motivators. This is especially true for those that wish to compete or improve, as well as when badges are seen as worthwhile credentials that showcase a particular set of skills. Conversely, in badge systems, and other online learning environments, a potential problem with extensive choice is apparent: the possibility that extrinsic motivation (e.g., badges as rewards) might undermine intrinsic motivation. With learners choosing the content based on rewards, they may become more focused on earning those rewards and less focused on deeper learning (Ahn, Pellicone, & Butler, 2014). This may be especially true as badges become more visible and accepted as credentials, at which point learners may work towards badges as a sign of status instead of as a step toward mastery of content. As such, badge systems and other high-choice learning environments could suffer from a lack of genuine interest, undermining the entire motivational argument and resulting in poorer performance and less learning.

Unfortunately, although a substantial amount of research literature has connected the supposed autonomy that learners gain from being provided with choices, very little research has investigated the impact of that autonomy on mental model formation.
The Goals of the Present Research

The instructional materials and assessments used in this research were initially created and tested as part of a larger research project (Valentine, Zhou, Moore, & DeVane, 2018). The materials consist of three learning sections – Understand, Challenge, and Play – and a summative post-test developed for previous research. The Understand section is a text- and image-based summary of ACC and its components, including what the system does, how to operate it from a user perspective, and the functions of each major part. The Challenge resource includes text- and image-based problem-solving scenarios highlighting ACC system limitations. These Challenge problems ask learners to determine how an ACC system will react in four different situations and how they, as a driver, would respond. Finally, the Play section leverages an interactive simulation (plAyCC) to give learners the opportunity to investigate how ACC systems function on roads with varying speed limits and curviness. As part of the Play materials, learners solve a series of problems in which simulation settings produce dangerous driving situations. For each problem, learners must reason about ACC and its functioning to discover the most appropriate change to the road.

In previous research, these materials have been used to examine collaborative learning about adaptive cruise control, with the assumption that few drivers learn about these systems in isolation (Valentine, Zhou, Moore, & DeVane, 2018). With that goal in mind, performance on an ACC post-test, as well as on the Challenge and Play scenario problems, was compared for individuals and collaborative pairs. In that previous research, collaborative pairs performed better on the Play scenario problems than the individual pairs, but no significant difference was found for the Challenge scenarios or post-test. The present research builds off of the individual learning condition from this previous work, in which all subjects followed a predetermined path,
Table 1 summarizes the data collection and analysis methods used in previous research as it applies to the present research. Below, examples of Challenge and Play scenario problems are included. All of these problems are included in Appendices B and C, respectively.

<table>
<thead>
<tr>
<th>Instructional Material</th>
<th>Relevant Data Collection</th>
<th>Relevant Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand (Appendix A)</td>
<td>None; this section is purely direct instruction</td>
<td>N/A</td>
</tr>
<tr>
<td>Challenge (Appendix B)</td>
<td>Problem solutions (collected via Qualtrics)</td>
<td>Rater scoring; Independent sample t-tests</td>
</tr>
<tr>
<td>Play (Appendix C)</td>
<td>Problem solutions (collected via Qualtrics)</td>
<td>Rater scoring; independent sample t-tests</td>
</tr>
</tbody>
</table>

Table 1. Data Collection and Analysis from Previous Research

Each Challenge scenario problem highlights a specific limitation of typical ACC systems. The first problem, reproduced in Figure 1, tasks learners with thinking critically about how ACC systems may have limited functionality on roads with many tight curves. All of the Challenge problems can be seen in Appendix B.

In the Play section of the instructional materials, learners instead use a low-fidelity simulation of ACC to explore ACC’s functionality on curving roads, with the driver and traffic around them traveling at varied speeds. Across problems, learners are able to vary the severity of curves in the road, the speed limit of the road, or both. These variations are made in order to improve the safety of the road in question, based on the use of ACC by some drivers on that road. As an example, the first problem is reproduced in Figure 2 below. In this problem, learners are able to adjust the curve of the road, but not the speed limit. All of the Play problems can be found in Appendix C.
These three learning modules take different approaches to the amount of explicit information about ACC that they present to the user and the manner in which they attempt to activate mental models about the limitations and contextual uses of ACC. While there are a known number of sequences that can be chosen from three learning modules (six possible sequences), given the variation in instructional approaches embodied in these resources, the potential effect of users’ choices in sequence on their understandings make different sequential configuration of these resources interesting objects of study. Learning using these resources may entail the acquisition of declarative knowledge about ACC and the development of situational understandings related to mental models and sequence may have a significant effect on outcomes.

Using these instructional materials, this research sought to address two major questions:

1. What effect does user choice of sequence have on the development of mental models of ACC when learning using OERs?

2. What relationship, if any, exists among performance on a post-test assessment of mental models and declarative knowledge, time spent on individual learning resources, and the order in which those resources were used?
CHALLENGE #1: CURVING ROADS

Your ACC system looks directly in front of you for other vehicles. Because it only looks forward, your ACC system may have trouble detecting traffic on curving roads.

In the image to the right, see how ACC’s field of view works when the road curves. Its view may include traffic in another lane. It may also miss vehicles in your own lane. In situations like this, your ACC system may not react appropriately to the traffic around you. In the example, your ACC system may unexpectedly slow down if it detects the semi in the other lane.

What would you do?
Look at scenario in the image to the right. Imagine yourself driving the blue vehicle. Think about the questions shown below.

As you approach the curve, how might your ACC system respond? How should you respond?

Figure 1. ACC Challenge Scenario 1
Situation: You are a road designer working with the Iowa Department of Transportation. You are working on an existing highway which has a speed limit of 55mph and contains a lot of tight curves. While most drivers stay near the speed limit of 55mph, some drivers go as high as 70mph on this road, leading to dangerous situations when systems like Adaptive Cruise Control (ACC) are used.

Your task: Redesign the road to fit the demands of traffic without changing the road’s state-mandated speed limit. In redesigning the road, you are only able to make changes to the curviness of the road. What is the smallest change you can make to the road’s curviness in order to eliminate dangerous situations (red ACC detection cone) involving cars exceeding the speed limit?

Figure 2. Play Scenario Problem 1
CHAPTER 3: METHODOLOGY

This chapter examines the methodological considerations for the present research. First, the study design, participants, and data sources are described. I then explain the design of the data sources based on the assessment of mental models of adaptive cruise control. Finally, the study procedures and analyses are discussed, including the process of quantitatively analyzing coded, qualitative data.

**Study Design**

The present study used an experimental, between-groups design to investigate the role of user choice of sequence on learning gains from open educational resources (OERs). For each condition, 42 college undergraduates were recruited. This sample size was larger than the minimum sample size (34) required to achieve statistical power of .90 for a two-tailed, independent-sample t-test (alpha = .05, large effect size) and the minimum sample size (39) required to achieve statistical power of .80 for a multiple linear regression analysis (alpha = .05, large effect size, 4 predictor variables), and allowed for counter-balancing of presented orders (Cohen, 1988). In the control condition, subjects engaged with the materials according to the prescribed, linear route used in previous research (see Table 2 for a summary of this route). In the experimental condition, subjects instead had free choice over the sequence in which they engaged with learning resources. The order in which materials were listed was counter-balanced so that no particular order would influence results for the experimental group. Only subjects without knowledge of adaptive cruise control, the focus of the materials, were included in the study.
Table 2. Study Sequence

To assess performance, subjects’ understanding of ACC was evaluated using a short assessment developed for previous research (Valentine, Zhou, Moore, & DeVane, 2018). The first, free-response portion of the post-test involved describing system functions and identifying major components. In addition, learners were presented with Likert-type items assessing how well they estimated the usefulness of ACCs system during various traffic situations. Overall post-test scores were analyzed as a measure of subjects’ understanding of ACC.

In addition, a multiple linear regression analysis was conducted to examine the relationship among post-test performance, chosen sequential order, and timing on each of the three learning resources (Understand, Play, and Challenge). This analysis used four predictors (chosen sequential order, time spent on Understand resource, time spent on Play resource, and time spent on Challenge resource) in building a model to predict post-test performance. Such an analysis allowed for the consideration of the effects of individual learners’ choices, as opposed to
just the *allowance* of choice. This reflects the concerns of Brown (2001) and others regarding the quality of learners’ choices in learning environments.

**Participants & Recruitment**

Participants for this study were recruited as part of two conditions, as mentioned the section above. 42 college undergraduates were recruited for each of the two conditions. Participants were recruited from an introductory educational psychology course as well as via email advertisements. All potential participants were then asked to fill out a brief screening and scheduling form before the consent process. This screening form gathered information about subjects’ knowledge of ACC. Only subjects who indicated that they were unfamiliar with ACC were eligible to participate. Subjects who were eligible, able to attend, and wished to participate then completed the consent process and the study procedures discussed later in this chapter. Data on gender, age, and other demographic factors were not collected as part of the recruitment or study procedures.

**Data Sources**

The instructional materials used for this study are OERs developed as part of a larger public information campaign. The content focuses on adaptive cruise control (ACC), a new car safety system that helps regulate speed and distance to the car in front. Versions of these materials are freely available online on the public information campaign’s website ([http://mycardoeswhat.org](http://mycardoeswhat.org)) and are summarized in more detail in Chapter 2.

All data were collected using Qualtrics forms based on the research materials used in previous studies (e.g., Valentine, Zhou, Moore, & DeVane, 2018). In addition to user responses, this allowed for the collection of timing data for each form, which was used in examining this study’s second main question regarding the relationship among timing, order, and post-test
performance. Timing data was only collected for the experimental (choice) group, in order to examine differences among users given the choice of sequence. This was done to allow consideration of the effects of particular sequential choices on learning. Responses for the Challenge and Play scenario problems were recorded and analyzed. Table 3 below summarizes how each data source and quantitative analysis method applies to the initial research questions.

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Data Sources</th>
<th>Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of user choice</td>
<td>- Post-test scores</td>
<td>Independent sample t-tests (α = .05)</td>
</tr>
<tr>
<td></td>
<td>- pIAyCC scores</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Challenge scores</td>
<td></td>
</tr>
<tr>
<td>Timing, order, and performance</td>
<td>- Post-test scores</td>
<td>Linear regression analysis</td>
</tr>
<tr>
<td></td>
<td>- Order of materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Timing data per resource</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Research Questions and Data

Mental Models and the Design of Data Sources

The instructional materials used in this research were developed based on the goal of helping learners develop accurate, functional mental models of ACC systems. Based on Norman’s (1983) description of mental models, it is important to differentiate between the mental model that users have and the conceptual model that is created in order to teach learners about the system. Assuming an accurate conceptual model, this direct relationship then leads to the ultimate goal of successful prediction of system behavior in various situations (Norman, 1983). This goal is reflected in the design of the Challenge materials used in this research. As previously mentioned, the Challenge section is comprised of text- and image-based scenario problems focused on the limitation of ACC systems. The materials give learners a brief
description of various ACC limitations before requiring them to assess how that limitation will affect performance in a related situation. As such, learners are tasked with engaging in the very type of behavioral prediction that Norman (1983) notes as a key aspect of mental model use. With this approach, the design team hoped to encourage the evolution of functional mental models based on complete, accurate information of system limitations.

The scenario problems used in this research align well with Norman’s (1983) view of mental models as being generated naturally through system interactions and complex problems. In particular, the Play section of the materials tasks learners with interacting with an ACC simulation in order to solve complex scenario problems. While this is a low-fidelity simulation of an ACC system that emphasizes a third-person systems perspective, pAyCC does present learners with the opportunity to take action and observe the effects of those actions within an interactive model of ACC. Those interactions then provide learners with another source of reliable, accurate information from which to develop their own mental models of ACC function.

Research on ACC-specific mental model development also affected the materials used for this research, with a large portion of the final, summative assessment based upon the work by Beggiato and Krems (2013), though part of the assessment was focused on declarative knowledge. In particular, the final portion of the post-test assessment involves learners answering questions using a Likert-type scale, indicating their belief as to the effectiveness of ACC systems in various situations. Some previous research has used entirely qualitative assessments of mental models of ACC, but long interviews and other forms of qualitative data collection, clear comparisons between groups is difficult. The quantitative data collected via Likert-type items, by contrast, allows for easier comparison between experimental conditions and quantification of mental model development as a result of instruction (Beggiato & Krems,
Use of this type of assessment by Beggiato and Krems (2013) was successful in indicating improvement in ACC mental models over time based on learners’ trust in the system, suggesting that the approach would be useful for the present research. The Likert-type scale used in this research was adapted from that used by Beggiato and Krems (2013), but was shortened in order to make the study more time efficient for users. A selection of the items used by Beggiato and Krems (2013) is included in Figure 3.

The final version of the post-test used for this study (included in Appendix F) contained two major sections, one focused on declarative knowledge of ACC and the second focused on assessing mental models using abstracted scenarios. First, learners were asked a series of free-response questions that primarily assessed their declarative knowledge of ACC, rather than their practical mental models. Topics covered on the first section of the post-test include the differences between ACC and conventional cruise control, the parameters a driver must set when using ACC, and the major components of the system. The second section of the test, as previously mentioned, was adapted from the trust and mental model assessment developed by Beggiato and Krems (2013), and was intended to assess learners’ mental models of ACC. The questions addressed various situations in which ACC might be used, and asked learners to indicate how effective they believed the system would be in those scenarios. Answers given by learners on this section of the post-test reflect their trust in the system and, by extension, their mental models of ACC.

**Study Procedures**

After the consent process, study subjects engaged with all three learning resources (Understand, Play, and Challenge). Study procedures are summarized below, as well as in Table 2. In the control (no choice) condition, subjects followed the predetermined sequence from
previous research. In this path, subjects first read the Understand section before continuing to the Play section. Subjects were asked to solve all three problems in the Play section before moving on to the Challenge section. Once again, learners solved all of the problem scenarios. After completing the Challenge section, learners took the ACC post-test to complete their participation in the study. The entire process took place online using Qualtrics forms over the course of approximately one hour per subject.

<table>
<thead>
<tr>
<th>ACC...</th>
<th>totally disagree</th>
<th>totally agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>... maintains a predetermined speed in an empty lane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... steers automatically</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... works on highways</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... reacts to stationary objects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... works on curvy roads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... reacts to cross traffic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... is overruled by pressing the brake pedal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... adjusts the speed to slower vehicles ahead</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... reacts to pedestrians in the traffic lane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... warns in case manual intervention is necessary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... reacts to trucks driving ahead in the same lane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... detects right of way regulations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... accelerates automatically after complete standstill if the car in front restarts again</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... reacts when vehicles approach from behind</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... reacts to passenger cars driving ahead in the same lane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... allows to drive faster than the set speed by pressing the accelerator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... regulates the distance in case of cut-in situations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>... reacts to traffic lights</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3. Selection of Likert-Type Items from Beggiato & Krems (2013)**

Subjects assigned to the experimental (user choice) condition did not follow a predetermined path through the instructional materials. These subjects were instead presented with a search engine results-like page with all three sections (Understand, Play, and Challenge)
listed. As with search engine results, subjects were provided with an image and brief description of each section in order to help them make their choice. Figure 4 shows an example of how the choice screen appeared to the subjects in the experimental condition. Subjects were able to select which section they wished to proceed to. After each choice, but before engaging with the chosen learning resource, subjects in the experimental condition were asked to justify their choice of sequence by answering a multiple-choice question. These questions are included in Appendix H. Subjects were then able to engage with their chosen resource. Following each individual resource, subjects were asked to choose another section until all three had been completed. Following their final choice, subjects were also asked a set of free-response questions to gauge their overall satisfaction with their choices as well as to gather feedback about the available choices. The free-response questions can be found in Appendix I. After answering the free-response questions, subjects took the same post-test as the control condition. Order of materials listed on the results page was counter-balanced in order to avoid confounding the effects of choice on performance with those of ordering.
The post-test was scored based on a standardized rubric for responses that was developed for previous research (Valentine, Zhou, Moore, & DeVane, 2018). Likert-type items were also scored using previously-developed scoring systems. Post-test questions can be found in Appendix F. The rubrics for the post-test (including Likert-type items) can be found in Appendix G. As with the problem scenarios, scoring was be completed by two raters. Post-test scores were analyzed using independent samples t-tests (α = .05).

