# An Investigation into the Benefits of Design Science Research for the Development of Wicked Educational Information Systems: A Case Study

by

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## Abstract

Wicked educational information systems (IS) address problems with unstable educational requirements, in educational environments that are ill-defined, where complex interactions among subcomponents of the problem and its solution exist. In this dissertation, a design science research methodology (DSRM) was used to evaluate projects that developed, implemented, tested, and evaluated two wicked educational IS: multimedia case studies and serious games. The original DSRM model was changed so that it could be used as the theoretical framework for this dissertation. An analysis of each project using this model answered the research question: how can a design science research methodology lead to the development of wicked educational IS?

In project one, multimedia case studies were implemented over a three year period in an Introduction to Engineering course with 696 students who were divided into experimental (multi-media case studies) and control (round table discussion) groups. A presage-pedagogy-process-product (4P) model was used to develop hypotheses. Survey data were collected using validated scales from literature and hierarchical linear regression analyses were conducted to test the hypothesized relationships of the 4P model. External evaluators collected qualitative data in the form of open-ended survey responses and focus group feedback. Concurrent triangulation was applied to compare quantitative and qualitative results, revealing that female and minority students using a

multimedia case study methodology earn higher grades than those using a round table discussion methodology.

In project two, a serious game was developed by a company, in cooperation with a university research laboratory, to increase student immersion in the topic of engineering design methodology. Students simulated building a water tower and a train bridge with constraints placed on the weight, cost, and load of their structure. As students progressed through the game, the level of difficulty increased. The project was implemented during three concurrent semesters of an Introduction to Engineering course with 238 students using experimental (serious games) versus control (lecture) groups. Hypotheses were developed using the 4-P model, survey data were collected using validated instruments, and analyzed using hierarchical linear regression analyses. External evaluators collected qualitative feedback in the form of open-ended survey responses and focus group feedback. Findings suggest that female students using a serious game methodology earn higher scores than those engaged in traditional lectures. In addition, students using a serious game experience higher levels of goal clarity compared to students in traditional classroom settings.

Analysis of each project using the DSRM model revealed that emphasis on planning, communication, and rigorous evaluation provide significant benefits. These findings led to development of a refined DSRM for wicked educational IS that provides detailed guidelines, via step-by-step recommendations, for potential developers of wicked educational IS.

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Table of Contents

## List of Tables

List of Figures

List of Abbreviations

| | |
|---|---|
| AACSB | Association to Advance Collegiate Schools of Business |
| ABET | Accreditation Board for Engineering and Technology |
| ASEE | American Society for Engineering Education |
| CONC | Concentration |
| CSR | Case Study Research |
| DiSC | Dominance, Influence, Steadiness, Conscientiousness |
| DS | Design Science |
| DSR | Design Science Research |
| DSRM | Design Science Research Methodology |
| GC | Goal Clarity |
| HOCS | Higher Order Cognitive Skills |
| ILS | Index of Learning Styles |
| IS | Information Systems |
| IT | Information Technology |
| LAESE | Longitudinal Assessment of Engineering Self-efficacy |
| LITEE | Laboratory for Innovative Technology and Engineering Education |
| PSML | Perceived Subject Matter Learning |
| MIS | Management Information Systems |
| NSF | National Science Foundation |
| SE | Student Enjoyment |

| | |
|---|---|
| STEM | Science, Technology, Engineering, and Math |
| 3P | Presage, Process, Product |
| 4P | Presage, Pedagogy, Process, Product |

# Chapter 1: Introduction

As an industry, education has often benefited from technological developments, specifically, presentation tools, such as the overhead projector and power point, and advancements in the Internet and World Wide Web, such as learning management systems and online education. The referenced cause of these benefits, whether real or perceived is most often associated with improved student engagement through preferred learning styles (Felder & Silverman, 1988). Within the abundance of literature discussing learning styles, it is evident that learner preferences can vary significantly, however findings suggest that specific learning styles should still be given credence when designing or adopting instructional materials (Cegielski, Hazen, & Rainer, 2011). This idea becomes more important when considering the demands of accrediting agencies. For example, ABET, Inc., the elite accrediting body for schools of engineering and the Association to Advance Collegiate Schools of Business (AACSB) require continual improvements from institutions seeking accreditation or re-accreditation. Both ABET and AACSB have called for improved student outcomes associated with problem-solving and real-world skills (AACSB, 2012; ABET, 2011). At the same time, ABET has placed more stringent requirements on faculty regarding the inclusion of technology in curricula and AACSB lists “use of technology” as a preferred skillset.

As the availability of pedagogical tools increases, so will the reliance on such tools by many educators. For instructors, the crux of their decision often involves which tool or material to implement in a specific situation. With a variety of choices, instructors are often unaware of all possible options, or they lack specific knowledge regarding the effects of a particular instructional material. Leidner and Jarvenpaa (1995) provided guidance for selecting from the available educational IS over a decade ago, however, a growing number of technology options has created a need to revisit their work through the examination of modern educational IS. While considering this new and growing list of choices, it's important to address the disparities in the effectiveness among them.

An article by DeSantis (2012) suggests that investment in education technology tripled between 2002 and 2011, to $429 million, the highest percentage of which occurred during a recession. As demand for educational technology increases, the appeal to venture capitalists appears to be the lucrative investment climate, rather than the need for measurable improvements in learning outcomes. However, as I explain in this dissertation, there are two very disparate categories of educational IS, one that applies technology to automate existing instructional processes or information, often in the absence of clear educational goals, and another that develops new processes for solving specific problems related to learning. The latter category is the focus of this research.

While waves of investment and development related to educational technology are hardly limited to recent years, historical narratives exist to warn of dysfunctional information systems resulting from hurried implementations with insufficient design (Ackoff, 1967). In recent years, however, a trend exists that involves hurried development and implementation of educational IS without thorough consideration of a specific problem the technology is seeking to solve. Popular examples of educational IS that have seen widespread adoption, yet are still unproven in many aspects, include the use of e-textbooks and tablets in higher education. After conducting a review of existing literature, Nguyen, Barton, and Nguyen (2014) found that benefits have been reported from the use of iPads in higher education, however, many adopters are still unclear how best to align and integrate them into their academic programs and workflows. With regard to e-textbooks, Rockinson- Szapkiw, Courduff, Carter, and Bennett (2013) found the use of e-textbooks to result in perceived benefits for students, but they did not observe significant results in students grades or cognitive learning when comparing e-textbooks to traditional texts. It appears that these recent educational IS developments, at least in their current state, are digitizing existing processes, rather than developing and implementing new instructional processes. Therefore, a primary motivation of this dissertation is to investigate situations where educational IS can solve problems by developing new processes, and to determine how this type of educational IS can be designed and developed. Throughout the remainder of this dissertation, I refer to this category of technology as wicked educational IS, and I define it by adapting the definition of a wicked problem, presented by Hevner and Chatterjee (2010). *Wicked educational IS* refers to information systems that address problems with unstable educational requirements, in educational environments that are ill-defined, where complex interactions among subcomponents of the problem and its solution exist.

**Design science research**

Design itself has been an object of study in technical disciplines for decades (e.g., computer science and engineering), however, the field of management information systems (MIS) only recently accepted design as a valuable alternative paradigm to behavioral research, with design topics now gaining acceptance in elite MIS journals.

Because IS research exists at the confluence of people, organizations, and technology (Hevner, March, Park, & Ram, 2004), it is natural that MIS research examines both technology's interaction with people and the design of technology itself. To meet recent demands, an area of research entitled design science research (DSR) has evolved to study the design of IT artifacts. Gregor and Hevner (2011) posit a view of the IT artifact that includes any designed solution aimed at solving a problem in context. Others have referred to this process as "exploring by building" (Vaishnavi & Kuechler, 2007) and argue for its ability to answer questions where there is sparse or nonexistent theoretical background.