Problem responses from the Challenge and Play sections were scored using rubrics developed for previous research. Appendix D includes the rubric for the Challenge scenario.
problems. See Appendix E for the rubric for the plAyCC problems. Scoring for each subject was be conducted by two separate raters. Inter-rater reliability is reported in subsequent chapters, and differences between raters were resolved through discussion, using the rubric as the final determinant of scores. Scores for each problem-based section were analyzed using independent samples $t$-tests ($\alpha = .05$).

The rating process discussed above for the Challenge, Play, and post-test questions is based upon Chi’s (1997) guide for handling qualitative data. The author provides a straightforward process with eight concrete steps for the analysis of qualitative data. These steps include: reducing or sampling data, segmenting the sampled data, developing a coding scheme, categorizing the data (mapping the evidence) and displaying it, finding patterns in the data, interpreting those patterns, and finally repeating the process as necessary (Chi, 1997). Each of these steps is discussed below, along with how each applies to the present research.

Chi’s (1997) first step, reducing or sampling the data, involves limiting the amount of qualitative data being coded. In the case of verbal data, this may include reducing a transcription covering dozens of pages to a much smaller sample using random sampling, preliminary coding to determine important areas, or other methods. Following reduction, the second step involves segmenting data into manageable components, making coding easier. In the present research, however, there was only a relatively small amount of qualitative data being coded. In particular, the free responses on the Challenge scenarios and portions of the post-test involve qualitative data resulting in a much smaller dataset than the videotaped discussions considered by Chi (1997). As such, the sampling step and segmenting steps were resolved by the nature of the data sources.
The third step of Chi’s (1997) protocol includes the development of a coding scheme for the data at hand. This is a crucial step, with individual codes determined based on what is important to the research questions being asked. Once the scheme is chosen, data must be categorized as described in Chi’s (1997) fourth step, operationalizing evidence for coding. Specific utterances (or written responses) must be able to be identified as part of the coding scheme or not, based on the codes and categories developed. For the present research, this coding scheme is represented in the rubrics in Appendices IV, V, and VI. The rubrics for the Challenge questions, Play questions, and post-test were developed via an iterative process in which I was directly involved. The questions, and their respective responses, were generated based on the goal of assessing learners’ developing mental models of ACC, as discussed previously. Both the questions and the rubrics were then revised on numerous occasions, based on the conceptual model being used to teach learners, input from subject-matter experts, and previous research on ACC mental model development. In each case, scores are dependent upon the representation in a learner’s answer of crucial components to appropriately addressing the system component, limitation, or other aspect of functioning examined in the question. Rubrics were also revised based on preliminary coding of the data. Two raters, myself and another graduate student, coded a subset of responses before discussing disagreements and possible revisions. Along with faculty input, and input of subject matter experts, these rubrics were then revised again a number of times in order to more accurately represent the necessary components of answers and the underlying mental models that would produce those answers. A substantial number of revisions were based on attempts to categorize individual responses, with challenges including the amount of meaning that could be inferred based on limited written data. The
rubrics were only finalized when all members of the team were satisfied that they accurately represented the understanding assessed by each question.

The final four steps of Chi’s (1997) process partially depend upon the data collected for. The fifth step, depicting the formalism, involves displaying the coding scheme and as much data as is needed for readers to make their own judgments as to the accuracy of the coding scheme. In the present research, the formalized coding schemes for the Challenge, Play, and post-test questions are depicted as rubrics in Appendices IV, V, and VI. In addition to depicting the formalism, following data collection and analysis, data should be reported as thoroughly as possible in order to provide readers the opportunity to judge results for themselves, as is recommended in the display step. This reporting is especially crucial for the Challenge questions and post-test, where much of the qualitative data for this study originates.

Seeking patterns in the data is Chi’s (1997) sixth step. This involves identifying where trends emerge in the qualitative data, such as areas in which learners are consistently succeeding or struggling, or where/when particular codes surface often. With regard to this research, such patterns have been found in previously-gathered data to create the current coding scheme (rubrics). The process of rubric revision is discussed above. Patterns in new data were assessed by the study’s raters, for which reliability was ensured as discussed above. The identification of those patterns then leads to Chi’s (1997) seventh step, interpreting patterns. This involves verifying the value, and validity of the patterns present. For this research, these patterns were assessed quantitatively, with high scores on assessments representing a well-developed mental model of ACC. This helps to clarify performance differences, whether between or within experimental conditions. The final stage of Chi’s (1997) protocol is repeating the entire coding process. This involves returning to the data, and engaging in each step again. To some extent,
this step has been completed thanks to the large numbers of revisions undertaken in finalizing the rubrics used for this research.
CHAPTER 4: FINDINGS

Data sources and learning resources utilized for this study include the Understand, Challenge, and Play resources, as well as the post-test. The Understand resource is a direct instruction tool, using text and images to help learners become familiar with adaptive cruise control (ACC). Text- and image-based scenarios form the bulk of the Challenge resource, which tasks learners with thinking about system function in a series of potentially dangerous situations based on ACC’s limitations. The Play resource leverages the plAyCC computer-based simulation and another set of scenarios oriented towards eliminating dangerous driving situations through changes to road design and traffic speed. Finally, the post-test includes two major sections: the first, free-response section primarily measures declarative knowledge about ACC, while the second, Likert-type section is focused instead on assessing learners’ mental models of ACC based on situational effectiveness and limitations of the system.

Due to the number of research questions and data sources included in this research, results from the data gathered are divided into a number of major sections. In the first section, I discuss the scoring and inter-rater reliability for the free-response questions included in the Challenge scenarios and post-tests. Then, I present descriptive statistics for the study’s learning assessments, including the Challenge scenarios, Play scenarios, and post-test. The final two sections of this chapter address the statistical analyses used to answer the two primary questions guiding this research. The first of these questions asks whether choice of sequence through open-educational resources (OERs) has an effect on the development of learners’ mental models, and is discussed in the third section of this chapter with relation to independent sample t-tests comparing group means on the study assessments. The second question attempts to determine if there is any relationship among the time spent on individual resources, the order in which
resources are viewed, and performance on the post-test. The fourth section of this chapter
discusses the regression analysis used to examine that second question, using data collected from
only the experimental (choice) group. Next, I discuss the results of a post-hoc, multivariate
Bonferroni procedure conducted in an attempt to clarify the results of the previous analysis.

As an additional source of data, this research sought to examine how and why subjects
made their specific sequential choices throughout the study process. Following each choice of
learning resource, but before engaging with that resource, subjects were asked a multiple-choice
question assessing their rationale. The results for these initial rationale questions are discussed
in the sixth section of this chapter. Following completion of all of the learning resources, but
before the post-test, subjects answered another series of questions. The first was an additional
multiple-choice question, asking subjects to look back on their overall rationale for their choices.
The remaining questions, which were free-response in nature, asked subjects what choices they
might make differently, as well as what types of choices they would like to see in a set of open
educational resources (OERs) like these. The sequence of questions within the study is
highlighted in Figure 5, while the multiple choice and free-response decision questions are
included in Appendices H and I, respectively. Subjects’ overall rationale for their choices is
considered in the final section of this chapter.

Overall, subjects in the control (non-choice) condition performed significantly better on
the post-test assessment than subjects in the experimental (choice) condition, per an independent
samples $t$-test of post-test scores ($t[82] = -2.116, p < .05, d = -0.462$). However, there was not
significance for $t$-tests of the Challenge and Play resource scenario problem scores. The multiple
regression analysis found a significant regression equation ($F(4,37) = 3.930, p < .05, R^2 = 0.28$)
for predicting post-test score within the experimental (choice) condition, though time spent on
the Understand resource was the only individually significant predictor of post-test performance \((p < .05)\). There are some apparent conflicts in these results, with non-sequential user choice appearing to have a negative effect on post-test performance despite the chosen order of resources not significantly predicting scores. These results are examined in more detail in subsequent sections.

**Interrater Reliability for Free-Response Challenge and Post-Test Questions**

As discussed previously, responses for the Challenge scenarios and post-test questions were scored by two independent coders using the rubrics included in Appendices D and G, respectively. Table 4 summarizes the nature of these questions, while they can be viewed in full as part of Appendices B and F. As the table shows, the Challenge scenarios present learners with a series of situational problems, in which they are asked to explain how the system will react and what a driver should do as a result. The post-test free-response questions, however, involve primarily declarative knowledge questions, including asking the learner to explain the flow of information within the ACC system.

Following initial coding of the answers to these free-response questions, coders discussed discrepancies and agreed upon final scores for statistical analysis. Interrater reliability for the initial coding was calculated using Cohen’s kappa (Landis & Koch, 1977), and is reported here for both the Challenge scenarios and post-test questions. Landis and Koch (1977) specify a benchmark scale for Cohen’s kappa, which includes all possible values ranging from zero to one. According to their scale, a value of Cohen’s kappa greater than 0.81 indicated nearly perfect interrater reliability (pg. 165). Altman’s (1991) more recent scale includes similar benchmarks and labels any value greater than 0.81 as very good interrater reliability. In this study, for the Challenge scenarios, the interrater reliability was found to be \(\kappa = 0.865 \ (p < .001)\), 95% CI
For the post-test questions, interrater reliability was found to be $\kappa = 0.945$ ($p < 0.001$), 95% CI (0.902, 0.988). These results highlight, in part, the experience of the raters. Both raters for the Challenge and post-test questions have worked previously with data generated from the same open educational resources used for this study (e.g., Valentine, Zhou, Moore, & DeVane, 2018), which helps explain the very high values for interrater reliability.

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Question Structure</th>
<th>Question Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenge</td>
<td>Explaining ACC’s reaction to a given situation</td>
<td>Situational</td>
</tr>
<tr>
<td>Challenge</td>
<td>Describing an ideal driver action</td>
<td>Situational</td>
</tr>
<tr>
<td>Post-test</td>
<td>Comparing ACC to conventional cruise control</td>
<td>Declarative</td>
</tr>
<tr>
<td>Post-test</td>
<td>Explaining ACC’s reaction to slower vehicles</td>
<td>Situational</td>
</tr>
<tr>
<td>Post-test</td>
<td>Describing ACC parameters</td>
<td>Declarative</td>
</tr>
<tr>
<td>Post-test</td>
<td>Explaining the flow of information across ACC components/functions</td>
<td>Declarative</td>
</tr>
</tbody>
</table>

Table 4. Challenge and Post-Test Free-Response Questions

Descriptive Statistics

Descriptive statistics relating to experimental and control group performance on the PlayCC scenarios, Challenge scenarios, and post-test are included in Table 5. Possible total points from each data source are listed, and are composites of the score on each item. The rubrics used for scoring the Challenge scenarios, Play scenarios, and post-test are included in Appendices D, E, and G, respectively. While many of the group means and standard deviations are very similar, a few stand out as potentially important. With regard to the Post-Test group
means, for example, the control group (13.905) outperformed the experimental group (12.560). However, this difference appears to be explained by the control group’s higher mean (8.179 compared to 6.774) on the free-response section of the Post-Test, while the experimental (5.786) and control (5.726) groups’ scores on the Likert-type items were almost identical. These two sections of the post-test differ from each other substantially, with the free-response questions primarily assessing declarative knowledge while the Likert-type items were more situational in nature. The other group means, for the Challenge and Play scenarios, were nearly identical.

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Condition</th>
<th>N</th>
<th>M</th>
<th>Possible Points</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Play Scenarios</td>
<td>Choice (E)</td>
<td>42</td>
<td>1.464</td>
<td>3</td>
<td>1.202</td>
</tr>
<tr>
<td></td>
<td>Non-choice (C)</td>
<td>42</td>
<td>1.429</td>
<td>3</td>
<td>1.309</td>
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<tr>
<td>Challenge</td>
<td>Choice (E)</td>
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<td>8.52</td>
<td>11</td>
<td>2.689</td>
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<tr>
<td>Scenarios</td>
<td>Non-choice (C)</td>
<td>42</td>
<td>8.95</td>
<td>11</td>
<td>1.807</td>
</tr>
<tr>
<td></td>
<td>Choice (E)</td>
<td>42</td>
<td>12.560</td>
<td>24</td>
<td>3.000</td>
</tr>
<tr>
<td>Post-test Total</td>
<td>Non-choice (C)</td>
<td>42</td>
<td>13.905</td>
<td>24</td>
<td>2.823</td>
</tr>
<tr>
<td>Post-test</td>
<td>Choice (E)</td>
<td>42</td>
<td>5.786</td>
<td>12</td>
<td>1.523</td>
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<tr>
<td>(Likert-type)</td>
<td>Non-choice (C)</td>
<td>42</td>
<td>5.726</td>
<td>12</td>
<td>1.650</td>
</tr>
<tr>
<td>Post-test Free-Response</td>
<td>Choice (E)</td>
<td>42</td>
<td>6.774</td>
<td>12</td>
<td>2.338</td>
</tr>
<tr>
<td></td>
<td>Non-choice (C)</td>
<td>42</td>
<td>8.179</td>
<td>12</td>
<td>2.021</td>
</tr>
</tbody>
</table>

Table 5. Descriptive Statistics for PlayCC, Challenge, and Post-Test

Statistical Analysis of Group Means

As discussed in the Methodology chapter, this study sought to use two-tailed, independent sample t-tests to investigate the effect, if any, that non-sequential user choice in OERs has on the development of mental models of ACC. These t-tests were completed to assess
any group differences in Play scenario scores, Challenge scenario scores, and post-test scores.
The results of this analysis are discussed below and summarized in Table 6. All t-tests were conducted at the .05 level of significance.

The independent sample t-test showed that the control (non-choice) group had significantly higher scores on the post-test than the experimental (choice) group ($t[82] = -2.116$, $p < .05$, $d = -0.462$), indicated that the control group performed better on the post-test. This difference is largely explained by the control group’s higher scores on the free-response (declarative) section of the post-test, and not by any difference in performance on the Likert-type (situational) section. The group differences found on the Play ($t[82] = .130$, $p = .897$) and Challenge ($t[82] = -.857$, $p = .394$) were not significant, which was unsurprising given the small size of the mean differences.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Group</th>
<th>95% CI for Mean Difference</th>
<th>t</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>PlayCC</td>
<td>Non-choice (C)</td>
<td>1.429, 1.309, 42</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Choice (E)</td>
<td>1.464, 1.202, 42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Challenge</td>
<td>Non-choice (C)</td>
<td>8.950, 1.807, 42</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Choice (E)</td>
<td>8.520, 2.689, 42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-test</td>
<td>Non-choice (C)</td>
<td>13.905, 2.823, 42</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Choice (E)</td>
<td>12.560, 3.000, 42</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Comparison of Group Means for Challenge, Play, and Post-Test Questions *p < .05

The present results point to a negative effect of non-sequential user choice on learning about ACC from open educational resources, at least for this sample. While the availability of choice did not seem to have an impact on questions associated with subject’s trust of ACC, as demonstrated by a lack of significance for the Challenge and Play questions, as well as the mental model-oriented section of the post-test, it did appear to have a detrimental effect on subjects’ development of factual knowledge, as indicated by significance of group differences for the post-test on the whole.
Regression Analysis

In order to investigate any relationship among time spent per learning resource, chosen sequential order of resources, and post-test scores, a multiple linear regression analysis was conducted with time variables (Understand time, Play time, and Challenge time) and chosen sequential order as predictors of the post-test score outcome variable among subjects in the experimental condition. This analysis was only completed with data from the experimental (choice) condition, as timing data were not collected for the control (non-choice) subjects. The results of this analysis are summarized in Table 7, and discussed below. Descriptive statistics for the timing variables are included in Table 8, while the order codes and their frequency are summarized in Table 9. Subjects on average spent substantially longer on the Challenge and Play scenario resources than on the Understand resource, but the standard deviation of time spent on those scenario resources was much higher than that of the Understand resource.

The multiple linear regression analysis was calculated to predict post-test scores based on Understand time, Challenge time, Play time, and chosen sequential order of resources. This analysis found a significant regression equation (F(4,37) = 3.930, p < .05) with an R² of 0.298. Predicted post-test score is equal to 8.745 + 0.446(Chosen Sequential Order) + 0.023(Understand Time) – 0.002(Play Time) + 0.002(Challenge Time), where chosen sequential order is coded quantitatively as indicated in Table 9, and time variables are measured in seconds. Understand time was the only significant individual predictor of post-test score (p < .05).