A major component of DSR is its ability to address *wicked problems*, that is, those problems that possess unstable requirements and ill-defined environmental contexts, or those problems where complex interactions among subcomponents of the problem and its solution exist (Hevner & Chatterjee, 2010). I posit that DSR is the most appropriate methodology for designing and developing wicked educational IS.

While many private technology companies are able to develop and distribute educational learning materials, the apparent mismatch between many of these technologies and student learning preferences suggests the existence of a wicked problem. Literature focusing on learning styles suggests that students have varying strengths and preferences in the way they take in and process information (Felder & Brent, 2005; Felder & Silverman, 1988). Thus, an attempt to develop a "one size fits all" solution in academia is inherently flawed. While it is not feasible or necessary to address the learning styles of every student in every situation, extant research supports the idea that a focus on learning styles can result in improvements in learning outcomes (i.e., more effective). Thus, wicked educational IS represents a problem that, without being addressed through proper design, may result in significant spending without additional benefits for learners.

A literature review revealed numerous DSR studies of properly designed IT artifacts that resulted in effective outcomes. Brohman et al. (2009) produced and implemented a framework for designing network-based customer service systems, Reinecke and Bernstein (2013) developed a prototype web application that supports cultural adaptivity, and Wu (2009) developed a system that allowed flexible form-based knowledge creation and was shown to be effective for problem solving and exploiting activities. Therefore, it is plausible that DSR has the potential to solve the aforementioned wicked problem within educational IS. However, the primary requirement of wicked educational IS, that is, to solve educational problems that result in improved learning outcomes, may be different from those required by designers of business information systems. After an extensive review of the literature, it appears that the application of DSR has been limited to learning in the workplace (M. Wang, Vogel, & Ran, 2011). While Venable (2011) attempted to include DSR in a business research methods course, his contribution to DSR in education was not intended to develop educational artifacts. This scarcity of extant research involving wicked educational IS presents a need to extend the application and testing of DSR methodologies into the domain of educational IS for higher education.

**Research Statement & Methodology**

With the current requirements placed on academic institutions and individual departments by administrators and accrediting bodies, such as ABET and AACSB, it is evident that pedagogy must evolve to meet new demands. Given that DSR literature provides an abundance of evidence supporting its ability to solve problems and produce effective IT artifacts (Gregor & Hevner, 2011; March & Storey, 2008), I believe it is possible that a DSR methodology focused on education can produce wicked educational IS. Thus, I present the following research question with the goal of providing and testing a methodology for developing and implementing wicked educational IS.

R1. How can design science research lead to effective development and implementation of wicked educational IS?

To answer this question, I examine several projects funded by the National Science Foundation and conducted by the Laboratory for Innovative Technology in Engineering Education (LITEE) at Auburn University. I apply a case study research methodology where both qualitative and quantitative data are gathered to investigate the processes applied during several projects that developed wicked educational IS. Table 1.1 lists the projects and their associated problems and solutions.

Table 1.1. LITEE projects as data sources

| NSF Grant # | Wicked Problem | Solution |
|---|---|---|
| 9752353 | Bridge theory, design, & practice | Address learning objectives using multimedia case studies |
| 9950514 | Missing links to STEM education | Include STEM content in multimedia case studies |
| 0089036 | Missing links to IT discipline | Include IT content in multimedia case studies |
| 0442531 | Lack of dissemination | Conduct workshops, publish textbook, offer mini-grants |
| 0736997 | Lack of specific skills in freshmen engineering students | Developed course map for multimedia case study implementation |
| 0623351 & 0966561 | An absence of global research opportunities for students | International travel and development of multimedia case studies by students |
| 0934800 | An absence of plan for implementing and evaluating case studies | Implementation and testing of multimedia case studies using the 4P model |
| 1110223 | Need for immersive instructional methodology | Development of Serious Games |

During the first six projects, LITEE was unaware they were facing wicked problems, however, prior to the start of the serious games project, the co-principal investigator and project manager, Chetan Sankar, recognized the appropriateness of DSR for the design and implementation of a wicked educational IS. Based on extant research involving DSR, I present a design science research methodology (DSRM) for developing effective educational information systems, modeled after the Peffers, Tuunanen, Rothenberger, and Chatterjee (2007) DSRM. Using exemplars in case study research as a guide, I present a post hoc analysis of the development of wicked educational IS and compare the processes used by those involved to the DSRM for wicked educational IS. The resulting data are then used to answer the research question above.

**Contributions of this dissertation**

This study contributes to the IS discipline in three important ways. The first involves the development of a new DSRM for wicked educational IS. The new methodology presented herein extends Peffers et al. (2007) DSRM by examining the efficacy of DSR to produce wicked educational IS. I analyze two wicked education IS to determine that increased communication can lead to a more robust wicked educational IS. Specifically, developers of wicked educational IS can benefit from additional channels of communication at various stages of the design process. Therefore, the updated DSRM requires additional communication at three specific stages: objectives for a solution, design and development, and demonstration.

The second contribution distinguishes between standard educational IS and wicked educational IS designed to solve specific measurable problems in academia, while applying wicked educational IS to STEM education. Much of the existing educational IS digitizes current processes, such as converting textbooks to an electronic format. However, the application of wicked educational IS can solve ill-defined problems that require entirely new processes, such as the development of a serious game. STEM education is faced with several challenges, such as the need for improved outcomes. The results in chapters five and six show that wicked educational IS can improve the learning effectiveness of students in STEM areas.

The third contribution provides a step-by-step description of how a modified DSRM can be applied to guide the development of wicked educational IS. Using a case study research methodology, chapter five applies the DSRM process to analyze the implementation and testing of multimedia case studies, and chapter six uses the DSRM process to develop, implement, and test serious games. These two case studies provide detailed examples that can help other researchers conduct similar experiments.

## Dissertation Outline

This dissertation is organized as follows. Chapter two consists of a literature review that explains the evolution of key constructs used to guide the research methodology. Specifically, I provide an in depth examination of DSR and explain its evolution and growing acceptance in MIS. I include a history of the existing methodologies in DSR used to develop IT artifacts, and I provide examples of successful developments of effective information systems resulting from the application of DSR. I then review the learning styles literature and position the associated theory within this research as a critical component of wicked educational IS design. I describe a variety of educational IS currently employed by academicians and the efficacy of those IS to produce effective outcomes. The literature review concludes by presenting an overview of the learning outcomes required by accrediting agencies and recommendations for meeting those outcomes.

Chapter three presents the research methodology used in this dissertation. A DSRM is presented for the development of wicked educational IS. I provide a rational for using a case study methodology, and explain how it allows one to examine the benefits of the DSRM for wicked educational IS. This chapter also details the procedures used to collect and analyze the data.

Chapter four describes the history, credentials, and work of the Laboratory for Innovative Technology in Engineering Education (LITEE). The work of LITEE, along with its academic and industry partners, developed the two examples of wicked educational IS examined in this study, multimedia case studies and serious games, and provided the necessary data to complete this dissertation. This chapter describes why the educational IS developed by LITEE is considered wicked.

Chapter five examines the implementation and testing of multimedia case studies as a wicked educational IS. Each step of the DSRM for wicked educational IS is explained in detail while examining the design, development, and testing of the multimedia case studies implementation. Data are collected in the form of qualitative narratives, both written and spoken, and quantitative data collected from students, instructors, developers, and the resultant scores from use of the multimedia case studies. Using these data, I compare the actual process used by the LITEE team to the processes recommended by the DSRM for wicked educational IS. A complete list of the LITEE team members is available in Appendix I. The efficacy of each step in the DSRM is examined during this comparison. The results of this analysis contributes to answering the aforementioned research question.

Chapter six applies the DSRM for wicked educational IS to the design and development of a serious game. I document the collaborative effort of LITEE and Toolwire during the design and development of a serious game. The final engineering design game was developed after the earlier iterations were not successful. The DSRM was applied throughout the development of the engineering design game, revealing additional insights that allowed me to answer the research question. A rigorous evaluation effort was conducted to examine the efficacy of the serious game, using both quantitative and qualitative data. The results from this chapter provide the data needed to answer the research question.

Chapter seven describes the key findings of this dissertation in the form of specific benefits associated with the DSRM for wicked educational IS. Chapter eight lists the limitations and future research opportunities associated with this dissertation. Chapter nine elaborates on the specific contributions of this dissertation for both academicians and developers of wicked educational IS, followed by a conclusion.

# Chapter 2: Literature Review

To address the research question discussed in chapter one, it is first necessary to provide an in depth review of the extant literature that served as the basis for this dissertation. This chapter describes DSR and its current state in MIS literature. As a means to bring education and design science literature together, I provide a review of the learning styles literature and learning outcomes literature. Examples of current wicked educational IS are provided along with a description of their effectiveness in higher education.

## Design Science Research

DSR provides a mechanism through which design, testing, and implementation of an IT artifact can be improved to the extent that it represents the essence of what the artifact ought to be. This research paradigm is based on a “build and evaluate” cycle that typically consists of multiple iterations before a final artifact is produced (March & Smith, 1995; Markus, Majchrzak, & Gasser, 2002). Simon (1996) uses the term artifact to describe something that is man-made, or artificial, as opposed to naturally occurring phenomena. Benbasat and Zmud (2003, p. 186) conceptualize an IT artifact as “the application of IT to enable or support some task(s) embedded within a structure(s) that itself is embedded within a context(s).” As DSR is applied to the development of artificial objects, aimed at providing support for problems, the focus of the designer becomes *what ought to be*, rather than *what is* (Simon, 1996).

In the earlier days of DSR, March and Smith (1995) clarified the primary component outputs, or artifacts, of a DSR project, advising that the end result need not be a fully functioning IS. According to March and Smith, common outputs of DSR include: *constructs* (vocabulary and symbols), *models* (abstractions and representations), *methods* (algorithms and practices), and *instantiations* (implemented and prototype systems). As problems arise, *constructs* provide the conceptual vocabulary for the problem or solution domain (Vaishnavi & Kuechler, 2007). Vaishnavi and Kuechler (2007) further explain that *models* provide propositions regarding the relationships among the constructs of interest. They suggest that *methods* are the steps used to perform a task, and *instantiations* operationalize the constructs, models, and methods.

The interaction among people, organizations, and instantiations has garnered the majority of attention from IS researchers through the application of the behavioral science paradigm, often times overlooking the complex nature of the artifact itself (Orlikowski & Iacono, 2001). However, the growing acceptance of DSR, as seen by the number of special issues focusing on this paradigm (Gregor & Hevner, 2011; Hevner & Zhang, 2011; March & Storey, 2008), acknowledges the importance of rigorous design processes and the importance of an effective IT artifact.

In the distant past, MIS programs within business schools made a shift from the design and develop paradigm, found in engineering and software development, to one of examining human computer interaction and the interpretation of systems' influences on the organizations in which they are embedded (Vaishnavi & Kuechler, 2007). Because of this shift, some leading scholars have suggested a return to focusing on the IT artifact itself (Orlikowski & Iacono, 2001). Others support this idea and posit that the limited breadth of recent decades of research can lead to “errors of exclusion” (Benbasat & Zmud, 2003), where the focus of research is too far separated from the artifact itself. However, a return to design and development, coupled with a rigorous methodology for testing, is appearing in the literature in the form of DSR. Kuechler and Vaishnavi (2008) note that a trend within some MIS departments dropping the ‘M’ from MIS has not been coincidental, as many of these departments are acknowledging the emergence of design in the field, and the study of the artifacts themselves is receiving increasing focus, rather than simply the use and impact of the artifacts on management.

Even in the midst of the emphasis on human computer interaction, the benefits of DSR have been touted by a minority of academics for many years (March & Smith, 1995; Nunamaker, Chen, & Purdin, 1991), suggesting that it is “a problem solving paradigm” (Hevner et al., 2004, p. 76). To produce solutions, design science focuses on the identification of a problem that can be addressed by a system or a systematic methodology. Common problems include development of new IS for which existing solutions are not present, or maintenance of current systems. According to March and Smith (1995), development and maintenance are both design activities. Hevner et al. (2004) state that design science creates and evaluates the IT artifacts that are often the object of study in behavioral science research.

Prior to Hevner et al. (2004) there was ambiguity regarding the process of conducting DSR, and existing literature provided a number of disparate starting points for the DS researcher. Much of the basis for conducting DSR revolves around the general design cycle presented by Takeda, Veerkamp, and Yoshikawa (1990). This five-step process began with the awareness of a problem, a suggestion, development of a solution, evaluation, and a conclusion. While this is similar to many of the design science methodologies, current representations have been refined to provide additional emphasis on the rigor of the research process and the communication of results to both technical and managerial audiences.

Hevner et al. (2004) produced the most cited design science article in IS that continues to guide much of today's research. Their work presented seven guidelines to assist researchers in the production of effective artifacts. These guidelines have acted as a catalyst for subsequent methodologies and are based on the premise that knowledge and understanding of a design problem are gained from building an artifact. Their first guideline illuminates the purpose of DSR, to design "a purposeful IT artifact created to address an important organizational problem" (Hevner et al., 2004, p. 82). The second guideline requires the problem to be relevant to "unsolved and important business problems" (Hevner et al., 2004, p. 84). The third guideline suggests that "the utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods" (Hevner et al., 2004, p. 85). The fourth guideline states that there must be "clear contributions in the areas of the design artifact, design construction knowledge (i.e., foundations), and/or design evaluation knowledge (i.e., methodologies)" (Hevner et al., 2004, p. 87). Their fifth guideline requires rigor in the research and design of the artifact, while the sixth guideline suggests that a search must be conducted for the best design, possibly the best available solution rather than the best solution if all possible solutions were known (i.e., satisficing). Finally, the seventh guideline states that research must be communicated to both technical audiences and management.

After examining the guidelines provided by Hevner et al. (2004), and conducting a thorough review of the design science literature, Peffers et al. (2007) proceeded to develop a DSRM to guide future DSR. Their intention was to develop a methodology for the production and presentation of DSR in IS to limit the growing disparity in the field. To achieve this goal, they used a consensus-building approach that incorporated well accepted elements from research in various disciplines. Their DSRM, therefore, included components of design science processes from seven exemplary papers. The resulting methodology, displayed in Table 2.1, contained six process elements: problem identification and motivation, definition of the objectives for a solution, design and development of the IT artifact, demonstration of the artifact's use, evaluation of the artifact, and communication of the process to researchers and other relevant professionals. I used the refined process, presented by Peffers et al. (2007), to create a methodology for developing and implementing wicked educational IS.