<table>
<thead>
<tr>
<th>Predictor</th>
<th>B</th>
<th>SE B</th>
<th>Adjusted B</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenge time</td>
<td>.002</td>
<td>.002</td>
<td>.167</td>
<td>.976</td>
<td>.335</td>
</tr>
<tr>
<td>Play time</td>
<td>-.002</td>
<td>.002</td>
<td>-.096</td>
<td>-.616</td>
<td>.542</td>
</tr>
<tr>
<td>Understand time</td>
<td>.023</td>
<td>.009</td>
<td>.430</td>
<td>2.700</td>
<td>.010</td>
</tr>
<tr>
<td>Chosen sequential order</td>
<td>.446</td>
<td>.358</td>
<td>.175</td>
<td>1.245</td>
<td>.221</td>
</tr>
</tbody>
</table>

Table 7. Multiple Regression Analysis Results

Note: R² = .298 (p < .05); Adjusted R² = .222
These results indicate that, together, time spent per resource and chosen sequential order are able to explain roughly 30% of the variation in post-test score, within this sample.

Understand time has the strongest, significant individual relationship with post-test score, while the other predictors have weak, non-significant relationships with it.

### Data Source

<table>
<thead>
<tr>
<th>Data Source</th>
<th>N</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenge time (sec)</td>
<td>42</td>
<td>467.02</td>
<td>187.74</td>
</tr>
<tr>
<td>Play time (sec)</td>
<td>42</td>
<td>635.02</td>
<td>286.96</td>
</tr>
<tr>
<td>Understand time (sec)</td>
<td>42</td>
<td>106.74</td>
<td>54.29</td>
</tr>
</tbody>
</table>

Table 8. Descriptive Statistics – Resource Timing

<table>
<thead>
<tr>
<th>Order Code</th>
<th>Order of Resources</th>
<th>Frequency of Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Understand, Challenge, Play</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>Understand, Play, Challenge</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>Challenge, Play, Understand</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Challenge, Understand, Play</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Play, Understand, Challenge</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Play, Challenge, Understand</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 9. Chosen Sequential Order Codes

Contrary to the expectation of the researcher, chosen sequential order was not a significant predictor of performance on the post-test. However, as Table 9 shows, the choice of sequential order was dominated by two specific sequences, likely restricting the possibility of finding an individually significant result for chosen sequential order as a predictor. Two order codes (3 and 6) were not chosen by any subjects, while all but seven of the subjects chose to complete the Understand section first (codes 1 and 2). In fact, the linear order presented to the control group (coded as order 2) was chosen by more than half of the subjects in the
experimental group (23/42). In order to further examine the results of the regression analysis and the \( t \)-tests, a post-hoc analysis was conducted.

**Post-Hoc Bonferroni Procedure**

The results of both the \( t \)-tests and the multiple regression analysis left open an important question, however. If chosen sequential order was not a significant predictor of post-test performance, where did the negative effect of non-sequential user choice come from? As Table 9 shows, more than half of subjects in the experimental (choice) group (23/42) chose the same order of resources that the subjects in the control (non-choice) group completed, while two of the possible orders were never chosen (those with the Understand resource last). The particular distribution of chosen orders raised the possibility that specific sequences could have led to poorer learning but not appeared as significant in the regression analysis due to a low number of subjects having chosen those sequences. To assess this possibility, a post-hoc, multivariate Bonferroni procedure was conducted (\( \alpha = .05 \)). Using the order codes in Table 9, along with the control group as an additional order code, group means on the post-test (overall) and its individual sections were compared.

When considering the post-test as a whole, neither the full model (\( p = .104 \)) nor any of the order code comparisons were significant, but the comparison of the control group to Order Code 1 (Understand, Challenge, Play) was approaching significance (\( p = .069 \)). However, when examining just the declarative knowledge section of the post-test, both the overall model (\( p = .028 \)) and the comparison of the control group to Order Code 1 were significant (\( p = .020 \)). No other comparisons, including all comparisons on the mental model-oriented Likert-type section, were significant. In other words, the primary source of the group differences when comparing the experimental and control groups appears to be the subjects in Order Code 1, and only on the
declarative knowledge section of the post-test. The significant result for the declarative knowledge section of the post-test suggests that subjects’ chosen sequential order may be important, while the non-significant results for all other comparisons may leave that question open. Another important question that these results raise, then, is why subjects made the choices they did with regard to sequence. This question is discussed in the next two sections.

Figure 5. Sequence of Rationale Questions

**Initial Rationale for Choices**

After every choice, but before interacting with the chosen resource, study participants in the experimental condition were asked to indicate why they made the choice of learning resource that they did. These items were multiple choice-type questions, with the option to explain in a free-response format if the subject preferred. Table 10 provides a summary of the rationale subjects used to make their decisions. As the table shows, for each choice, at least half of the subjects indicated that they made their decision to aid their understanding of ACC.

In addition to the most typical answer, Table 10 indicates the most common resource chosen when each type of rationale was used. As an example, for the first choice of resource, 33 subjects (78.57% of the total) indicated that they made their decision based on what they believed would help them understand ACC. Of those 33, 97% (32 subjects) chose the
Understand resource for that choice. Perhaps unsurprisingly, for example, the Play section was the only resource ever chosen because it appeared fun to the study subjects.

<table>
<thead>
<tr>
<th>Rationale</th>
<th>Choice Stage</th>
<th>Number of responses</th>
<th>Percent of total responses</th>
<th>Most Commonly Chosen Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chosen in listed order</td>
<td>1</td>
<td>2</td>
<td>4.76%</td>
<td>Challenge/Play (50%)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>4.76%</td>
<td>Play/Understand (50%)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>9</td>
<td>21.43%</td>
<td>Challenge (89%)</td>
</tr>
<tr>
<td>Liked the image</td>
<td>1</td>
<td>0</td>
<td>0%</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0%</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>0%</td>
<td>N/A</td>
</tr>
<tr>
<td>Liked the description</td>
<td>1</td>
<td>1</td>
<td>2.38%</td>
<td>Understand (100%)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4</td>
<td>9.52%</td>
<td>Play (50%)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>0%</td>
<td>N/A</td>
</tr>
<tr>
<td>Help me understand ACC</td>
<td>1</td>
<td>33</td>
<td>78.57%</td>
<td>Understand (97%)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>21</td>
<td>50%</td>
<td>Play (48%)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>29</td>
<td>69.05%</td>
<td>Challenge (62%)</td>
</tr>
<tr>
<td>Looked like the most fun</td>
<td>1</td>
<td>2</td>
<td>4.76%</td>
<td>Play (100%)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4</td>
<td>9.52%</td>
<td>Play (100%)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>0%</td>
<td>N/A</td>
</tr>
<tr>
<td>Chosen Randomly</td>
<td>1</td>
<td>1</td>
<td>2.38%</td>
<td>Understand (100%)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4</td>
<td>9.52%</td>
<td>Understand/Challenge (50%)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>2.38%</td>
<td>Play (100%)</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>3</td>
<td>7.14%</td>
<td>Understand (67%)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>7</td>
<td>16.67%</td>
<td>Play (86%)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3</td>
<td>7.14%</td>
<td>Play (67%)</td>
</tr>
</tbody>
</table>

Table 10. Initial Choice Rationale
While most subjects made their choices based on improving their understanding of ACC, the most common specific resource chosen by subjects using that rationale varied at each stage of the study. The progression of this change (Understand, Play, Challenge) is a match for the linear order followed by subjects in the control (non-choice) condition. Again, this indicates that while good intentions might be the norm, the specific choices being made do not appear to have a large impact on eventual learning.

<table>
<thead>
<tr>
<th>Rationale</th>
<th>Number of responses</th>
<th>Percent of total responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chosen in listed order</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Liked the images</td>
<td>2</td>
<td>4.76%</td>
</tr>
<tr>
<td>Liked the descriptions</td>
<td>3</td>
<td>7.14%</td>
</tr>
<tr>
<td>Help me understand ACC</td>
<td>34</td>
<td>80.95%</td>
</tr>
<tr>
<td>Looked like the most fun</td>
<td>1</td>
<td>2.38%</td>
</tr>
<tr>
<td>Chosen Randomly</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>4.76%</td>
</tr>
</tbody>
</table>

Table 11. Overall Choice Rationale

**Overall Rationale for Choices**

Table 11 summarizes subjects’ responses to the overall rationale multiple-choice question. This question is included for reference in Appendix H. As with the individual, initial rationale questions, a large majority of subjects – roughly 80% – indicated that they made their choices based on what they believed would best help them understand ACC. Unlike the initial rationale questions, however, no subjects indicated that they chose based on the listed order of resources or randomly, and a small number of subjects indicated that they made their choices based on how well they liked the images used to represent each choice. As Table 10 shows, no subject indicated during the initial rationale questions that they made choices based on images.
In addition to the set choices, two subjects indicated another reason for the choices that they made. One subject indicated that they made their first choice based on the consent process (during which they felt the plAyCC simulation was explained more than the other resources). The second subject stated that they chose the Challenge resource first because they wanted to complete the most difficult option first, and then chose randomly after that first choice.

**Free-Response Coding**

Following the learning activities, but before the post-test, subjects in the experimental (choice) condition were asked a pair of free-response questions to gauge their reaction to the learning resources. Specifically, these questions asked what changes, if any, the subject would make to the choices they made and what changes/additional choices, if any, they would like to see added to the learning activities they created. In order to assess what changes subjects would make, either to their own process or to the entire learning environment, thematic codes were developed for each question to categorize responses. Responses grouped by thematic code are included in Tables 12 and 13. These codes were developed based on the answers provided by subjects on the free-response questions asked regarding changes they would make to their own learning or in future learning environments, and address major themes that emerged in those responses. The codes are discussed further below.

The first free-response question that subjects were presented with asked subjects to indicate if there were any choices that they had made that they would change, if given the opportunity. As Table 12 indicates, more than half (25/42) of the subjects in the experimental condition did not indicate any changes that they would make. Among those that did indicate changes, a large majority (13/17) said that they would change the order of resources in some way. For example, one subject noted that they “would have chose [sic] the challenge (my last
pick) before the play (my second pick) … [because] it would have been more beneficial learning some of the drawbacks of the ACC before I did the play simulation.” Of these 13 who would change the order, 9/13 would have moved Challenge before Play, while keeping Understand first. Among the remaining four, two subjects stated they would choose the Play resource earlier, while one noted that they would have preferred to read the Understand resource earlier. The single remaining subject indicated that they would skip the Understand section altogether. A small number of subjects also indicated that they would either spend more time on particular aspects of one of the resources (2/42), or that they would read instructions more carefully to benefit more (2/42).

A substantial number of subjects wanting to make some change to their process, including 13 indicating that they would change the order, may indicate something about the effects of user choice on post-test performance, as well as the significance (or lack thereof) of chosen sequential order as a predictor for that performance. Doubt over the correct order, or concern that they could have learned more, may have contributed to poorer post-test scores among the experimental group. However, the lack of significance for chosen sequential order as a predictor is still difficult to examine in-depth, since there was so little variation in chosen sequential order among subjects. Perhaps the changes that these subjects wished they could make would have produced a change.

For the second free-response question, subjects were asked what additional choices they would like to see included in a learning environment like the one they had engaged with. This question produced a slightly wider array of responses than the previous question, which is reflected in a slightly larger code set, as detailed in Table 13. While a substantial number of
participants (12/42) indicated that they would not want any changes to be made to the learning environment, the majority had at least one suggestion.

<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
<th>Prevalence</th>
<th>Example</th>
</tr>
</thead>
</table>
| O    | **Order Changes**  
Subject notes that they would change the order of resources that they chose | 13/42 | “I would switch the sequence of the 2\textsuperscript{nd} and 3\textsuperscript{rd} activity.” |
| I    | **Instructions**  
Subjects indicate that they would more carefully read instructions, but not necessarily change anything else | 2/42 | “I believe the first challenge I didn’t read the first question correctly” |
| T    | **Time**  
Subject states that they would spend more time on certain resources, but does not indicate that they would change order | 2/42 | “Play around with the simulation more” |
| NA   | **None**  
Subjects do not indicate that they would make any changes to their learning process | 25/42 | “Wouldn’t make any changes. I picked the order that I did so I could understand them the most.” |

**Table 12. Coding Scheme for Changes to Subject Choices**

The most common type of comment (15/42) involved suggestions to change or update the nature/medium of instruction, such as including videos or audio recordings in addition to existing materials. A handful of subjects (8/42) also indicated that they would like to see additional controls or user perspectives in the Play simulation. For example, one subject mentioned that they thought, “It would be interesting to have a driver’s perspective, so instead of looking from
above you would be looking at the street in front of you. Instead of a using a mouse and to change the speed you could have a steering wheel in front of you.” Another common theme was a suggestion for new scenarios/situations in which to test ACC (5/42 subjects). One subject in particular suggested “a simulation in which pedestrians are involved and how they affect ACC.” The final, small group (2/42) suggested a feedback system, in which learners would receive information about correct answers following the completion of scenario problems. Many of these suggestions involve learners receiving more information somehow (feedback, different scenarios, different perspectives), which could point to there actually not being enough choice.

<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
<th>Prevalence</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Nature of Instruction</td>
<td>15/42</td>
<td>“A video of how ACC works instead of pictures”</td>
</tr>
<tr>
<td>M</td>
<td>More choices/scenarios</td>
<td>5/42</td>
<td>“Weather conditions, different sized cars, driving experience (parents vs teens)”</td>
</tr>
<tr>
<td>F</td>
<td>Feedback</td>
<td>2/42</td>
<td>“I would like to see free-response choices, which then are answered on the next slide, so that you know what you are looking for going forward”</td>
</tr>
<tr>
<td>C-P</td>
<td>Controls &amp; Perspective</td>
<td>8/42</td>
<td>“Maybe a first-person type of view from the drivers [sic] to see how well the ACC adapts when you are actually viewing it from the car.”</td>
</tr>
<tr>
<td>NA</td>
<td>None</td>
<td>12/42</td>
<td>“There are no other choices I can think of”</td>
</tr>
</tbody>
</table>

Table 13. Coding Scheme for Suggestions for Future Learning Environments
CHAPTER 5: DISCUSSION & CONCLUSIONS

The present research includes a substantial amount of data, as well as a wide-ranging set of results. This chapter, then, seeks to discuss and examine those results in terms of their relevance both to the current research questions and the wider body of research literature. To that aim, this chapter includes nine major sections, with each seeking to address either an important aspect of the results or the implications that can be drawn from them.

First, I explore why there was a negative effect of non-sequential user choice on post-test performance with regard to declarative knowledge but not mental models. I do this by examining possible explanations for this finding in the existing research literature. These possible explanations include the possibilities of choice overload, the influence of subjects’ poor decision-making, frustration and confusion due to the unguided nature of the learning process, and apathy among subjects as a result of user choice. Second, with regard to the multiple regression analysis conducted as part of this study, I inquire into why time spent on the Understand resource was a significant predictor of post-test performance despite a lack of significance for subjects’ chosen sequential order of learning resources. Next, I attempt to address the apparent incongruence between the two findings mentioned above: that non-sequential user choice had a negative effect on post-test performance, but that subjects’ chosen sequential order was not a significant predictor of that performance. The source of the negative effect of user choice, as indicated by a post-hoc Bonferroni procedure, is also considered. Then, I discuss the implications of these findings for the existing design literature. In the next section, I examine the relationship of this study’s findings to the larger field of educational psychology. I then propose areas of future research and discuss the limitations of this study. Finally, I consider
the overall implications of this study and the need for additional research to address issues of non-sequential user choice in open learning environments.

**Explaining the Negative Effect of User Choice**

The present research included two core research questions. In this section, I attempt to explain and interpret the results of the current study to provide an answer to the first of those questions. In the first question, I sought to investigate what effect, if any, non-sequential user choice had on the development of mental models of adaptive cruise control (ACC) when learning from open educational resources (OERs), as measured by a post-test assessment and a set of scenario problems embedded in two of the learning resources. Two-tailed, independent sample t-tests were conducted to compare the performance of the choice (experimental) and non-choice (control) groups on the Challenge scenarios, Play scenarios, and post-test assessment. A significant difference was found on the post-test assessment at the .05 level, with the non-choice group showing better performance on the post-test than the choice group. No significance was found for the Challenge or Play scenarios. In other words, the presence of non-sequential user choice had a significant, negative effect on post-test performance. As the post-test was primary measure for the first research question, this indicates that non-sequential user choice had a detrimental effect on these subjects’ development of mental models of ACC. The specific results are discussed further in Chapter 4.