Table 2.1. Peffers et al. (2007) Design Science Research Methodology

| Activity | Description |
|---|---|
| 1. Problem identification and motivation | Define the specific research problem and justify the value of a solution |
| 2. Define the objectives for a solution | Infer the objectives of a solution from the problem definition and knowledge of what is possible and feasible |
| 3. Design and development | Determine the artifact's desired functionality and its architecture and then create the actual artifact |
| 4. Demonstration | Demonstrate the use of the artifact to solve one or more instances of the problem |
| 5. Evaluation | Observe and measure how well the artifact supports a solution to the problem |
| 6. Communication | Communicate the problem and its importance, the artifact, its utility and novelty, the rigor of the design, and its effectiveness to researchers and other relevant audiences. |

**Learning Styles and Required Skills**

Design science literature explains that awareness of a problem can arise from new developments in industry or within a specific reference discipline (Vaishnavi & Kuechler, 2007). In the current study, I begin by explicating the potential mismatch between the learning styles of students and some of the traditional instructional materials employed in higher education. Considered a problem by many, the mismatch between instructional materials and learning styles has been the focus of much research when discussing a need for effective educational IS. As a result, a multitude of instruments have been developed, across various disciplines, to measure the learning styles of students. Of these instruments, two stand out as the most commonly applied measures of student learning styles, the Learning Styles Index (Kolb, 1981), and the Index of Learning Styles (Felder & Silverman, 1988). Although these measures share many characteristics, such as interpreting their results as learning preferences that can vary over time and based on environment, the Learning Styles Index (LSI) gained traction in the management literature, while the Index of Learning Styles (ILS) became the predominant measure in technical disciplines, such as engineering. I applied the ILS in the current study to gain insight regarding a sample of engineering students.

Felder and Spurlin (2005) define learning styles as the different strengths and preferences in the ways people take in and process information. These strengths and preferences are divided into four distinct categories, each of which represents two ends of a continuum: active (learn by trying things out, prefer working in groups) or reflective (learn by thinking things through, prefer working individually); sensing (concrete thinking, practical, oriented towards facts and procedures) or intuitive (abstract thinking, innovative, oriented toward theory and underlying meaning); visual (prefer visual presentations, such as pictures, diagrams or flow charts) or verbal (prefer written and spoken explanations); and sequential (linear thinking process, learn in small steps) or global (holistic thinking process, learn in large leaps). Table 2.2 briefly describes each of the learning styles, however, more detailed explanations are provided by Felder and Silverman (1988). The ILS consists of 44 forced-choice items, resulting in a score for each of the four dimensions, ranging from -11 to 11. Scores falling at the ends of the continuum (e.g., 9 to11 or -9 to -11) represent a strong preference for a particular style, while scores near the middle of the continuum (e.g., -1 to 1) represent the absence of a preference, or a weak preference for a particular learning style).

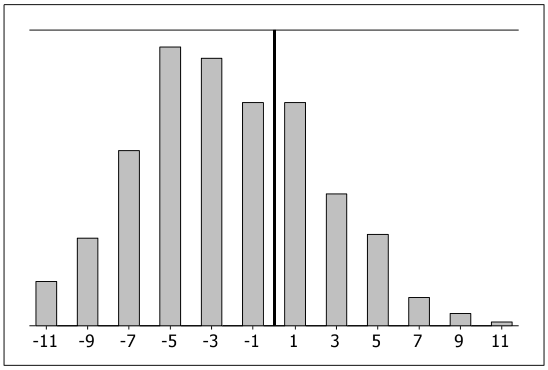
Table 2.2. Description of learning styles. (Felder & Silverman, 1988).

| Dimension | Description |
|---|---|
| Active-Reflective | Active learners prefer to learn by trying things out. Reflective learners think things through and prefer working alone. |
| Sensing-Intuitive | Sensing learners are concrete thinkers who prefer facts and procedures. Intuitive learners are abstract thinkers and are oriented towards theories. |
| Visual-Verbal | Visual learners prefer visual representations of material, such as pictures, diagrams, or charts. Verbal learners prefer written or spoken words. |
| Sequential-Global | Sequential learners prefer a linear thinking process, or thinking in small incremental steps. Global learners prefer holistic thinking, often learning in large leaps. |

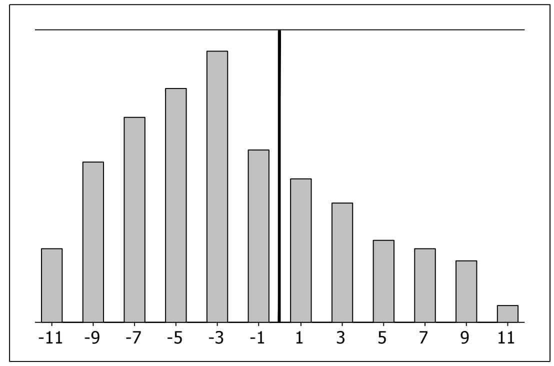
In an effort to examine the learning styles of engineering students, the population of interest in this study, we conducted a survey of multiple “Introduction to Engineering” courses at Auburn University and Hampton University using the Index of Learning Styles questionnaire. Data collection occurred over the course of five semesters: spring 2010, summer 2010, fall 2010, spring 2011, and fall 2011. We administered the ILS survey at the beginning of each semester using the online questionnaire provided by (Felder & Soloman, 1991). Seventy-five percent of the individuals who completed the survey were male. In addition, 57% of the students were freshmen, 15% were sophomores, 9% were juniors, and 19% were seniors. Seventy-six percent of the students came from Auburn University, with the remaining 24% representing Hampton University, a Historically Black College and University (HBCU). The use of two universities representing two distinct races resulted in 73% of the students categorized as Caucasian, 23% African-American, and 4% representing other ethnicities.

The analysis revealed that students have an inclination towards the following learning styles: 70% active, 70% sensing, 90% visual, and 70% sequential. While these percentages reflect the primary learning styles observed in this study, it is also important to consider the strength of each learning style, as these are continuous variables (e.g., -11 to 11), rather than categorical (e.g., active or reflective). The following mean scores and standard deviations represent the strength of each observed learning style: active-reflective is -2.23 (*SD*=4.33), sensing-intuitive is -2.28 (*SD*=5.34), visual-verbal is -5.68 (*SD*=4.45), and sequential-global is -1.73 (*SD*=4.30). Figure 2.1 provides a visual representation of the learning styles observed in this study.

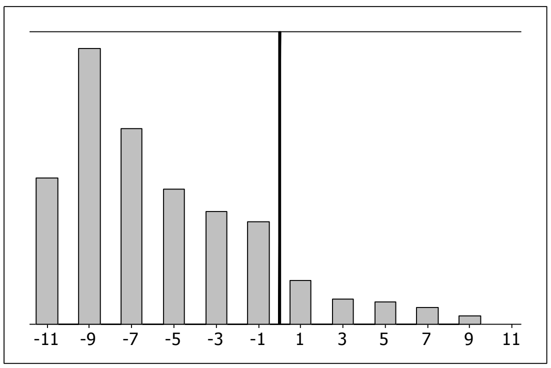
The four graphs in Figure 2.1 represent the frequency of student responses for each learning style dimension. The top-left graph displays students' scores for the active-reflective dimension. The majority of scores on this graph are negative numbers, suggesting a preference for active, rather than reflective learning. Active learning is associated with engaging activities, such as "hands-on" activities or discussion. The top-right graph displays students' scores for the sensing-intuitive dimension. The emphasis on sensory learning (i.e., results in the negative range of numbers) suggests that these students prefer facts or concrete ideas, rather than theories or abstractions. The lower-left graph displays students' scores for the visual-verbal dimension. The high frequency of large negative numbers displays a strong preference for visual learning. Learners in this category prefer pictures and diagrams, as opposed to written or spoken explanations. The lower-right graph displays the results of the sequential-global dimension. The accumulation of scores in the center of the graph suggests a weak preference for a particular style, or the absence of a preference. Based on these findings, I classify these students as active-sensing-visual-sequential, although we cautiously apply the label of sequential learners to these students.



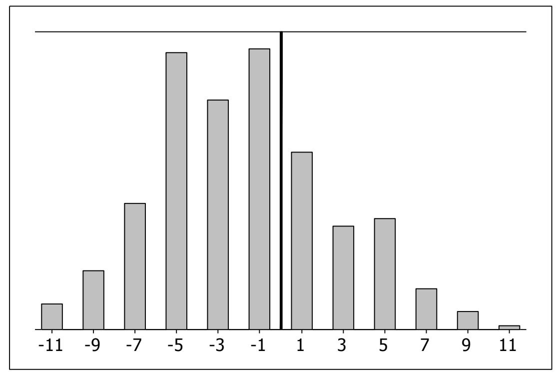

Active (negative) – Reflective (positive)




Sensing (negative) – Intuitive (positive)




Visual (negative) – Verbal (positive)




Sequential (negative) – Global (positive)

*Note.* *n*=393.

Figure 2.1. Learning styles of engineering students.

In an effort to determine the validity and reliability of the ILS instrument, Felder and Spurlin (2005) compared several studies involving engineering classrooms. The results of their comparison revealed a trend among the learning styles of engineering students that is closely aligned with the results of this study, suggesting that engineering students are active-sensing-visual-sequential. These findings provide validation for my results and direction for the development and implementation of wicked educational IS for engineering students.

Cegielski et al. (2011) found support for their assertion that tailoring classroom instruction to students' learning styles may result in better task performance. Their results support both extant research (Felder & Brent, 2005; Hayes & Allinson, 1993, 1996), and my position that DSR involving wicked educational IS should begin by examining student learning styles.

## Learning Outcomes

With knowledge of the preferred learning styles of students, we look towards accrediting bodies, such as the Association to Advance Collegiate Schools of Business (AACSB) and the Accrediting Board for Engineering and Technology (ABET, Inc.), for guidance regarding necessary learning outcomes. As a component of accreditation, most, if not all accrediting organizations specify specific learning outcomes that are currently underemphasized by today's academicians and must be addressed through changes to current curricula. Specific outcomes requested by ABET include the ability to: function on multidisciplinary teams, solve problems, and communicate effectively (ABET, 2011, p. 3). Likewise, AACSB provides specific learning outcomes for colleges of business, such as the need for communications abilities, problem-solving abilities, and ethical reasoning skills (AACSB, 2012, p. 62). As accrediting bodies work to improve the quality of graduates entering the workforce, educators and researchers are provided with a list of outcomes to guide the development of wicked educational IS. Therefore, developers of wicked educational IS must strive to ensure that these learning outcomes are achieved through appropriate design.

## Effective and Innovative Wicked Educational IS

For most of the world, IS has become an ever increasing part of our personal and business lives, and this is no different when considering education. The current generation of students, also referred to as "digital natives" (Prensky, 2001), have been trained from childhood to handle large amounts of information quickly, use various methods for gathering information, and use alternative methods to communicate (Gibson, Aldrich, & Prensky, 2007). We see a recognition of this in academia and industry, with higher projected investments for online learning initiatives (Dick, Case, Ruhlman, Van Slyke, & Winston, 2006). In recent years, wicked educational IS have been introduced in the form of multimedia case studies, simulations, serious games, and a variety of other alternatives aimed at improving learning outcomes and increasing access to education.

With a wide selection of technology tools at their disposal, the problem for many educators has become how to choose the appropriate tools for a particular discipline and a specific course. This is often done through trial and error, or based on recommendations from colleagues and publishers, rather than an examination of student learning styles and required outcomes. A primary argument of the current study is that an appropriately designed wicked educational IS can be used to effectively improve most learning outcomes, thus meeting the needs of industry professionals and accrediting institutions. Fortunately, extant literature includes many examples of technology use in education, providing a starting point for the journey into the design of an artifact aimed at improving educational outcomes. However, close scrutiny is required to distinguish between educational IS that simply digitize existing processes, and wicked educational IS that address specific problems. While the description of all existing artifacts is beyond the scope of this study, DS researchers can benefit from an awareness of the wicked educational IS currently used in their discipline. For example, business and engineering employ techniques such as simulations (Kachra & Schnietz, 2008), and multimedia case studies (V. W. A. Mbarika, C. S. Sankar, & P. K. Raju, 2003). In addition, there is a growing area of wicked educational IS focusing on digital games and their ability to improve learning outcomes (Burgos, Tattersall, & Koper, 2007; Gibson et al., 2007; Prensky, 2001).

## Chapter Summary

In summary, this chapter reviewed the DSR literature, providing an overview of key methodologies employed by researchers. The DSRM developed by Peffers et al. (2007) provides the basis for the current research and its examination of wicked educational IS. I discussed the learning styles construct and provided an overview of the dominant learning preferences in our population of interest, engineering students. Two accrediting bodies were discussed, AACSB and ABET, and specific learning outcomes were listed as problem areas for designers of wicked educational IS. Finally, a selection of existing wicked educational IS were mentioned as options for achieving the abovementioned learning outcomes.

# Chapter 3: Methods

## Research Methodology

Having discussed the ability of DSR to produce valuable IT artifacts, I contend that a methodology is needed to address the problems specific to wicked educational IS. Therefore, the goal of this dissertation is to compare existing design, development, and implementation practices to a DSRM for wicked educational IS, and this comparison is completed in two primary steps.

The initial stage of the methodology section involves the development of the DSRM for wicked educational IS. This is done by expanding the framework developed by Peffers et al. (2007). While their framework is a valuable tool for conducting general DSR, I provide a detailed approach for addressing the development of wicked educational IS.

The second stage of the methodology section explains the process for data collection and analysis of wicked educational IS. Two examples of wicked educational IS were developed and implemented by LITEE. In the latter chapters of this dissertation, each of these is closely scrutinized using the DSRM for wicked educational IS. The process of comparison, for the purposes of this dissertation, is being conducted post hoc, however, I was involved as an evaluator in the original data collection and implementation. My involvement provides unique insight in the original testing process of the multimedia case studies, and allows me to compare that process to the DSRM developed in this chapter. The methodology used to conduct the comparison is a case study comprised of both quantitative (i.e., data from the evaluation stages of the multimedia case study implementation and the serious games development) and qualitative data (e.g., data collected from focus groups, survey responses, and additional data documenting the process of development). The results of this comparison will allow refinement of the DSRM for wicked educational IS while answering the following question:

R1. How can design science research lead to effective development and implementation of educational IS?

**A DSRM for Wicked Educational IS.** Using the methodology developed by Peffers et al. (2007) as a basis, I articulate a methodology for effectively developing and implementing wicked educational IS. The intent of this methodology is to develop a roadmap for designers in academia and industry to apply to a variety of wicked educational IS design projects. I developed this methodology with two objectives in mind. First, industry developers and academicians, working in collaboration, could benefit from a rigorous roadmap focusing on both the research techniques applied by academicians and the technical experience of industry professionals. Second, by providing a starting point for the design of wicked educational IS, those applying this methodology can produce practical artifacts while contributing to the theoretical conversation of DSR. The resultant methodology appears in Figure 3.1, with a description of each step appearing in the subsequent sections.