In contrast to the expectations of the researcher, the presence of non-sequential user choice appeared to have a negative effect on performance on the post-test, while no significant effect was found for either set of scenarios. An important issue to consider, then, is why the availability of choice would have a negative effect, particularly considering the growing support for expanded user choice in recent years. Four possible explanations for this negative effect are
discussed below and summarized in Table 14. These explanations include the risk of choice overload (e.g., Chernev, Böckenholt, & Goodman, 2015); the argument that learners may simply make poor choices of sequence, the amount of time spent per resource, or content (e.g., Brown, 2001); the possibility dangerous misconceptions fueled by frustration and confusion could develop in unfamiliar, high-choice environments (e.g., Kirschner, Sweller, & Clark, 2006); and the development of apathy due to the presence of substantial user choice (e.g., Garland & Noyes, 2004).

**Effects of Choice Overload on Post-Test Performance**

One possible explanation for the negative effect of non-sequential user choice comes from the literature on consumer behavior. As shown in a now-classic piece of research by Iyengar and Lepper (2000), excessive choice can lead to poor satisfaction with choices made in consumer settings as well as poor performance on academic work. In their original work, Iyengar and Lepper (2000) examined subjects’ eventual satisfaction with their choices of both food products (jams and chocolates) and optional classroom essays (various topics). Satisfaction was indicated differently for each set of choices, but was primarily measured through number of purchases (or lack thereof), a brief survey about enjoyment of, and regret over, eating chocolate, and the choice to write an optional classroom essay. In all three studies, subjects in the “limited” choice group were more satisfied than subjects in the “extensive” choice group. In addition, in the classroom essay study, subjects from the limited choice condition wrote significantly higher quality essays, on average, than those in the extensive choice condition. These results support the authors’ “choice overload” hypothesis, and suggest that providing too much choice may result in not only lower levels of satisfaction, but poorer performance on academic measures. Choice overload may contribute substantially to explaining the present results, considering that
subjects who were given the ability to choose their learning sequence performed worse on the post-test assessment than those who had the learning sequence chosen for them.

<table>
<thead>
<tr>
<th>Framework</th>
<th>Literature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Choice Overload</strong></td>
<td>Iyengar &amp; Lepper (2001); Chernev, Böckenholt, &amp; Goodman (2015)</td>
<td>When presented with a large number of choices, previous research indicates that both consumers and learners can become overloaded by choice. Consumers are less satisfied with their purchases and purchase fewer items, while learners are less satisfied with content choices and produce lower-quality work. In this study, subjects in the experimental (choice) condition may have experienced choice overload, resulting in reduced post-test performance. In online learning environments with substantial choice over content, time spent per resource, and sequence, learners may make poor choices about how to engage with content. Subjects in the experimental (choice) condition may have chosen unhelpful learning sequences, may have skipped important ideas in the learning process, or rushed through the resources to finish quickly. As a result, they may have learned less than the control (non-choice) condition, resulting in poorer performance.</td>
</tr>
<tr>
<td><strong>Poor Choices</strong></td>
<td>Brown (2001)</td>
<td>In unguided learning environments, learners may become frustrated and confused. In addition, misconceptions are more easily formed when there is little guidance. Subjects in the experimental (choice) condition may have had too little guidance, and developed misconceptions about the content. This could then lead to poorer post-test performance. Previous research suggests that when a learning process is identified as optional (as opposed to mandatory), fewer learners complete the learning task and learners tend to see the learning process as less valuable or important. In the present study, subjects in the experimental (choice) condition may have believed that the availability of non-sequential user choice indicated that the sequence and learning process were unimportant.</td>
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Table 14. Explaining the Negative Effect of User Choice
The “choice overload” effect has been confirmed by further research as well. Chernev, Böckenholt, and Goodman’s (2015) meta-analysis of research into choice overload is a useful reference point. In examining nearly 100 studies with over 7200 participants, the authors were able to not only confirm the presence of choice overload, but also suggest possible factors that can contribute to it. Important factors from this previous work for the present research include a high level of choice uncertainty and task difficulty.

One potential problem with the choice overload approach is the seeming lack of applicability to educational research. It is true that the majority of the existing choice overload literature has examined the effect choice has on consumer behavior (e.g., purchasing food). However, that research presents implications for, and even evidence of, the influence that choice overload can have in educational settings. In fact, in Iyengar and Lepper’s (2000) classic research, effects of choice overload on academic success were examined via the quality of written essays. Among students provided many choices of topic to write about (choice of content), essays were of poorer quality than those written by students provided only a small set of topics to choose from. While the present research leverages a different learning context (OERs as compared to a face-to-face college course) and is examining another type of choice (choice of sequence vs. choice of content), the connection is clear: choice overload can lead to poorer performance on educational measures.

One possibility in the present research is that the non-sequential user choice provided to subjects in the experimental condition may have resulted in an uncertain set of choices. Subjects were unfamiliar with adaptive cruise control (ACC), and may well have been unfamiliar with open educational resources (OERs). When pairing difficult learning tasks (in a content area which subjects had little to no knowledge about) with a relatively new type of environment, the
choice condition in the present study could have led subjects to experience choice overload. That choice overload may have then reduced satisfaction and performance on the eventual post-test assessment.

Unfortunately, the possibility of choice overload seems unlikely in this situation. In Iyengar and Lepper’s (2000) classic research, the “lower” level of choice included six possible choices, similar to the present study’s choice condition. In fact, the authors note that previous research indicates that “choice among relatively limited alternatives is more beneficial than no choice at all” (Iyengar & Lepper, 2000 pg. 996). This would seem to contradict the present findings, in which a limited set of sequential choices had a negative effect. Chernev, Böckenholt, and Goodman (2015) confirm the relatively high threshold for choice overload, noting that the vast majority of “large” sets of choices include at least 11-15 choices, while “small” sets often include as many as 10 choices. These discrepancies with the present research suggest that it is highly unlikely that choice overload is the reason for choice group’s poorer performance on the post-test.

**Poor Choices, Poor Post-Test Performance**

Another potential explanation for the negative effect of non-sequential user choice is the simple possibility of subjects making bad choices. Brown (2001) examined the effect of choice of time spent per learning module (including no time at all) in computer-based training modules relative to test-based learning outcomes. Brown found that the quality of learners’ choices regarding time spent on the learning process had a substantial effect on learning gains. In particular, poor choices about content and how much time to devote to learning are connected with poor learning outcomes. The author points out that “Learners may skip practice that is critical for building understanding of the material … [or] move quickly through training”
(Brown, 2001 pg. 290-291). In other words, when given the ability to make important decisions, learners’ have a large influence on their performance based on the specific decisions they make – high-quality choices lead to improved performance, while low-quality choices reduce it. While Brown (2001) did not consider non-sequential user choice specifically, the results related to skipping sections and time spent on learning seem especially important to the present research, particularly considering the use of time spent as a predictor of post-test success in this study. Brown’s findings indicate the need for further research investigating the effect of non-sequential user choice in computer-based learning, including the present research.

Taken at face value, the effect of users’ poor choices about learning sequences seems like a reasonable explanation for the present results. Subjects in the choice condition may have simply made poor choices when selecting the order of resources, they may have skipped through resources, or they could have moved too quickly through them to try to complete the learning process as soon as possible. Those poor-quality choices could then have been the tipping point between choice and non-choice groups, with regard to post-test performance.

Unfortunately, the results of the regression analysis appear to exclude poor choices as an explanation as well. While it is certainly possible that subjects in the choice condition did make poor choices, the lack of significance for the chosen sequential order predictor for predicting the post-test score indicates that any poor decisions were not influential enough to be able to predict (and so, presumably, affect) performance. This of course does not disprove the possibility that poor choice of sequence could affect learning, or reduce the need to additional research, but it does indicate that another explanation is needed for the present results.
Misconceptions, Confusion, and Frustration Due to Lack of Guidance

In addition to the possibility of choice overload and poor choices, it may be that the choice group performed worse on the post-test due to the frustration and confusion discussed by Kirschner, Sweller, and Clark (2006). The authors argue that learning environments with a high level of learner control can actually be detrimental, while more heavily guided learning environments may improve student learning due to a reduction of cognitive load and other factors. In addition, work by Brown and Campione (1994) suggests that unguided learning can be “dangerous,” and that learners “are quite adept at inventing … misconceptions” in unguided discovery learning settings that allow high levels of individual control (pg. 230). In such high-control situations, learners may learn ideas incorrectly and become frustrated with the learning environment due to confusion over how best to operate within that environment (Kirschner, Sweller, & Clark, 2006).

As a result of the dangers associated with unguided learning, Brown and Campione (1994) champion “guided discovery” learning, in which learners do have some control over the learning process, but with supervision and assistance from teachers and/or more experienced learners. The learning environment in the present research, on the other hand, gives choice of sequence to subjects in the experimental group while providing very little guidance. Although a research assistant was always present, they did not provide instructional support to subjects, meaning that study subjects largely engaged in an unguided learning process. This could have potentially led to the misconceptions (Brown & Campione, 1994) and/or frustration and confusion (Kirschner, Sweller, & Clark, 2006) that can occur in unguided learning environments. These issues could then be primary contributors to the choice group’s poorer performance on the post-test assessment.
One possible source of support for this argument in the present research comes from what subjects noted they would change about their choices, if given the chance. Nearly a third of subjects in the choice condition (13/42) indicated that they would change the order of resources that they chose. In addition, two subjects stated that they would increase the time they spent on specific resources, while another two noted they would read resource instructions more carefully. Such a large proportion of subjects desiring a change may suggest that they were unhappy with their choices and were confused or frustrated with those choices. The large number of subjects indicating that they would change the order in which they viewed resources is especially interesting here, as it further suggests either unhappiness with choices or confusion as to what would help the learning process most. One distinct possibility that arises from these results is that subjects may have benefitted from, and appreciated, more guidance in making their choices regarding learning sequence. If subjects were, in fact, unsure about what was involved in each learning resource, it is likely that additional guidance could have helped subjects by eliminating confusion or misconceptions about the materials themselves. Guidance could also potentially reduce the prevalence of misconceptions about ACC by improving the learning process and helping to establish important concepts earlier. The present research does not appear to specifically contradict this explanation, unlike the previous two.

**Development of Choice Apathy as a Result of User Choice**

Another possible explanation of the negative effect of non-sequential user choice is a lack of investment in the learning process as a result of the choices provided to subjects in the choice (experimental) condition. It is certainly possible that factors in the learning environment, combined with the non-sequential user choice provided, could have resulted in a sort of “choice apathy” for research subjects. This choice apathy approach has support in the research literature.
Garland and Noyes (2004), for example, examined the use of computer-based learning programs for learning economics. In particular, the researchers sought to investigate effects of allowing learners to choose whether or not to complete the learning process (optional learning) or forcing them to complete it (mandatory learning). Not only did substantially more subjects in the mandatory (no choice) learning condition complete the learning process, but the subjects in the mandatory condition also tended to believe that the learning program was more valuable than the students in the optional learning condition. Furthermore, nearly half of the subjects in the optional learning condition who did not use the program indicated that they did not because they “could not be bothered” or “could not see the need” for the program (Garland & Noyes, 2004, pg. 271). As the authors go on to note, the mandatory learning (no choice) condition emphasized the importance and relevance of the learning environment, leading to more learner engagement. On the other hand, subjects in the optional condition, with more choice available, seemed to view the program as less important, resulting in less engagement and, therefore, less learning.

Subjects in the experimental (choice) condition in the present research were asked to choose the order of resources, but to still complete all of those resources. As a result, they may have been less invested in their choices as compared to subjects who followed the prescribed route in the control (non-choice) condition. For these subjects, the choices they made may have seemed less valuable or important, simply because they were allowed to make them. This lack of investment echoes the results of Garland and Noyes (2004), and may have impaired mental model development as a result of subjects not being as engaged in the learning process. In essence, by not investing in and engaging with the learning process as deeply, subjects in the experimental condition may have made less effort in crafting an accurate mental model than
subjects in the control condition. This effect could be a result of the presence of choice in the experimental condition downplaying the importance of the learning process.

This issue of choice apathy may have also been exacerbated by the small number of choices available. After all, more than 70% (30/42) subjects in the choice condition indicated that they would have liked to see at least one other type of choice included, ranging from different scenarios in existing tools to completely new methods of engaging with the content. This lack of satisfaction with the choices available could have furthered any choice apathy that was developing among subjects in the choice condition.

While none of the presented explanations appear perfect for explaining the negative effect of non-sequential user choice, they provide a starting point for considering the implications of that effect. From among these explanations, the most likely possibilities appear to be the presence of choice apathy and frustration or confusion as a result of too little guidance during the learning process. Regardless, the present results suggest that the presence of non-sequential user choice in OERs can have a detrimental effect on the development of mental models of ACC.

**Predicting Success with Chosen Order and Time Spent Learning**

The second core research question examined here was focused on the relationship, if any, among time spent on each learning resource (Understand, Challenge, and Play), order of viewed resources, and performance on the post-test. In order to assess this question, a multiple linear regression analysis was completed (as detailed in Chapter 4), using Understand time, Challenge time, Play time, and chosen sequential order as predictors for the post-test score outcome variable. Data were only available from the choice (experimental) condition for this analysis, as the non-choice (control) condition was recruited previously and time data had not been collected.
The overall model was significant at the .05 level, indicating that, together, these variables were significant predictors of post-test score within the choice group. Specifically, the model was able to predict roughly 30% of the variance in post-test score ($R^2 = .298$), which is a substantial amount. Among the predictors, however, only time spent on the Understand resource was an individually significant predictor of post-test score. Challenge time, Play time, and chosen sequential order were all non-significant on their own. These findings raise a number of topics of interest, three of which are discussed below. Specifically, I examine why chosen sequential order was not a significant predictor, reasons why Understand time was significant (but Challenge time and Play time were not), and possible areas of further analysis using these (or similar) instructional materials.

**Examining the Relationship Between Chosen Sequential Order and Post-Test Score**

The researcher originally believed that a significant model would be found with this regression analysis due to the apparent importance of the predictor variables in determining preparedness for the post-test assessment. For example, the time variables, ideally, represent the amount of effort and investment that a given learner invested in developing their mental model of ACC. These variables should, therefore, be strong predictors of later success. Additionally, learner’s choice of sequential order is at the core of this research, with the effect of non-sequential user choice being a primary focus of the study. It would be expected, particularly alongside a significant effect of choice, that chosen order would have a substantial effect on post-test success. With these factors in mind, it is unsurprising that the regression analysis produced a significant prediction model for post-test scores using the time and chosen sequential order variables. The model does provide surprises, however, with the lack of significance of chosen sequential order, and the lone significance of Understand time as a predictor.
Perhaps the best explanation for the lack of significance of chosen sequential order variable as a predictor of post-test score comes from the number of choices made available to subjects. Just as there were too few choices to justifiably argue that choice overload (e.g., Iyengar & Lepper 2000) was a viable explanation of the negative effect of non-sequential user choice, the small number of choices here may have impacted the viability of chosen sequential order as a predictor. With only three resources to choose from, and with clear descriptions indicating that the Understand resource would help subjects learn about ACC, the dominance of Understand as the first choice fits well with subjects’ reported rationale of choosing their learning sequence based on how they could best learn about the system. As a result, the two most common chosen sequential orders are not surprising, and the data available for this variable become inherently limited. With only two primary chosen sequential orders, comparisons among all possible orders become substantially more difficult, reducing the possibility of significance.

This insight provides a reasonable explanation for why chosen sequential order was not an individually significant predictor of post-test performance. However, it still leaves two questions open regarding the regression analysis on the whole. The first, regarding Understand time being found to be the only individually significant predictor, is discussed below. The second, the apparent incongruence between the t-test and multiple regression analyses, is discussed in the third major section of this chapter.

**Understand Time, Instructional Alignment, & Mental Models**

The second notable finding from the regression analysis was the sole significance of time spent on the Understand resource as a predictor of post-test score. This section of the chapter seeks to address why time spent on the Understand section was a significant predictor of post-
test success, based on the alignment of the Understand section with the questions asked on the post-test. In addition to this specific examination of alignment, this section will also discuss the general alignment, or lack thereof, of the instruction with the post-test assessment. This discussion may allow for further recognition of why only Understand time, and not Challenge or Play time, was a significant predictor of post-test score.

Before examining the potential effects of instructional alignment, it is worthwhile to define the term as it is used here. For the present discussion, instructional alignment may be conceptualized as the level of similarity between a set of instructional materials and the assessment(s) used to measure learning from those materials (Cohen, 1987). In other words, the more similar the Understand resource is to the post-test, the more highly aligned the resource is with the post-test. As one example, the How to Use It section of the Understand resource tells learners that “you will have to start by setting a cruising speed and a following distance to the car ahead,” before going on to describe, in detail, how to establish these settings. On the post-test, one of the free-response questions specifically asks learners to identify the two parameters they need to set to use ACC. Important ideas from the Challenge scenario problems, on the other hand, such as the fact that an ACC system may not react to a car merging into your lane, are not assessed within the free-response section of the post-test. Based on this single example, at least, it appears as though the Understand resource would be more highly aligned with the post-test than the Challenge resource.

Another underlying issue for this discussion is the development of mental models of ACC from these learning resources. As previously discussed, and as defined by Norman (1983), mental models are practical, cognitive frameworks that are applied to real-world systems when interacting with those systems. The learning resources used in this research were designed with
the development of accurate mental models of ACC as a primary goal, along with knowledge of ACC systems and their components. Per previous research (e.g., Beggiato & Krems, 2013), mental models of ACC can be assessed via their connection to system trust. That is, if a user trusts an ACC system in situations in which the system functions well – and does not trust it in the situations in which the system will likely fail – then that user can be said to have an accurate mental model of ACC.

Two of the learning resources used in the present research (Challenge and Play) were designed to help develop accurate mental models by highlighting the situations in which ACC would not perform well (limitations of the system), while the other resource (Understand) supported users’ acquisition of declarative knowledge about ACC. The post-test assessment is similarly divided. The first section, which was comprised of free-response questions, primarily assessed users’ factual knowledge of ACC, including asking users to identify major components and explain the system’s main function. The second section instead utilized a set Likert-type items (adapted from Beggiato & Krems, 2013) to assess users’ trust of ACC in various situations, and therefore their mental models of the system. Together, instructional alignment and the differing goals of resources with regard to mental model development may explain the issues surrounding the results of the present study’s regression analysis.

The first issue to consider in examining the alignment of instructional methods – including the mental model and declarative knowledge resources – with study assessments is why the Understand time variable was such a strong predictor of post-test score. The Understand resource, as previously detailed, is a text- and image-based direct instruction tool designed to introduce learners to the basic concepts of ACC systems. The resource primarily presents instructions about how to use ACC, as well as facts about its functions, components, and
settings. The majority of the free-response section of the post-test is focused upon assessing declarative knowledge of ACC systems, including basic characteristics, uses, and modes of operation. There appears to be a strong alignment between the content, and instructional method, associated with the Understand resource and the post-test’s assessment of declarative knowledge of ACC. This close alignment between instructional method and assessment may help explain why the Understand time variable was a significant predictor of post-test score. Essentially, the more time a given subject spent learning from the Understand section, the more of that content we would expect them to learn. With the strong alignment between the Understand section and the post-test, that extra learning would then contribute to a higher score on the post-test.

The close alignment between the Understand resource and the post-test raises an interesting question: why were Challenge and Play time not significant predictors of post-test score? Despite the alignment between the Understand resource and the post-test, there appears to be a substantial misalignment among the Challenge resource, Play resource, and post-test. With few exceptions, the post-test (especially the free-response section) is heavily oriented towards declarative knowledge about ACC’s components and functions. The Challenge and Play resources, on the other hand, are primarily focused on situational applications of knowledge, including understanding the usefulness, or lack thereof, of ACC in various situations meant to highlight the limitations of the system. In fact, the Challenge and Play resources align more closely with each other, and with the goal of mental model formation, than they do with the post-test assessment. The result of this is that while it is entirely possible that performance on these two resources could be strongly related, it is unlikely that the time spent on either would have a substantial effect on performance on the post-test due to the primary focus of the post-test
(especially the first section) on declarative knowledge instead of mental model formation. At least with these materials and this post-test, then, it is a perfectly reasonable finding that only Understand time is a significant predictor of post-test success. Future work might include an updated post-test with items that align more closely with the mental model development goal of the Challenge and Play resources in order to address this design concern.

**Future Analyses Based on These Instructional Materials**

This research and its findings present a number of opportunities for future research and analyses using the same – or similar – instructional materials. Three major areas in particular may be especially valuable to consider, based on the present study’s findings. First, a larger sample size may improve the viability of chosen sequential order data. Second, providing additional choices throughout the learning process may further increase the value of non-sequential user choice in predicting performance. Finally, it may be useful to include an examination of the relationship among Play resource score, Challenge resource score, and chosen sequential order. Each of these areas for future analysis are discussed below.

One of the primary concerns that this researcher has regarding the present study’s findings is related to the lack of significance of chosen sequential order as a predictor for post-test performance. While there are a number of factors at play, perhaps the most substantial issue affecting the possibility of finding significance is a lack of diverse chosen orders among the subjects in the choice condition. Although there is no guarantee that future subjects’ choices would be more diverse, a larger sample size may produce a wider range of chosen sequential orders, allowing for a more realistic analysis of the predictive power, if any, of this variable.

In addition to increasing sample size, providing additional choices about resources may also increase the viability of chosen sequential order as a predictor of post-test performance.
This could be accomplished in a number of ways. With existing materials, individual resources could potentially be split into multiple, smaller resources. For example, each of the four Challenge scenarios could be included as its own resource. There are risks associated with this approach, however, including substantially increasing the complexity of data analysis (and/or increasing the number of subjects needed for sufficient power) and causing loss of fidelity of existing resources (e.g., the Play scenarios were designed to be completed in a particular order). The other main option would be to develop and include additional resources. When asked about choices they would like to see in online learning environments like that used in this study, a majority of subjects (28/42) suggested some sort of major addition or change, including new instructional media, additional scenarios, or varied perspectives on existing materials. Such additions could increase the number of choices available, potentially creating a more diverse set of chosen sequential orders for analysis.

Finally, it may be worth examining the relationship among the Play resource, Challenge resource, and chosen sequential order, including the amount of time spent on each resource. As mentioned earlier in this chapter, the Play and Challenge resources (and their embedded scenario problems) appear to align more closely with each other than with the declarative knowledge section of the post-test assessment. In addition, the primary variations that did exist in subjects’ chosen sequential orders were with regard to the ordering of these two resources, with Understand almost always chosen earlier than either Challenge or Play. Together, these factors suggest the possibility that these resources and the order in which they are viewed could be more likely to have a strong relationship with each other than they do with post-test performance. Overall, these potential areas for new research or analysis could allow further examination of the effects of non-sequential user choice even with the same materials used in the present research.
These new investigations may shed more light on the importance, or lack thereof, of providing access to this type of choice when learning from open educational resources.

**Effect of User Choice vs. Lack of Chosen Sequential Order Significance**

The most surprising finding, to the researcher, from the multiple regression analysis was the lack of significance of the chosen sequential order predictor variable. Particularly with the significant, negative effect of non-sequential user choice on post-test performance, the lack of significance for chosen sequential order as a predictor of that performance seems especially strange. With a negative effect of user choice, this researcher would have expected to see certain chosen sequential orders having a large effect on post-test score. Below, I examine one possible reason for this apparent incongruence between results, as well as a connection between the regression results and the rationale used by subjects in the choice (experimental) group.

Thankfully, user choice data collected from the choice group may provide insight as to how and why the disparity may have occurred between the negative effect of non-sequential user choice and the lack of significance of chosen sequential order. In re-examining Table 9 (pg. 45), it is clear that chosen sequential order was largely dominated by two specific sequences (Order Codes 1 and 2). The most common of these sequences, represented by Order Code 2, was actually the same sequence that subjects in the non-choice (control) group followed (Understand, Play, Challenge). The second most common sequence simply reversed the order of the Challenge and Play resources (Understand, Challenge, Play).

This dominance is also reflected in the choices subjects indicated they would change if given the chance – the majority of those who stated they would make a change were interested in changing the order of these two resources, while leaving the Understand resource at the beginning of the process. Because both of these common sequences are so similar (with
Understand serving as the subjects’ introduction to ACC), it is perhaps no longer surprising that chosen sequential order was not a significant predictor of post-test performance. In other words, there is so little data associated with other possible orders that it would be nearly impossible to find significance. With this in mind, the disparity between these two findings appears to simply be an artifact of a limited set of data for the chosen sequential order variable.

On a related note, the lack of significance for chosen sequential order as a predictor for post-test score has an interesting connection to subjects’ indicated rationale in choosing the order of resources. For every individual resource choice in the sequence (e.g., the first choice, the second choice, etc.), at least half of subjects indicated that they made their decision based on what they believed would help them best learn about ACC. At the end of the learning process, when considering the learning experience as a whole, roughly 80% of subjects made the claim that they made their decisions based on what would help them learn best. Despite the substantial majority believing that they were making choices to benefit their learning (or perhaps because of it), the order chosen by subjects does not appear to be particularly important, at least for the present study. This finding about chosen sequential order implies that while subjects may have good intentions in choosing resources, their specific choices appear to have little effect. While subjects may have believed that there was a “best” learning sequence, and even as the presence of non-sequential user choice had a significant negative effect, no one choice of sequence was a significant predictor of test performance. This paradox may be primarily due to the limited set of chosen orders (essentially, a limited dataset).

**Post-Hoc Analysis: Finding the Source of the User Choice Effect**

While the above discussion provides a reasonable explanation as to why chosen sequential order was not a significant predictor of post-test performance despite the apparent
negative effect of user choice, it still leaves open the question of where the negative effect of user choice came from. As discussed in more detail in Chapter 4, a post-hoc, multivariate Bonferroni procedure was conducted in an attempt to resolve that question. By comparing subjects based on the order in which they viewed resources, the analysis found a significant difference between the control (non-choice) group and the Order Code 1 (Understand, Challenge, Play) subjects from the experimental (choice) group on the declarative knowledge section of the post test. No significance was found for any other comparisons.

The major possibility in conducting this post-hoc analysis was that specific chosen sequential orders may have had an effect on subjects’ post-test performance, but not produced significance in the regression analysis due to the low number of subjects who chose each possible sequence. The results of the post-hoc analysis suggest that Order Code 1 may have been particularly influential for subjects’ learning, as this experimental (choice) subgroup performed significantly worse than the control while the other subgroups did not. This raises the possibility that, despite its lack of significance as a predictor for post-test performance, chosen sequential order may well be an important factor in determining how much users of these materials learn. In addition, these results do provide an explanation of the source of the experimental and control group differences on the post-test: the subjects in Order Code 1.

However, the possibility that chosen sequential order may still be important is tempered by two caveats. First, the sequential order difference was only significant for the declarative knowledge section of the post-test, and not the mental model section or overall post-test performance. Thus, while Order Code 1 may have hurt subjects’ acquisition of declarative knowledge, it did not appear to have an influence on mental model formation. Second, the non-significance of all other comparisons, including within the experimental group, raises questions
about the scope of the implications of the single significant result. One possible reason for the lack of significance for the other orders may be the small number of subjects that chose those orders. Therefore, additional research is necessary to more clearly determine the importance, or lack thereof, of chosen sequential order in learning environments like those used in this study.

A Negative Effect of User Choice and the Research Literature

Earlier sections of this discussion chapter examined possible explanations of the negative effect of non-sequential user choice, in some cases based on the available literature on user choice in general. This section, however, seeks to flip the focus, and instead examine the relationship of this finding to the existing literature, as well as the implications for that literature. In particular, the connection between the negative effect of non-sequential user choice is discussed in reference to the instructional design literature, which perhaps most strongly supports the findings of the present research.

As Alessi and Trollip (2001) indicated, the field of education has long believed that “learners may be able to make better sequencing decisions” than the designers or teachers attempting to help them learn. These authors, as well as others in the realm of instructional design (e.g., Brown, 2001; Hannafin, 1984; Kirschner, Sweller, & Clark, 2006) have suggested that, despite this widely-held belief, the presence of non-sequential user choice (or substantial user choice in general) may not always be beneficial. Alessi and Trollip (2001) and Hannafin (1984), for example, both note that low levels of structure are most effective for learners who are already familiar with a topic or content area, while learners who are unfamiliar with that topic may benefit from more structure (and, therefore, less choice).

Given the recruitment process for this study, the principle that low levels of structure are most effective for learners familiar with a content area may, in part, explain the negative effect of
non-sequential user choice. Subjects were specifically recruited based on a lack of knowledge of adaptive cruise control (ACC) in order to eliminate confounding variables related to prior knowledge, thereby reducing any potential need for a pre-test assessment. As a result of this lack of familiarity with ACC, subjects in this study may have been adversely affected by the lack of structure. Conversely, if this study had been focused on more knowledgeable participants, then perhaps the lower amount of structure may have been beneficial (Alessi & Trollip, 2001).

Similarly, it is likely that many of the subjects participating in the present research were also inexperienced with navigating open educational resources (OERs) in which they had control over learning sequence (or even OERs in general). Their lack of prior experience with the instructional medium may have compounded subjects’ difficulties arising from the lack of prior knowledge of adaptive cruise control.

Assuming this trend holds, these subjects may now be more well-equipped to engage with OERs or other learning environments focused on ACC that provide non-sequential user choice. During completion of the present research, subjects were exposed to new information about ACC and asked to apply it. This existing learning process would establish a baseline mental model of ACC systems, potentially aiding future learning. In addition, subjects would have gained experience with navigating and using OERs that provide non-sequential user choice, further preparing them for future learning. As suggested in previous literature (Alessi & Trollip, 2001; Hannafin, 1984), a choice-focused structure like that used in this study would likely be more beneficial following initial learning about ACC (or other topics), such as could be provided via the Understand resource. Completion of this set of materials (or previous experience before using these materials) would provide the prior knowledge base that appears necessary to benefit from substantial user choice.
These findings also hold significant value in re-examining the research literature on user choice in learning environments. As mentioned previously, the findings from the present research align well with the general recommendations of Alessi and Trollip (2001) and Hannafin (1984) in the tradition of instructional design. However, the overall results also contrast with those of more recent research, such as Kelly and Bishop (2014). These authors suggest that high-performing learners actually chose to engage with more guided (structured) forms of instruction than low-performing learners, which appears to contradict the traditional instructional design literature. In contrast with the findings of Kelly and Bishop (2014), the present research aligns with the past scholarship in instructional design which indicates that learners without much knowledge in a topic area (more closely aligned with the low-performing category) benefitted significantly from the structure provided in the non-choice (control) condition. While this single study is of course unable to entirely discount the findings of Kelly and Bishop (2014), it does provide support for the notion that more substantial user choice should be implemented only when learners are already familiar with a topic. While at the outset of this study, it was not my hypothesis that my findings would align with these principles in the older instructional design literature, the results of this study are more in agreement with this older work than with most recent research on open learning environments.

Although this study supports previous work in instructional design, there is still much more research that needs to be completed in order to establish a better understanding of the effects of non-sequential user choice in open learning environments. The findings of this study suggest that there is substantial nuance to the relationship between non-sequential user choice and outcomes on assessments of declarative knowledge. Four possible explanations for the negative effect of non-sequential user choice in the present study are presented previously in this
chapter. First, given the extensive research on choice overload (see Iyengar & Lepper, 2000), it may be that subjects in the experimental (choice) condition were overloaded with choices, producing less satisfaction with their choices and poorer overall academic performance. Second, as Brown (2001) suggested, poor performance in the choice condition may have been due, at least in part, to poor decision-making on the part of subjects. Subjects in the choice condition may not have chosen the order of resources that would have helped them most, they may have skipped over important sections of the learning resources, or they could have rushed themselves in order to complete the learning experience as quickly as possible. Third, a lack of guidance associated with the choice condition may have led to misconceptions about the content (Brown & Campione, 1994). As Kirschner, Sweller, and Clark (2006) argue, the limited amount of guidance provided to subjects in order to aid their decision making could have caused confusion and frustration, resulting in poor performance. Finally, subjects in the choice condition may have developed a sense of choice apathy, or a sense that the learning process did not matter, as a result of being given choice over the learning sequence. As Garland and Noyes (2004) note, when a learning process is optional, it is common for fewer learners to complete the process and for those learners to feel as though the learning process is less important.