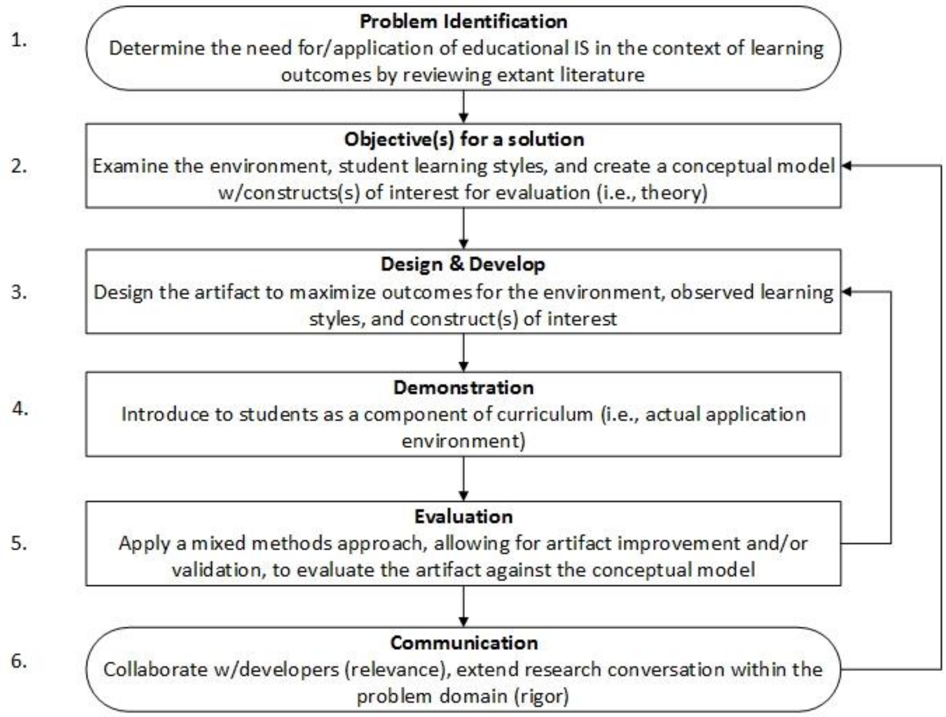



Figure 3.1. DSRM for developing wicked educational IS

***Step 1: Problem identification.*** Regardless of the DSRM used, consensus exists that all approaches must begin with the recognition of a *wicked problem*. I argue that the design and development of wicked educational IS to accommodate the learning styles of students while improving learning outcomes is such a problem. As noted in Figure 3.1, designers of wicked educational IS should consider their needs in the context of learning outcomes. While this is easily stated, there is still much discussion and confusion regarding the appropriate methods for each situation and discipline to meet desired learning outcomes. In essence, the complexity of this problem and the lack of a clear solution is a superb example of a wicked problem.

Holmström, Ketokivi, and Hameri (2009, p. 71) add clarification to the problem identification step in DSR by explaining that “it is not the finding or identification of problems per se that is challenging, it is the way problems are framed….because there are typically multiple ways in which any given problem can be framed." Within the realm of education, several problems abound that might appear to benefit from educational IS, however, it is important that the researcher frame their problem after examining extant research to determine whether the problem exists because of a lack of effective instructional methodologies or something entirely unrelated, such as inappropriate implementation (e.g., over or under use). Further, because this methodology is intended to address the cross-disciplinary nature of wicked educational IS, each researcher should begin by examining the current knowledge base for existing solutions in both their specific discipline, and related disciplines that may have addressed the problem. If an existing educational IS exists, but is ineffective, the researcher should frame the problem using a theoretical argument to support the need for an improved instantiation. Throughout this process, the researcher must remember that in order to qualify as DSR, the resulting contribution must do more than apply current processes. Instead, the result should produce expanded IS capabilities or its application to areas that were "not previously believed to be amenable to IT support" (Markus et al., 2002, p. 180).

***Step 2: Objectives for a solution.*** As an argument for a specific problem becomes accepted by the community within a particular discipline (e.g., professional skills are necessary but underdeveloped in technical students), the DS researcher must define the objectives for the solution (Peffers et al., 2007). Adhering to the emphasis on rigor in DSR, I suggest that specific characteristics of the student population of interest be examined before engaging in the action of design and development. Specifically, I contend that DS researchers should become aware of the learning styles of students using a reliable and valid technique. The most common instrument applied in the technical disciplines is the Index of Learning Styles Questionnaire (Felder & Soloman, 1991). In the field of management, the articulation of learning style dimensions and types by Kolb (1981) presents a slightly different method for determining learning styles via the Learning Styles Inventory (LSI). Both of these instruments have found wide acceptance in their respective literature and appear to provide a starting point for acceptable objectives for a solution when designing wicked educational IS.

To further clarify the objective(s) for a solution, I suggest that the researcher develops a conceptual model to exemplify the desired relationships of a successful implementation. For example, a DS researcher interested in the development of serious games may posit that stickiness (Zott, Amit, & Donlevy, 2000), playfulness (Martocchio & Webster, 1992), and flow (Csikszentmihalyi, 1991) contribute to the success of the serious game. In this instance, it is the responsibility of the researcher to define the constructs and any hypothesized relationships, using extant literature as a basis for design and development.

The researcher must also examine the context or environment surrounding the problem. March and Smith (1995) suggest that one of the difficulties of design rests in the designer's incomplete understanding of the environment in which the IT artifact is intended to operate. Within the realm of education, individual faculty often have a teaching philosophy consisting of a specific learning model. Leidner and Jarvenpaa (1995) provide an overview of common models of learning and the assumptions that accompany these models. For example, one model of learning assumes that the instructor is the source of objective knowledge that is relayed to learners (e.g., objectivist model), while another assumes that individuals must discover things on their own and construct knowledge (e.g., constructivism). In other cases, instructors might encourage learning through collaboration (e.g., cooperative or collaborative learning). Failure to appreciate the intricate details of the learning environment during design can result in inappropriate design or unintended side effects. For this reason, developers should be aware of the characteristics and requirements of their specific implementation before designing wicked educational IS.

***Step 3: Design and development.*** The third step entails the actual design and development of the artifact, whether it be a construct, model, method, or instantiation (March & Smith, 1995). Peffers et al. (2007) explain that this activity includes determining the artifact's desired functionality and then creating the artifact. Because IS researchers may not have the time or resources to engage in professional design and development of an wicked educational IS, I acknowledge, and reiterate the recommendation by Hevner et al. (2004) to seek collaboration between industry and academia. Realizing that design science is an iterative process, this step may require the researcher to begin by designing and developing an artifact within temporal or monetary constraints, such that a minimum solution is found for the initial iteration (i.e., satisficing) (Simon, 1996). While some observers might perceive the acceptance of an incomplete or minimally acceptable artifact as a weakness of DSR, it may actually be a strength of the process, allowing DS researchers to progress through the iterative activity of building and evaluating, while collecting valuable data that will strengthen the effectiveness of the final product. It is this stage where designers apply the information gathered about student and environmental characteristics. If, for example, the population of interests is predominantly comprised of visual learners, it may behoove the designer to account for this learning preference via the inclusion of images, video, or animation. At the same time, an instructor may apply learning models based on collaborative work, suggesting the wicked educational IS should be designed around group or team activities. Trigwell, Prosser, Ramsden, and Martin (1998) found a correlation between student-centered teaching approaches such as active and cooperative learning and students' adoption of deep learning.

***Step 4: Demonstration.*** Options for demonstrating the wicked educational IS will also vary based on the type of IS and the intended environment for application. However, as academicians, we benefit from readily accessible sample populations. Peffers et al. (2007) suggest that demonstration could include experimentation, simulation, case studies, proofs, or other appropriate activities. However, when examining a functioning wicked educational IS, I contend that experimentation in an actual classroom setting will allow for the most rigorous methods of evaluation and the most conclusive feedback for subsequent iterations of the design process.

Most institutions of higher education require an institutional review prior to conducting studies involving human subjects (e.g., institutional review boards). While this is often perceived to be a cumbersome process, it is a necessity that warrants inclusion in this methodology due to its protective characteristics for participants and the additional guidance provided to researchers. For some, it is possible that the review process contributes rigor, while encouraging researchers to clarify their goals and methods used. Additionally, the process of institutional review board approval may assist researchers during publication (i.e., step six, communication).