Given the presence of a number of plausible explanatory frameworks for this study’s findings, more research is needed to understand the effects of non-sequential user choice on learning from open learning systems. Additional studies should examine the relationships among non-sequential user choice, the potential for choice apathy or choice overload to develop, instructional media used, assessment type, learner characteristics, and knowledge domain. While previous work in instructional design and guided learning provide some considerations, the body of literature in these areas do not yet adequately address the findings and questions presented in
this paper. Existing research in this area has examined some aspects of learner characteristics that may impact the quality of choices (see Alessi & Trollip, 2001; Brown, 2001; Hannafin, 1984), but there are substantial gaps in the educational research literature with regard to choice overload, choice apathy, and the type of guidance that should be provided to learners in making decisions about learning sequence.

Implications for Scholarship and Future Research

The present research examined the effect of non-sequential user choice on the process of learning from open educational resources (OERs) about adaptive cruise control (ACC). In addition, it investigated the connection of chosen sequential order and time spent on individual OERs to performance on a post-test assessment of mental models and declarative knowledge of ACC. This research has broad implications for the field of educational psychology, and for design of open learning environments. The debate surrounding how much guidance learners should be given in those environments continues, and there are connections to be made from this research to that debate. In particular, it is worthwhile to re-examine of the effects of user choice in previous research, the implications of the present research to the design of learning environment, how much guidance designers or instructors should provide to learners, and the influence of aligning instructional materials with assessments. These areas are discussed in the next major section.

In addition, this paper seeks to propose future research based on the limitations of this study, as well as new areas opened up by its findings. Future work should include research focused on larger sample sizes and more substantial choices, different forms of guided choice, additional content areas, and varied learning contexts. The limitations of this research – including the lack of timing data for the control condition, limited choices for the experimental
condition, and a learning context that may be difficult to apply to real-world settings – as well as the implications of those limitations for future work must also be considered. These areas of future research, and limitations of the present research, are examined in more detail in subsequent sections.

**Relationship to the Existing Literature in Educational Psychology**

In recent decades, the field of open, online learning has seen substantial growth in the volume of scholarship, the number of practitioners engaged, and the amount of resources devoted to understanding and creating these instructional systems. From massive open online courses (MOOCs) and open educational resources (OERs) to online gaming and badge systems, open learning technologies open the possibility for considerable changes to how we teach and learn in the 21st century. Efforts are underway in both the public (e.g., Iowa Department of Education, 2013; Office of Educational Technology, 2017) and private (e.g., Pearson Education, 2016) sectors to revolutionize our educational systems to better fit the needs and technologies of today.

As one section of the open, online learning trend in education, the OER movement pushes for the production of freely available, online learning materials that can be used nearly anywhere and at any time. This movement, and the OERs it produces, seek to reshape education into a more learner-centric approach, providing learners with more choices in determining their process of learning than ever before (Lane & McAndrew, 2010). Despite the substantial efforts by proponents of OERs, as well as others supporting the larger trend, the effects of increased user choice are poorly understood. This section, then, seeks to re-examine what we *do* know about how users choose to experience OERs, the effects of such choices on learning, and the implications of the present research for that developing understanding. Specifically, I begin by
briefly discussing the current study’s relationship to the literature on the effect of user choice in
general and non-sequential user choice in particular. Then, I narrow my focus slightly,
considering the implications for the instructional design literature. Next, I examine the
possibility of a new way of looking at guided user choice. Finally, I discuss the issue of aligning
instructional methods with assessments, and how that may play into these and future results.
Major implications from each of these four sections are summarized in Table 15.

Re-Examining the Effects of User Choice on Learning

Despite the large-scale changes that the open learning movement seeks to produce, we
understand relatively little about the effects of user choice on learning. While the thematic focus
of the relevant scholarly literature ranges from workplace training to social gaming and from
traditional instructional design to discovery- and inquiry-based learning paradigms, there is little
consensus as to how much choice learners should have or what the effects of that choice will be.
Part of the problem may be how broad and undefined the term “choice” really is in scholarship
on learning and design. In the literature, the question of choice ranges from control over pacing
of instructional materials to deciding whether or not to engage with specific materials at all, and
everywhere in-between (Andreu & Jáuregui, 2005). As Brown (2001) explains, even with this
broad definition, there is relatively little research looking at the effects of choice on learning at
all, and even less examining online learning.

In the existing work related to the use of user choice in learning environments, there is
substantial disagreement on how much user choice there should be in online learning
environments. Researchers examining formal, online learning environments (e.g., Lee, Pate, &
Cozart, 2015), narrative choices in learning games (e.g., Turkay & Adinolf, 2015), reward
choices in badge systems (e.g., Davis & Fullerton), and other online learning environments argue
that varied types of user choice can improve engagement, and therefore learning, from these online tools. In contrast, other researchers have found inconsistent (and sometimes detrimental) effects (e.g., Kelly & Bishop, 2014; Alessi & Trollip, 2001), dissatisfaction as a result of too much choice (e.g., Iyengar & Lepper, 2000), increased feelings of apathy (e.g., Garland & Noyes, 2004), and the formation of dangerous misconceptions in highly user-controlled learning environments (e.g., Brown & Campione, 1994). The general user choice research suggests the need for further research in the area.

The present research focused on a single aspect of the larger user choice umbrella: non-sequential user choice. Non-sequential user choice is defined by Chou (2003) as the ability, or lack thereof, of learners to use resources to engage with content in a non-linear, non-prescribed way. Choice of sequence is even less well-studied than other aspects of user choice, including choice of content, modality, and medium. The current study, then, may be able to contribute substantially to our understanding of the effects of non-sequential user choice on learning, particularly from OERs.

The findings of the present research suggest that the availability of non-sequential user choice may, depending upon the structure of choice and the content domain, be a detriment to successfully learning factual knowledge from OERs. The subjects recruited for this study were entirely unfamiliar with adaptive cruise control (ACC), which may be an important factor in the negative effect of non-sequential user choice (see Alessi & Trollip, 2001). Regardless, these results indicate that the availability of non-sequential user choice may not benefit learners.

This study has substantial implications for our understanding of user choice in general, and non-sequential user choice in particular, but also for the design of online learning environments. In an era in which learners are provided more control over the learning process
than ever before, the present research suggests that individual control should possibly be limited. These findings may also imply that the use of at least some guidance is helpful for online learners about the most appropriate sequence of resources in a learning environment. In the case of MOOCs, OERs, and similar online tools, it may be that learner control over sequence, content, and time spent should be constrained in order to allow novices to learn more effectively. The question remaining is what the present results actually mean for the future of research and design. The subsequent sections consider this question.

**Implications of the Present Research for Instructional Design**

Much of the instructional design literature examining user choice takes a somewhat critical, or at least restrained, view of the modern trend toward extensive user choice. Kirschner, Sweller, and Clark (2006), for example, argue that proponents of extensive user choice often ignore evidence about the effectiveness (or lack thereof) of high-choice learning environments. Alessi and Trollip’s (2001) findings echo this argument, with the authors noting that high-choice environments tend to benefit those who are already familiar with a content area, but may hurt novices.

The results of the present research also appear to support the arguments seen in the instructional design literature. As Alessi and Trollip (2001) suggested, in the present study, subjects (all of whom were unfamiliar with ACC) in the choice (experimental) group performed worse on the post-test assessment than subjects in the non-choice (control group) with a more rigid, guided structure to the learning process. These results further the argument that, at least for novice learners similar to those enrolled in this study, the presence of non-sequential user choice can harm the learning process. The results also reinforce the importance and applicability of the existing instructional design literature to the open learning movement. While it may be
popular to provide learners with additional choices as they learn, we must consider when, and where, such additions are helpful, and the instructional design literature includes substantial evidence for addressing that question.

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<tr>
<th>Research Area</th>
<th>Description of Implications</th>
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<td><strong>User Choice</strong></td>
<td>There is relatively little research on the effects of user choice in general, and non-sequential user choice in particular, on learning. The literature available is split as to how much user choice should be provided to learners. This study’s findings indicate a negative effect of non-sequential user choice on the learning of factual information about adaptive cruise control from open educational resources by novice learners, as measured by a post-test assessment of declarative knowledge. The negative effect of non-sequential user choice implies that some restrictions on learner control of sequence, content, and time spent per resource should be included in open learning systems for novices. Further research is needed to establish why. Previous research in instructional design has suggested that unguided discovery learning can result in frustration and confusion (Kirschner, Sweller, &amp; Clark, 2006), which then lead to poor learning. In addition, Alessi and Trollip (2001) argue that learner control of the learning process should be restricted when learners are unfamiliar with the content area. The present research supports these assertions, while also highlighting the need for future research. Choice of sequence has often been ignored in the instructional design literature, and this study emphasizes the need for additional research in instructional design to address this aspect of user choice. Brown and Campione (1994) indicate that truly unguided learning is often dangerous, as learners can easily form misconceptions about important ideas. Kirschner, Sweller, and Clark (2006) go even further, suggesting that frustration and confusion will result as a lack of guidance. The present research suggests that a lack of guidance in choosing the sequence of learning may indeed be detrimental to learning. The findings also highlight a common discrepancy between the laboratory environment and the informal learning environments in which open learning systems are often used. In research settings, we often have far more control over the learning process than in realistic learning settings. If designers wish to include constraints on learners’ choices in open learning systems, those constraints must be designed into the systems themselves, rather than simply assumed for research. The instructional materials used in the present research are divided into three main resources: Understand, Challenge, and Play. An examination of the materials and the post-test assessment indicates that the Understand resource is most closely aligned with the post-test due to its focus on declarative, factual knowledge. This alignment raises the possibility that these findings, and perhaps other findings on user choice, could be due to such alignment of instruction and assessment, rather than a strong effect of choice. This is a design concern that warrants further study.</td>
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*Table 15. Implications of This Study for Existing Research Literature*
In terms of what the present research adds to the existing instructional design literature, it emphasizes the importance of non-sequential user choice as a topic of research. While sequencing is occasionally mentioned in the literature (Alessi & Trollip, 2001), it is often ignored in favor of examining choice of content or time spent on individual resources. While these are, of course, important areas to consider, the present research, when considered with current educational trends in mind, serves as a reminder that non-sequential user choice can have a substantial impact on learner success. Further research in the instructional design literature into when, if ever, non-sequential user choice could have a positive effect on performance is needed.

The present research and the existing literature in instructional design are especially relevant to work with OERs, since the goal of these resources is to reach as many learners as possible. If we know that novice/beginning learners will probably learn less as a result of this built-in choice, the implication may be that we omit choice in favor of structure. Indeed, the more structured, constrained approaches favored in the instructional design literature may be more likely to work effectively for the wide audiences that OERs seek to reach. Perhaps the largest contribution that the present research makes to the existing literature is in highlighting the continued relevance of research in instructional design. Despite this strength, however, the instructional design literature is not the only area that may benefit from the present study’s results.

Toward a New Paradigm of Guided Choice

While the results of the present research align well with some aspects of the instructional design research, and the opponents of the modern user choice trend, there are other areas that
could still benefit from these findings. As Brown and Campione (1994) indicate, truly unguided learning environments can be dangerous due to easily-formed misconceptions. Those misconceptions may also lead to frustration and confusion among learners, further reducing performance (Kirschner, Sweller, & Clark, 2006). Brown and Campione (1994) instead argue for a guided discovery approach, in which learning is still driven by the learners and their interests, but in which an instructor (or instructional tool) provides substantial guidance to help those learners make good choices. Although the present study did not indicate that the specific choices learners made (i.e., chosen sequential order) were significant predictors of post-test performance, this lack of significance is likely due to limitations of the study and its materials, leaving the door open for a confirmation of Brown’s (2001) argument that the quality of choices made is a substantial factor in determining success.

In addition to the possibilities above, one of the primary questions that may arise from adoption of the methods furthered in the instructional design literature is how to constrain learning structures such that they are beneficial but not onerous to learners. Taken together, this issue and the case for guided discovery suggest that we may need a new paradigm for guided choice in learning, in which learners are free to make their own choices about learning sequence, but with assistance from an instructor or instructional tool. Such a system could take on a number of forms, from simple prompts encouraging learners to pick a particular resource first, to detailed suggestions and explanations of those resources, with justification included for the encouraged choices. An approach like this might also align well with existing literature on choice. Iyengar and Lepper (2000), for example, suggest that the illusion of choice is often enough to achieve the satisfying effects of that choice (at least with a limited choice set, which the present study used). Allowing the learner to choose, but providing specific
recommendations, maintains the sense of empowerment derived from choice while still allowing us to keep some control over the learning process. This combination may allow the best of both approaches, while avoiding the downfalls of each.

Beyond the specific arguments of Brown and Campione (1994), however, this author sees important implications of the present research for the open learning movement on the whole, and the researchers seeking to better understand its impacts. A perennial problem in educational research, particularly in open education, is a misalignment between how research is conducted in laboratory settings and how learners engage with open educational resources (OERs) at home and in other learning environments. When learning resources are designed and evaluated, they are often assessed in highly controlled environments, in which it is assumed that learners complete the materials in the originally-intended way. In fact, previous research using the same instructional materials utilized here (Valentine, Zhou, Moore, & DeVane, 2018) took this approach, with subjects engaging with materials in a predetermined sequence. If constraints on user choice with regard to sequence, content, and timing are not designed into a system, then designers have no control over how learners engage with them.

The present research serves to partially bridge the gap between these two highly varied approaches to learning with OERs. While learners did complete all materials in a single session (as opposed to the spaced-out completion that may occur in informal environments), the provision of non-sequential user choice provides a closer comparison to how learners might actually use these resources. The present results, including a negative effect of non-sequential user choice on post-test performance, indicate that guidance is needed for learners engaging with new, unfamiliar content. Beyond that, however, these results also indicate that the structure enforced in research settings may be important to implement within the open, freely-available
versions of OERs distributed to the public, at least if researchers and designers wish for existing data collection methods to be representative of how learners are engaging with and learning from their resources in informal learning environments such as the home.

Guidance in publicly-available materials could take a number of forms, but likely needs to go beyond the limited descriptions provided for subjects in the choice condition of the current research. In the present research, the small amount of information provided to subjects to aid their decision-making did not appear to be substantial enough to allow for effective choices to be made. The rationale questions asked of subjects in the experimental condition also suggest that learners are interested in learning as much as possible from the resources that they engage with, but are simply unable to effectively determine which resources should be used first. Designers and researchers may wish to provide more explicit, specific prompts to encourage learners to engage with resources in the order in which they were originally intended in order to overcome this concern. In addition, considering the possibility of choice apathy developing as a result of providing non-sequential user choice, it may be that only more advanced learners in open learning systems should be afforded the ability to choose among options. This restriction could help reduce the possibility that learners simply become uninterested in the learning process.

Regardless of what shape this guidance takes, however, it is clear that additional guidance is needed in informal learning environments if our controlled laboratory environments are to be effective measures of effectiveness. In contrast, it may also be possible to adjust how we assess designs in a research environment such that they more accurately represent how informal learning takes place with OERs and other resources. However, substantial changes in the lab carry risks of their own, including a higher risk for confounding variables (or more work to mitigate their effects).
Revisiting the Alignment of Instructional Materials and Assessments

In a previous section, I examined the alignment of instructional materials and assessments in light of the results of the regression analysis (Understand time being the only individually significant predictor of post-test score). In this section, I come back to the issue of instructional alignment because it is another area where we may be able to learn from the results of the present study. As previously discussed, it is likely that time spend on the Understand module was a significant predictor of post-test performance largely because the Understand resource aligns substantially with the bulk of the post-test. This alignment – and the lack of the alignment among the Play resource, Challenge resource, and post-test – indicates that a substantial concern for this research is one of instrument and material design.

There is a wide body of research over many years (e.g., Cohen, 1987) supporting the argument that alignment of materials with assessments produces improved test scores. In the present research, it appears likely that the results of the regression analysis – with time spent on the Understand section significantly predicting post-test score – can at least partially be explained based on the close alignment of the Understand resource and the declarative knowledge section of the post-test. While that explanation does not provide widespread implications for the field, as there is substantial research in the area of instructional alignment, it does highlight the nuance between different section of the post-test assessment used in this study. The differences present in the two sections of the post-test, with one section focused on declarative knowledge and the other on mental model formation, may reflect the results of the study. The control (non-choice) group did perform significantly better on the post-test than the experimental (choice) group, but when group means are examined for individual sections, the group difference resulted almost entirely from the declarative knowledge section of the post-test.
(see Table 5 for descriptive statistics). The choice and non-choice groups varied little on the mental model-oriented section of the post-test, with the choice subjects even very slightly outperforming the non-choice subjects. This suggests that the presence of non-sequential user choice may have had a larger impact on the acquisition of declarative knowledge than on the development of mental models. In fact, the group mean difference on the declarative knowledge section of the post-test was large enough to provide significance for the post-test on the whole, while the mean difference on the mental model section of the test was far too small to indicate an effect.

I previously suggested future analyses using the same materials used in this study, with the Play scenario problems as the outcome of interest, and the Challenge resource and chosen sequential order acting as potential predictors. Based on the high level of alignment between the Understand resource and the post-test, and the similarities between the Challenge and Play resources, it seems likely that such an analysis would result in another significant result. The important possibility here, then, is that the primary explanation for the results of this study come from instructional alignment, rather than any aspect of non-sequential user choice. While this researcher believes that there is likely at least a small effect of non-sequential user choice influencing the results, it is a possibility that would warrant further study.

**Proposed Future Research**

The present research has substantial value, and will be able to make a number of contributions to the research literature. However, there are of course other areas that may be investigated. This section, then, is devoted to highlighting some of the areas where further research would be warranted. First, I discuss possibilities for future research that employs larger sample sizes and/or updated versions of the current study’s learning materials. Second, I suggest
additional research that examines possible forms of guided choice that could be embedded in open, online learning systems. Next, I examine the possibility of future research with new content areas or additional learning resources included in the learning system. Finally, I propose an analysis of various learning contexts and their interaction with the presence of non-sequential user choice. Each of these areas of future research is both discussed below and summarized in Table 16.

Sample Size and Material Updates

One of the primary limitations (discussed further in the next major section) of the present research is the limited chosen sequential order data from the choice (experimental) group. Future research could address this problem in a number of ways, two of which I will discuss here. First, additional research could use larger sample sizes. Second, future work could include updates to existing learning resources to include more substantial choices. Each of these approaches is discussed below.

As discussed previously, the chosen sequential order data from the choice group was severely limited by the dominance of two specific chosen orders. Examinations of the influence of chosen sequential order would be substantially easier, and likely more accurate, if those data could be improved. A replication of the present research with a much larger sample size might allow for this, as more subjects overall would likely result in more subjects choosing the rarer sequences. This would then allow for a more robust regression analysis examining the relationship of chosen sequential order to post-test score, or any other outcome variable of interest (e.g., Play score).

In addition to a larger sample size, an update to this study’s learning materials could also make examining chosen sequential order simpler. As discussed earlier, with only three learning
resources, subjects’ actual choices are quite limited. Individual resources could be split into smaller components and treated as separate predictor variables for future regression analysis, which would allow for a better understanding of the effect of specific choices. For example, learners might choose to complete the first Challenge scenario problem before looking at the Play scenarios, but wait to finish the other Challenge problems until after completing the Play resource. The primary risk with this approach, and the reason it was not done for the present study, is that the existing resources were designed as whole units. Splitting them into individual components could potentially improve chosen sequential order data, but it could cause problems in the actual learning process, because portions that depend on each other could be completed out of order (e.g., later Play problems reference earlier ones). In addition, splitting these components could cause statistical problems with the regression analysis, at least if the time variables were still in consideration – extra predictor variables would then necessitate a much larger sample size.

**Envisioning Guided Choice as Embedded in Open Learning Environments**

As examined earlier in this paper, the results of the present research suggest the possibility of new ways of thinking about guided instruction and guided choice in learning environments. Future research examining non-sequential user choice could delve more deeply into this issue, even using the same materials from this study. In the present study, choices were made with very limited guidance – each choice was made on a splash screen which provided subjects with only a brief description of each resource.

Future work could expand choice guidance in a number of ways, potentially including a comparison among types of guidance. In addition to the minimal guidance provided in this study, one version might include simple suggestions in addition to descriptions (e.g., “We
suggest reading the Understand resource first!”), but with no explanation as to why learners should make that decision. Additional conditions/versions could use progressively more explicit recommendations, including more complete descriptions and explanations as to why an order is suggested (e.g., “You should complete Challenge Problem 1 before moving on to the Play resource, because Challenge 1 helps you learn about curving roads and you will work with curving roads in the Play scenarios!”). Such additions could allow for a more fine-tuned picture of what guidance novice ACC learners should have.

Beyond ACC: Using OERs to Learn Varied Content

One of the sources of data included in the present study was a question asking subjects what kinds of choices/resources they would like to see in online programs like the one they were using. As discussed previously and summarized in Table 12, eight subjects asked for new controls or perspectives for materials, five asked for additional scenarios or resources, and 15 asked for changes to the nature of the instructional methods. Combined, that indicates that roughly two thirds of choice (experimental) group subjects would have liked to see some change to the content of their learning experience in this study. Suggestions from subjects included adding videos, introducing a first-person view for the Play simulation, and including additional weather conditions. Future research could examine the efficacy of these various instructional formats on different learning outcomes.

These suggestions present another valuable avenue for future research. Additional perspectives for the learner, for example, could help evaluate learner understanding and, potentially, increase applicability (i.e., a first-person view is more realistic than a top-down view). Additional scenarios, resources, or types of instruction could improve the learning
environment while also providing additional chosen sequential order data, allowing for a more in-depth examination of the effects of non-sequential user choice in the process.

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<tr>
<th>Future Research</th>
<th>Explanation of Goals</th>
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<tr>
<td>Larger Sample Size</td>
<td>This study’s examination of the influence on chosen sequential order on post-test performance was limited by a lack of diversity among chosen sequential orders. This limitation could be overcome with a larger sample size, as each possible sequential order would likely be chosen by more subjects. This could more accurately indicate whether or not chosen sequential order is a useful predictor of post-test performance. Just as there were too few subjects to completely assess the influence of chosen sequential order, there may have also been too few choices for learners to make. Learners were only asked to make three choices (with six possible sequential orders). Individual resources could be split into component parts (e.g., each Challenge question becoming an independent resource) in order to provide more substantial choices for learners to make. This could improve the examination of chosen sequential order as a predictor for post-test performance, but would run the risk of hurting the learning process by eliminating built-in sequencing. Subjects in the experimental (choice) condition in this study had very limited information provided to them when making their choices regarding sequence. Additional research should be completed to more deeply examine the influence of guidance on non-sequential user choice. Different amounts, and types, of guidance might be compared in a learning environment in which learners still choose their learning sequence, and these variations could be compared to an environment in which the sequence is predetermined.</td>
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<tr>
<td>Updated Learning Materials</td>
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<td>Embedded Guidance</td>
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<td>Varied Content</td>
<td>This study examined the effect of non-sequential user choice specifically for learning about adaptive cruise control (ACC), a technology-based car safety system, and with only a small set of learning materials. Roughly 2/3 subjects in the experimental (choice) indicated that they would have liked to see some sort of change to the learning content, including new perspectives or additional scenarios. In addition, future research could examine learning about other car safety systems, as well as other knowledge domains. This additional work would lead to a better understanding of how, and when, non-sequential user choice affects learning. The present research is focused on the use of open educational resources (OERs), with the goal of modeling use at home or as part of a driver education course. While there are implications for other types of learning environments, additional research is needed to confirm whether the findings from this study would hold across contexts. More realistic representations of both formal and informal learning environments would be useful in furthering our understanding of the effects found in the present study. In particular, additional research in classrooms, home-based informal learning environments, and workplace learning environments would be particularly useful, as there is little research examining the effects of choice in these contexts.</td>
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<td>Varied Contexts</td>
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Table 16. Areas for Future Research
Additional content, however, need not simply include updates to the present materials. Indeed, work with other driver safety systems would be useful for comparison and replication. In addition, similar materials for other broad content areas would allow for an examination of how consistent, or not, the discovered negative effect of non-sequential user choice truly is.

**Applications to the Workplace and Other Learning Contexts**

Finally, the learning context is an important aspect of this study that could be examined or changed in future work. The present study took place in a lab setting, but the study was originally designed to mimic at-home learning (where learners would not be told when to use each resource). Future work could expand that mimicry by comparing lab settings to at-home learning. In addition, since these materials were originally designed with drivers’ education courses in mind, it could be useful to compare the effects of choice in a more formal learning environment as well.

More generally, work on non-sequential user choice could be expanded to entirely different learning contexts, including the workplace. Workplace learning environments, and work-based learning environments (college-based courses designed to help train workers for future employment), are substantially different from traditional classroom learning environments, and often require different approaches to learning as a result (Le Maistre & Paré, 2004). With a wide variety of training programs used in workplace training, from highly-structured tutorials to entirely self-paced resources, an investigation of the effects of user choice on this type of learning environment could be instrumental in developing best practices. Research in this area might include a consideration of varied content areas as well, as the effects of choice may vary in different fields and for various aspects of a single job.
The present research has revealed a wide array of possible avenues of future research. Going forward, additional work could include larger sample sizes and updates to existing materials. Content areas and varied approaches to guided choice might also shed new light on the generalizability of non-sequential user choice. Additional learning contexts – including classrooms, informal learning environments, and workplace training programs – could also provide further insights into the effects of user choice on learning.

John Dewey argued more than a century ago that “reflection involves not simply a sequence of ideas, but a consequence – a consecutive ordering in such a way that each determines the next as its proper outcome…The successive portions of the reflective thought grow out of one another and support one another; they do not come and go in a medley” (Dewey, 1910, pg. 3). In effect, Dewey is making it clear that the sequence of learning is inherently important, as each piece builds off of the last piece. If the sequence of learning is changed, therefore, important building blocks for future learning may be missing. At the core of this research, and future research in this area, is a crucial question: how can choice of sequence help to foster deep, reflective, critical thought? With Dewey’s argument about sequence and consequence in mind, is that even possible in a learning environment in which learners choose which portions of the environment to engage with? If it is, how do we go about designing learning environments to achieve it? The present research begins to examine these fundamental questions, but more work is needed to determine just how much control learners should have over the sequence, content, and timing of their learning, and what form that control should take.

Limitations of this Research

While the present research has a number of strengths, it is of course not without limitations. These limitations help inform the extent to which the findings of the study can be
applied, and as such are worth discussing here. Specific limitations of this research include a lack of timing data for the non-choice (control) condition, a limited set of chosen sequential order data for the choice (experimental) condition, and a learning context that may restrict applicability to real-world situations. Each of these is discussed briefly below.

Due to the nature of data collection for this study, in which subjects in the non-choice condition was recruited as part of previous research, data for the Understand time, Challenge time, and Play time predictor variables were only collected for subjects in the choice condition. While the existing data were acceptable for the analyses completed as part of the present research, the lack of timing data for the non-choice condition limits the claims that can be made about the influence of time spent on each resource. Future replications would benefit from this data being collected from both conditions in order to more effectively assess the relationship of timing to post-test performance.

In addition to the lack of timing data for the non-choice condition, the chosen sequential order data from the choice condition are limited. This is represented in the dominance of two specific chosen sequences among subjects in that condition, and limits the ability of the multiple regression analysis to find any relationship that may be present. As mentioned in the section on future research, this could be addressed in future work through larger sample sizes and/or more substantial user choices.

Finally, the specific learning context of the present study may limit applicability and generalizability. While some previous research (e.g., Beggiato & Krems, 2013) has demonstrated that learning in lab settings can transfer well to driving simulators, and from there to actual driving. The question of transfer to such real-world scenarios was not assessed as part of the present study. Future learning contexts, as mentioned previously, could help address this
issue by bringing these materials to driver education courses and, as a result, into an application-focused learning environment. This limitation is worth considering with regard to the effectiveness of the instruction for future drivers, but is less of a concern in terms of the theoretical construct of non-sequential user choice, since the present study was focused on its effect on learning from open educational resources.

**Non-Sequential User Choice in OERs: A Negative Effect and a Need for Further Study**

In concluding this work, it is worth returning to the major themes at play in the present research. In recent years, open, online learning has become ever-more popular, and with it, we have seen the rise of more highly learner-controlled learning environments. Both the public and private sectors have invested time, effort, and financial resources into the open learning movement in order to effect widespread change in our educational systems.

Despite the growing popularity of learner-controlled learning environments, relatively little is known about the effects that user choice can have on the learning process. The available research literature, from both inside and outside the field of education, has failed to reach a consensus as to whether extensive user choice is a positive or negative design feature. Indeed, research into control over sequence, or non-sequential user choice, has been even more limited, with very little empirical evidence for or against the implementation of such systems in open, online learning.

The present research, then, sought to investigate the effects of non-sequential user choice on learning from open educational resources (OERs), one of the major types of learning environment furthered by the open learning movement. In addition, this research also sought to investigate any relationship among timing spent on individual resources, the order in which resources are chosen, and performance on an assessment of declarative knowledge. To address
these major questions, this study utilized a set of OERs designed to instruct learners about adaptive cruise control (ACC), a newer driver safety technology. These OERs included three sections: Understand, a text- and image-based description of ACC; Challenge, a set of text- and image-based scenario problems highlighting ACC’s limitations; and Play, a set of scenario questions using the plAyCC computer-based simulation. Performance was measured for the Challenge questions, Play questions, and a post-test.

Overall, this study found a significant negative effect of non-sequential user choice on ACC mental model development, as measured by performance on a post-test assessment of primarily declarative knowledge. In addition, a multiple regression analysis found a significant relationship among time spent on each resource, chosen sequential order, and post-test score. Among these predictor variables, only time spent on the Understand resource was individually significant, which is likely indicative of the alignment of this resource with the post-test. While this study of course has limitations, its findings suggest that, at least for learners unfamiliar with ACC, the presence of non-sequential user choice has a detrimental effect on learning from these OERs, despite no evidence of chosen sequential order individually predicting post-test performance. Taken together, this study’s results support existing instructional design and guided learning research, indicating that non-sequential user choice may not be useful for some learners. Despite the alignment of this study’s findings with the existing literature, there is a need for further research in the area of non-sequential user choice. The combination of a negative effect of non-sequential user choice with a lack of evidence that specific chosen orders impacted post-test performance presents a paradox that should be resolved with further study. This paper discusses possible explanations for this paradox, but additional research is needed to confirm the factors at play.
REFERENCES


Nebel, S., Beege, M., Schneider, S., & Rey, G. D. (2016). The higher the score, the higher the learning outcome? Heterogeneous impacts of leaderboards and choice within educational videogames. *Computers in Human Behavior, 65*, 391-401.


APPENDIX A – UNDERSTAND RESOURCE

MyCarDoesWhat.org
Deeper Learning

ADAPTIVE CRUISE CONTROL

Understand

WHAT IS IT?
Conventional cruise control can maintain a steady speed that you set. Adaptive cruise control (ACC) is an enhancement of conventional cruise control. ACC automatically adjusts the speed of your car to match the speed of the car in front of you. If the car ahead slows down, ACC can automatically match it. Once the car ahead moves out of your lane or accelerates beyond your car’s set speed, your ACC allows your car to return to the speed that you have set. Other than setting your speed, you only need to turn on the system and select your preferred following distance.

HOW TO USE IT?
The specific controls will be different depending on your particular car type, but usually you will have to start by setting a cruising speed and a following distance to the car ahead.

Activation/Deactivation
Most systems are operated by controls on the steering wheel. You can also intervene at any time by use of the brake or accelerator pedal.

Setting the speed
You can set the speed using the +/- speed button. You can also accelerate as normal until the desired speed is reached. Then you press a button to have the ACC “remember” the speed. Most ACC systems will work down to about 23 MPH.

Setting the distance
ACC systems allow you to set a following distance, or time interval, between your car and the car ahead. ACC systems provide various car-to-car distance options, such as short, medium, or long distance. You can change the setting at any time as traffic conditions change. A longer setting is recommended for most driving.

HOW DOES IT WORK?
Like standard cruise control systems, ACC keeps your car at the speed you set, as long as there is nothing in front of you. A sensor unit is added to determine the distance between your car and other cars in front of you.

Speed and distance sensors.
ACC uses information from two sensors: a distance sensor that monitors the gap to the car ahead and a speed sensor that automatically accelerates and decelerates your car. ACC uses information from these sensors to adjust your speed and maintain the set distance from the car in front of you.