***Step 5: Evaluation.*** A primary differentiating characteristic between design and DSR is the rigor required in the evaluation stage. Therefore, it is crucial that evaluation techniques measure the relationships among the constructs of interest, specified in the conceptual model in step two (i.e., objectives for a solution). Peffers et al. (2007) note that the method of evaluation may vary, depending on the nature of the problem and the artifact involved. However, I offer some guidance here, suggesting that the nature of the problems addressed by wicked educational IS are best evaluated using the most rigorous approach that provides the most specific guidelines for future iterations. I proffer that a mixed methods approach meets these criteria for both its exploratory and explanatory value. In mixed methods research, the researcher collects and analyzes both quantitative and qualitative data, based on the specific research questions of the study. Then, the data are mixed or integrated, whether concurrently, by combining the data, or sequentially, by allowing one method to build on the other (Creswell & Plano Clark, 2011). While qualitative research can provide many benefits for the development of wicked educational IS, through its open ended method of inquiry, quantitative analyses provide the structured techniques for examining the validity of wicked educational IS to perform as it is intended (i.e., answering specific questions). An example of mixed methods research may be the collection and analysis of both survey data and focus group data. Together, these techniques can provide ideas for subsequent alterations of the wicked educational IS and testing its value in the classroom. Hevner et al. (2004, p. 85) explain that "IT artifacts can be evaluated in terms of functionality, completeness, consistency, accuracy, performance, reliability, usability, fit with the organization, and other relevant quality attributes." This step of the methodology, therefore, should receive thorough consideration during the initial identification of objectives for a solution.

***Step 6: Communication.*** The contribution of DSR goes beyond the IT artifact developed during the aforementioned steps. March and Smith (1995) suggest that "explicating and evaluating IT artifacts" will contribute to the field through ease of categorization, and the reduction of wasted efforts aimed at building and studying artifacts that exist or have been studied. Hevner et al. (2004) explain that research must be communicated to both technology-oriented audiences and management-oriented audiences. This dual communication provides the basis for avoidance of time wasted, as suggested by March and Smith, and the guidance for managerial audiences to construct and apply the artifact in the necessary context.

The expanded DSRM presented in this research provides specific requirements and examples for designers of wicked educational IS that were heretofore unstated within the literature. Therefore, either validation or refinement is necessary for this DSRM to achieve status as an acceptable methodology within the DSR literature. The following section explains the method by which I attempt to validate this new DSRM.

**Case study methodology.** As research in the area of IS matures, the number of methods available to IS academics continues to grow. The choice of a specific method, or multiple methods, depends on the topic area, research question, researcher's background, and the audience (Palvia, En Mao, Salam, & Soliman, 2003). More recently, major publications have become more accepting of a variety of methods for studying phenomena (Gregor & Hevner, 2011), however, certain methods have consistently been preferred for their rigor and practicality. Specifically, case study research (CSR) has gained wide acceptance in recent decades as evidenced by increased publications in top journals, and the creation of new case study specific journals. Palvia et al. (2003) explain that case studies allow the opportunity to study a phenomenon in greater depth, typically in an organizational setting. They further suggest that CSR is credited with high levels of internal validity. Others, such as Lee (1989), argue that CSR can have as much rigor as quantitative research. Gibbert and Ruigrok (2010) also assert the rigor of case study research and clarify both the criteria and techniques for ensuring rigorous case study research: construct validity, internal validity, external validity, and reliability. While these criteria for rigorous research mirror those in positivist research, the techniques used to clarify these to the audience differ in case study research. During the data collection and analysis stages of this dissertation, I follow the recommendations of Gibbert and Ruigrok (2010), in which they explain how to insure validity and reliability in case study research. The specific steps taken are explained in more detail in the next chapter.

In the latest edition of his seminal book discussing case study research, (Yin, 2008, p. 18) defines CSR as "an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident." Creswell (2009) further explains that cases are bounded by time and activity, where researchers collect data using a variety of techniques over an extended period of time.

While case studies can be conducted for varying purposes, such as descriptive, exploratory, or explanatory reasons, several scholars contend that exploratory case studies are the most appropriate use of the methodology and play to the strengths of the case study method (Pan & Tan, 2011; Siggelkow, 2007). I classify the current study as exploratory in that its goal is to test a new methodology. Prior to this study, the DSRM for wicked educational IS was untested, and merely conceptual. This aspect of the study highlights a strength of the methodology. Specifically, case studies provide an avenue to illustrate conceptual models.

## Procedures

**Population and sample.** The population of interest is comprised of technical designers from industry and academia intent on developing wicked educational IS. Considering that many academicians currently rely on prepackaged software in their classes, the number of potential consumers of this information, at the time of this writing, is small. This is fitting for the application of a case study, that is, a situation where only few organizations or samples exist to provide the necessary data for the study (Siggelkow, 2007). As the use of DSR for the development of wicked educational IS gains traction, this trend may change.

Considering the limited availability of organizations whose' mission is to develop wicked educational IS, the Laboratory for Innovative Technology in Engineering Education (LITEE) is an appropriate sample for the current case study research. Siggelkow (2007) explains that it is often desirable to choose a particular organization, rather than using random selection, when the focus of the research is to gain certain insights that other organizations would not be able to provide.

In 1996, a collaborative effort began between two professors at Auburn University, one representing the college of business, and the other representing the college of engineering. The goal of this effort was to create instructional materials for developing the professional skills of engineering students in order to meet the changing needs of ABET, Inc. and the interests of the National Science Foundation (NSF). As a result, LITEE was formed. Through the acquisition of grants from the NSF, LITEE produced a curriculum based on the use of multimedia instructional materials. In total, LITEE has attracted 12 grants from the NSF, budgeted at $2.5 million and sixteen grants from Auburn University and private industry, budgeted at $125,000. For more than ten years, LITEE has developed multimedia instructional materials in collaboration with students, and the resulting materials are currently used in classrooms at Auburn University and a variety of other universities in the United States. In total, LITEE has partnered with 23 universities. The result of LITEE's efforts produced 31 multi-media case studies based on real world scenarios in actual companies (LITEE, 2014). Dissemination efforts have resulted in the creation of a the *Journal of STEM Education: Innovations and Research*, numerous publications of articles and books, and workshops around the country (LITEE, 2012). A more thorough description of LITEE’s work is offered in chapter 4.

**Data collection.** Data collection for this dissertation was driven by the aforementioned DSRM for developing wicked educational IS, while following a case study methodology. Therefore, collection for each step of the DSRM process occurred by examining the design, development, and implementation of multimedia case studies and comparing the processes used to those described in the DSRM. The results of this data collection provide the basis for my analysis and allow me to answer the aforementioned research question. The majority of data examined in this dissertation were drawn from archival sources, such as reports, meeting minutes, and previous data collections.

Following the social sciences tradition of rigorous data collection, I applied tactics identified by Yin (2008) to ensure construct validity and reliability during the collection process. In order to defend a claim of construct validity, Yin suggests the use of multiple sources of evidence, establishment of a chain of evidence, and allowing informants to review a draft of the case study report. To meet these criteria for construct validity, data were collected from a minimum of two sources for each step of the DSRM, and dozens of sources for the overall process. Appendix A provides a list of sources used. Considering the abundance of sources available, it is feasible to expect a chain of overlapping evidence to appear in the multitude of sources used in this study. Prior to the submission of the final draft of this case study, key informants were asked to review the case for errors, including those of omission.

Regarding the concept of reliability, Yin suggests that researchers apply methods to ensure that data collection can be repeated by others and result in the same or similar findings. To allow for consistency, I adhered to the data collection sources found in Appendix A for qualitative measures, and I generated quantifiable measures and counts, such as the amount of communication among the design team via meeting minutes and email exchanges. As a component of this study, I created a database to house both qualitative and quantitative data.

As a subcomponent of the data collection process described above, further data collection occurred for the evaluation stage of the DSRM. The data collection and analysis for the evaluation stage is described in depth below.