Looking under the hood: Radar-based systems.
Let’s take a look at one ACC technology: radar-based ACC. Some ACC systems send radar waves that reflect off objects in front of your car. Based on the radar reflection, ACC uses distance, direction, and relative speed to detect if the car is within the distance you set. ACC predicts the path of your car and then decides whether any of the vehicles ahead are within your set distance.
APPENDIX B – CHALLENGE RESOURCE

ADAPTIVE CRUISE CONTROL

CHALLENGE #1: CURVING ROADS

Your ACC system looks directly in front of you for other vehicles. Because it only looks forward, your ACC system may have trouble detecting traffic on curving roads.

In the image to the right, see how ACC's field of view works when the road curves. Its view may include traffic in another lane. It may also miss vehicles in your own lane. In situations like this, your ACC system may not react appropriately to the traffic around you. In the example, your ACC system may unexpectedly slow down if it detects the semi in the other lane.

What would you do?
Look at scenario in the image to the right. Imagine yourself driving the blue vehicle. Think about the questions shown below.

As you approach the curve, how might your ACC system respond?

How should you respond?

COLLEGE OF EDUCATION

THE UNIVERSITY OF IOWA
CHALLENGE #2: HILLS

Just as your ACC system may struggle with curving roads, it may also have trouble on hilly roads. ACC looks straight in front of the vehicle, and can’t bend its view up or down hills (or around curves). The image shows how the system’s field of view may not see everything when on a hilly road, and may respond incorrectly. In the example, your car’s ACC system may not detect Car B, and could unexpectedly speed up.

What would you do?
Look at scenario in the image to the right. Imagine yourself driving the blue vehicle. Think about the questions shown below.

As you approach the the top of the hill, how might your ACC system respond?

How should you respond?
**CHALLENGE #3: MERGING TRAFFIC**

ACC systems detect other vehicles directly in front of you. Because of the system’s field of view, ACC may not detect a vehicle that is in your lane but not directly ahead of your car. This can include vehicles that are merging into or out of your lane. In the example, Car A may be outside of your ACC’s field of view and yet still in front of you.

**What would you do?**
Look at the scenario in the image to the right. Imagine yourself driving the blue vehicle. Think about the questions shown below.

<table>
<thead>
<tr>
<th>How might your ACC system respond?</th>
<th>How should you respond?</th>
</tr>
</thead>
</table>

Experts Challenge Answer

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MyCarDoesWhat.org
Deeper Learning
CHALLENGE #4: SLOW AND HEAVY TRAFFIC

ACC systems can help regulate speed in traffic, but they may struggle in heavy traffic. Your ACC system has to detect a vehicle and also judge its distance and speed. Quick lane changes and braking in heavy traffic situations may cause the system to struggle. In slow traffic, many systems will disengage below a certain speed.

What would you do?
Look at the scenario in the image to the right. Imagine yourself driving the blue vehicle. Think about the questions shown below.

How might your ACC system behave in this situation? How should you respond?
Problem situation 1 (Curve):

PIAyCC Settings

Situation: You are a road designer working with the Iowa Department of Transportation. You are working on an existing highway which has a speed limit of 55mph and contains a lot of tight curves. While most drivers stay near the speed limit of 55mph, some drivers go as high as 70mph on this road, leading to dangerous situations when systems like Adaptive Cruise Control (ACC) are used.

Your task: Redesign the road to fit the demands of traffic without changing the road’s state-mandated speed limit. In redesigning the road, you are only able to make changes to the curviness of the road. What is the smallest change you can make to the road’s curviness in order
to eliminate dangerous situations (red ACC detection cone) involving cars exceeding the speed limit?

**Problem situation 2 (Speed):**

**PlAyCC Settings**

*Intro:* You and your team did so well with the highway that the DOT have assigned you to another problematic road. The speed limit here is 35mph, with some tight curves. Some drivers go as quickly as 55mph with ACC active, and this creates similarly dangerous situations.

*Your task:* Unfortunately, the state has no funds available to make any changes to the road. Instead, they have given you permission to adjust the road’s speed limit. What is the smallest change you can make to the speed limit in order to eliminate dangerous situations (red ACC detection cone) involving cars exceeding the speed limit?

**Problem situation 3 (Budget):**

**Settings**

*Intro:* You have been brought in to consult on adjustments to one final highway. The road has a lot of tight bends and a speed limit of 45 mph. However, some drivers create dangerous situations by driving at up to 65mph with their ACC active.

*Your task:* In creating a safer situation, you are able to adjust the speed limit as well as the curve of the road. Unfortunately, the state has limited funds to pay for the changes. Your team has $100 to spend on the changes. The tables below summarize the costs associated with the changes you can make. What cost-effective changes can you make that will make the road safe? Choose the new average traffic speed (speed limit) and road curve.
**Challenge 1: Curving Roads (3 points)**

1a. As you approach the curve, how might your ACC system respond? (2 points)

<table>
<thead>
<tr>
<th>Points</th>
<th>Rubric</th>
</tr>
</thead>
</table>
| **2 points** | Mentions both aspects:  
• How the ACC system will respond  
AND  
• Why the ACC system will respond  

Ex: My ACC system may not detect Car A when it goes around the curve, and so could unexpectedly accelerate. **OR** My system may detect Car B in the other lane and slow down. |
| **1 point** | Mentions one of the two aspects:  
• How the ACC system will respond  
OR  
• Why the ACC system will respond |
| **0 points** | A response includes nothing correct about the situation |

1b. How should you respond? (1 point)

<table>
<thead>
<tr>
<th>Points</th>
<th>Rubric</th>
</tr>
</thead>
</table>
| **1 point** | Mentions a safe personal response to the indicated ACC system response.  
Ex: I should manually maintain a safe distance from Car A. **OR** I should control my speed manually until the road straightens. **OR** I should move into the right lane. |
| **0 points** | A response does not include a safe response to the situation |

**Challenge 2: Hilly Roads**

2a. As you approach the top of the hill, how might your ACC system respond? (2 points)

<table>
<thead>
<tr>
<th>Points</th>
<th>Rubric</th>
</tr>
</thead>
</table>
| **2 points** | Mentions both aspects:  
• How the ACC system will respond  
AND  
• Why the ACC system will respond  

Ex: My ACC system may not detect Car A (when it goes over the hill) and so could unexpectedly accelerate. |
| **1 point** | Mentions one of the two aspects:  
• How the ACC system will respond  
OR  
• Why the ACC system will respond |
| **0 points** | A response includes nothing correct about the situation |
2b. How should you respond? (1 point)

<table>
<thead>
<tr>
<th>1 point</th>
<th>Mentions a safe personal response to the indicated ACC system response.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ex: I should disengage ACC and maintain a safe distance (slow down) until the road is less hilly.</td>
</tr>
<tr>
<td>0 points</td>
<td>A response does not include a safe response to the situation</td>
</tr>
</tbody>
</table>

**Challenge 3: Merging Traffic**

3a. How might your ACC system respond? (2 points)

<table>
<thead>
<tr>
<th>2 points</th>
<th>Mentions both aspects:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• How the ACC system will respond AND • Why the ACC system will respond</td>
</tr>
<tr>
<td></td>
<td>Ex: My ACC system may fail to brake in time in response to Car B because Car B is not yet in my detection area/because Car B is going so much slower than Car A/because of Car A’s speed</td>
</tr>
<tr>
<td>1 point</td>
<td>Mentions one of the two aspects:</td>
</tr>
<tr>
<td></td>
<td>• How the ACC system will respond OR • Why the ACC system will respond</td>
</tr>
<tr>
<td>0 points</td>
<td>A response includes nothing correct about the situation</td>
</tr>
</tbody>
</table>

3b. How should you respond? (1 point)

<table>
<thead>
<tr>
<th>1 point</th>
<th>Mentions a safe personal response to the indicated ACC system response.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ex: I should switch lanes to allow Car B to merge. OR Slow down to allow Car B to merge</td>
</tr>
<tr>
<td>0 points</td>
<td>A response does not include a safe response to the situation</td>
</tr>
</tbody>
</table>

**Challenge 4: Heavy Traffic**

4a. How might your ACC system respond? (1 point)

<table>
<thead>
<tr>
<th>1 point</th>
<th>Describes:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• How the ACC system will respond, potentially including an explanation as to why</td>
</tr>
<tr>
<td></td>
<td>Ex: Since many ACC systems are not designed to function under 25MPH, ACC may turn off in a slow, heavy traffic situation. OR ACC may not respond adequately.</td>
</tr>
<tr>
<td>0 points</td>
<td>A response includes nothing correct about the situation</td>
</tr>
</tbody>
</table>
4b. How should you respond? (1 point)

| 1 point | Mentions a safe personal response to the indicated ACC system response.  
  Ex: I should control my speed and distance to the vehicle ahead manually in low speed situations |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0 points</td>
<td>A response does not include a safe response to the situation</td>
</tr>
</tbody>
</table>
1. What is the smallest change you can make to the road’s curviness in order to eliminate dangerous situations (red ACC detection cone) involving cars exceeding the speed limit? Choose the new road curve. (1 point)

| 1 point | Meets both criteria:  
|         | • Answer is correct (road curve of 4)  
|         | AND  
|         | • Both desired speed (70mph) and average traffic speed (55mph) are at their starting points |

| .5 point | Meets both criteria:  
|         | • Answer is nearly correct (road curve of 3 or 5)  
|         | AND  
|         | • Both desired speed (70mph) and average traffic speed (55mph) are at their starting points |

| 0 points | Final answer is incorrect, or the unused parameters are changed |

2. What is the smallest change you can make to the speed limit in order to eliminate dangerous situations (red ACC detection cone) involving cars exceeding the speed limit? Choose the new average traffic speed.

| 1 point | Meets both criteria:  
|         | • Answer is correct (average traffic speed of 45-46mph or 51-52mph)  
|         | AND  
|         | • Both desired speed (55mph) and road curve (5) are at their starting points |

| .5 point | Meets both criteria:  
|         | • Answer is nearly correct (average traffic speed of 47-50mph)  
|         | AND  
|         | • Both desired speed (55mph) and road curve (5) are at their starting points |

| 0 points | Final answer is incorrect, or the unused parameters are changed |

3. What cost-effective changes can you make that will make the road safe? Choose the new average traffic speed (speed limit) and road curve.

- Points ARE given for Question 3 based on the table below ONLY if:
  - The desired speed (65mph) is the same as its starting point

<table>
<thead>
<tr>
<th>Curve</th>
<th>Average Traffic Speed</th>
<th>Points Given</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>59</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>57-58</td>
<td>.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>6</td>
<td>60+</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>59</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>57-58</td>
<td>1.5</td>
</tr>
<tr>
<td>6</td>
<td>50-56</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Below 50</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Above 54</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>53-54</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>51-52</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>45-50</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Below 45</td>
<td>0</td>
</tr>
<tr>
<td>4 or below</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
APPENDIX F – POST-TEST QUESTIONS

Questions 1-3

What are major differences between Adaptive Cruise Control and conventional cruise control?

If you are driving on a highway using ACC, the car ahead slows down, how would your ACC respond? Why?

What are the two parameters you need to set when you use ACC?
Question 4

Explaining ACC

Explain how ACC works using the image above as a reference. Describe the function of the three components labeled and how information flows in the system.
### Question 5

How much do you think your ACC system would help you in avoiding a collision in the following situations?

<table>
<thead>
<tr>
<th></th>
<th>Very well</th>
<th>Fairly well</th>
<th>Poorly</th>
<th>Not at all</th>
<th>Don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>In heavy stop-and-go traffic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In rain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On a city street with stoplights</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On interstates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In heavy, flowing traffic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On curving roads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On highway exit ramps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On roads with low speed limits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In snow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On a hilly road</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Following a motorcycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX G – POST-TEST RUBRIC

1. What are major differences between Adaptive Cruise Control and conventional cruise control? (3 points)

<table>
<thead>
<tr>
<th>3 points</th>
<th>Mentions both relationships:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Adjusts speed based on the car in front</td>
<td>AND</td>
</tr>
<tr>
<td>• Maintains distance to car in front</td>
<td>Ex: Detects the car in front, adjusts speed as needed to maintain your set following distance.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 points</th>
<th>Mentions two features of ACC:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Adjusts speed based on the car in front</td>
<td>OR</td>
</tr>
<tr>
<td>• Maintains distance to car in front</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1 point</th>
<th>Mentions one feature of ACC:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Detects the car in front</td>
<td>OR</td>
</tr>
<tr>
<td>• Adjusts speed</td>
<td></td>
</tr>
</tbody>
</table>

| 0 point | A response includes nothing correct about ACC |

2. If you are driving on a highway using ACC, the car ahead slows down, how would your ACC respond? Why? (3 points)

| 3 points | [When the car ahead slows down,] ACC would adjust/reduce my speed so that my car maintains my set following distance. |
| 2 points | Partial understanding; car slows down and detects something. |
| 1 point | States that car will slow down without any other explanation. |
| 0 point | A response includes nothing correct about ACC’s response |

3. What are the two parameters you need to set when you use ACC? (2 points)

| 2 points | Desired speed and following distance |
| 1 point | Desired speed OR following distance |
| 0 point | A response includes nothing correct about the two parameters |

4. Explain how ACC works using the image as a reference. Describe the function of the three components labeled and how information flows in the system. (4 points)

A: 1 point

ACC **user controls**: set speed and distance (1/2 point for just the label; 1/2 point for saying you set controls)

B: 1 point

Distance sensor: monitors the gap to the car ahead (1/2 point for just the label)
C: 1 point  
Speed sensors: measures your speed (1/2 point for just the label)  
Because of Understand section, give point for saying the speed sensor automatically accelerates or decelerates (adjusts speed).

Information flow: 1 point  
Specify some relationship between the distance (B) and speed (C) information  
E.g., ACC uses information from these sensors [and the speed and distance the user set] to adjust the speed and maintain the set distance from the car ahead

5. (Likert items) How much do you think your ACC system would help you in avoiding a collision in the following situations?

<table>
<thead>
<tr>
<th>Situation</th>
<th>Very well</th>
<th>Fairly well</th>
<th>Poorly</th>
<th>Not at all</th>
<th>Don’t know</th>
</tr>
</thead>
<tbody>
<tr>
<td>In heavy stop-and-go traffic</td>
<td>0</td>
<td>0</td>
<td>.5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>In rain</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>.5</td>
<td>0</td>
</tr>
<tr>
<td>On a city street with stoplights</td>
<td>0</td>
<td>0</td>
<td>.5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>On interstates</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>In heavy, flowing traffic</td>
<td>0</td>
<td>1</td>
<td>.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>On curving roads</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>On highway exit ramps</td>
<td>0</td>
<td>.5</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>On roads with low speed limits</td>
<td>0</td>
<td>0</td>
<td>.5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>In snow</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>.5</td>
<td>0</td>
</tr>
<tr>
<td>On a hilly road</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Following a motorcycle</td>
<td>0</td>
<td>0</td>
<td>.5</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Choice 1 Rationale

Thank you for making your choice! Before you start the learning activity, please tell us the primary reason why you chose the activity you did.

- It was listed first
- I liked the image
- I liked the description
- I thought it would best help me understand ACC
- It looked like the most fun
- I chose randomly
- Other (Please explain)
Thank you for making your second choice! Before you start the learning activity, please tell us the primary reason why you chose the activity you did.

- It was listed first
- I liked the image
- I liked the description
- I thought it would best help me understand ACC
- It looked like the most fun
- I chose randomly
- Other (Please explain)
Before you start the final learning activity, please indicate why you left this activity until the end.

- It was listed last
- I liked the image least
- I liked the description least
- I thought it would be least helpful in understanding ACC
- I thought I should do the other two activities first to better understand this one
- It looked like the least fun
- I chose randomly
- Other (Please explain)
Overall Rationale

Please complete the questions below examining the choices you made during your learning activities. Afterwards, you will take a short test to assess what you have learned.

Looking back at the activities you've completed, what was the primary (overall) reason for the order you chose?

- I chose them in the order they were listed
- I chose them in the order of how well I liked the images
- I chose them in the order of how well I liked the descriptions
- I chose them in the order that seemed the most fun
- I chose them in the order that I thought would best help me learn about ACC
- I chose them randomly
- Other (Please explain)
Please complete the questions below examining the choices you made during your learning activities. Afterwards, you will take a short test to assess what you have learned.

If you could go back, what choices, if any, would you make differently?

What type(s) of choices would you like to see included in an online learning program like this?