**Data analysis.** Data analysis consists of a comparison of the process used to implement multimedia case studies by LITEE to the six stages of the DSRM for developing effective wicked educational IS. To do this, a problem-driven content analysis was conducted. Krippendorff (2004, pp. 342-343) suggests that a problem-driven content analysis derives “from a desire to know something currently inaccessible and the belief that a systematic reading of potentially available texts could provide answers.” Therefore, the data listed in Appendix A were analyzed through frequency counts of team member communications (i.e., minutes from meetings, emails, etc.), and content analysis of journal articles, conference papers, and annual reports to identify the designers ability to clarify specific components of the DSRM, such as problem identification or objectives for a solution. The comparisons in chapters five and six of this dissertation provide an examination of the alignment between the actual design processes used and the DSRM for wicked educational IS. The results of this analysis provide insights regarding the effectiveness of the wicked educational IS, and providing detailed answers to the research question stated above.

In order to meet the demands of internal validity, Yin suggests that case study researchers must do pattern matching, explanation building, address rival explanations, or use logical models. Through the collection of minutes from meetings, annual reports, and focus group responses, I determine the existence of patterns for each of the steps in the DSRM. In addition, more extensive literature reviews were conducted to find alternative explanations for our findings.

Typically considered the heart a behavioral research study, the evaluation process must be given considerable attention and completed in a rigorous and detailed manner. Within a DSR study, however, evaluation is a single component of a multistep process.

Therefore, the evaluation and analysis processes are described separately from the other stages of the DSRM in subsequent chapters.

## Chapter Summary

In summary, this chapter advanced a modified DSRM for developing wicked educational IS. The six stages of this DSRM were described in detail with recommendations for educational designers. The method of research for this dissertation, case study research, was presented as a valid method for answering the research question. The sample and data collection process was described. Finally, an overview of the qualitative and quantitative analysis techniques was presented to compare the actual design of the wicked educational IS to the recommended steps in our DSRM.

# Chapter 4: The evolution of wicked educational IS at LITEE

## Overview

In order to provide the context and justification for the development and implementation of the multimedia case studies and serious games produced by LITEE, it is beneficial to view the evolution of projects conducted by this organization. To do this, I describe the work of LITEE across a span of time in which they completed six projects funded by the National Science Foundation (NSF). To clarify the connection to DSR and wicked educational IS, I summarize each of LITEE's projects by stating the educational problem faced, and the resulting solution. The documentation of these projects provides a historical narrative to detail the actions of the LITEE team and provide a springboard for the application of the DSRM for wicked educational IS in the following chapters. Each project described in this chapter was completed with financial support from the NSF and with the general purpose of producing and implementing new innovations for teaching engineering in higher education. Table 4.1 summarizes the projects completed by LITEE, including the multimedia case study implementation and serious game design described in chapters five and six, respectively. These grants represent NSF's Division of Undergraduate Education (DUE), Engineering Education and Centers (EEC), Industrial Innovation and Partnerships (IIP), and International Science and Engineering (ISE).

Table 4.1. Re-presentation of LITEE projects as data sources

| Grant # | Wicked Problem | Solution |
|---|---|---|
| 9752353 | Bridge theory, design, & practice | Address learning objectives using multimedia case studies |
| 9950514 | Missing links to STEM education | Include STEM content in multimedia case studies |
| 0089036 | Missing links to IT discipline | Include IT content in multimedia case studies |
| 0442531 | Lack of dissemination | Conduct workshops, publish textbook, offer mini-grants |
| 0736997 | Lack of specific skills in freshmen engineering students | Developed course map for multimedia case study implementation |
| 0623351 & 0966561 | An absence of global research opportunities for students | International travel and development of multimedia case studies by students |
| 0934800 | An absence of plan for implementing and evaluating case studies | Implementation and testing of multimedia case studies using the 4P model |
| 1110223 | Need for immersive instructional methodology | Development of Serious Games |

This chapter proceeds as follows. The initial section briefly describes the purpose and organization of LITEE, while the following sections serve to document the history of LITEE by examining six projects conducted over fifteen years (i.e., 1997-2011). Each project is summarized, providing details relating to the length of the project, the scope of the project (i.e., people, organizations, funding), and outputs associated with the project. Specific emphasis is given to the outcomes of the projects and the processes by which they were achieved. The final section of this chapter provides lessons learned from the aforementioned projects, and their contribution to LITEE's shift towards DSR.

**History of LITEE**

Since its inception in 1996, LITEE has focused on producing innovative instructional materials that allow engineering students to meet the changing expectations of industry professionals. As a collaborative effort between the college of business and college of engineering at Auburn University, LITEE has relied on interdisciplinary techniques to generate numerous multimedia case studies that present real-world problems to students. Aided by undergraduate and graduate students, the faculty members of LITEE have amassed resources and expertise, which are applied to the development and implementation of innovating instructional techniques at Auburn University, and have subsequently been used by approximately 60 academic and industry partners throughout the world (LITEE, 2012). Over 10,000 engineering and business students have used LITEE case studies in classes, and LITEE has trained over 50 practicing engineers. In recognition of their work, LITEE has received several awards and honors for developing innovative instructional techniques and for integrating theory, design, and practice into Mechanical Engineering design courses.

The majority of LITEE's work focused on the development and testing of multimedia case studies, that is, case studies that teach by combining several types of media, such as text, graphics, video, animation, music, and sound effects (Bradley, Mbarika, Sankar, Raju, & Kaba, 2007). Over the course of the last decade, the LITEE team has harnessed the funding of the NSF to develop these case studies. LITEE's initial grant was awarded in 1997, launching a string of nine projects, documented herein. Table 4.2 lists each of LITEE's NSF funded projects and the multimedia case studies developed or improved as a result of each project.

Table 4.2. Cases developed or improved

| Grant # | Time Frame | Case Studies Developed or Improved |
|---|---|---|
| 9752353 | 1997-2000 | Crist, Della, STS51L, AUCNET |
| 9950514 | 1999-2003 | Della, Chick-fil-a, Crist, STS51L, In Hot Water, AUCNET, Lorn |
| 0089036 | 2002-2008 | Powertel, Yuquiyu Motors, Lorn, Crist, Chick-fil-a, Superstar, Larsen & Toubro, Wellborn, Yuquyi Motors, Spanish Della |
| 0442531 | 2004-2011 | N/A, Dissemination of case studies |
| 0736997 | 2009-2010 | N/A, Implementation in Freshmen Engineering course |
| 0623351<br>0966561 | 2007-2011 | Acoustic Emission Testing, Automatic Weld Inspection, Data Synchronization, Thermal Comfort I, Solar Panel Installation at a Rural Village, Handbag Design from Rural India, Thermal Comfort II, Functional Dormitory Design, Laser Ultrasonic, Impact Echo Prototype and Business Plan, Telemedicine, Induction Welding, Mauritius Auditorium Design. |

**Funded Grant 9752353**

During the time frame between 1997 and 2000, LITEE conducted a study entitled Bringing Theory and Practice Together in Engineering Classrooms: A Research Project to Develop Cost-Effective Instructional Material. This project produced several multimedia case studies.

**Problem.** When reviewing the archival records associated with this project, it was apparent that the LITEE team was faced with two problems. First, in many technical disciplines, such as engineering, instructors have struggled to bring together theory, design, and practice in such a way that students graduate ready for the workforce. This problem was particularly concerning for members of industry who hire engineering students and expect a basic set of skills that oftentimes go beyond the theoretical learning expectations of academia. This lack of preparation can result in additional investments in training by employers. The second problem facing LITEE was the limited higher-level cognitive skill development of students. Decades of traditional learning where educators lecture from a podium, while students take notes at the desk, had failed to produce effective decision makers who are able to examine alternatives and make appropriate choices. The unstructured and ill-defined nature of this problem represent a truly wicked problem.

**Solution.** In order to solve each of the aforementioned problems, the LITEE team decided that certain student learning objectives must be met. It was determined that the first problem, bringing together theory, design, and practice, could be addressed through the acquisition of two specific areas of skills (a) technical, financial, credibility, and management issues in decision making, and (b) team working and effective communication. The second solution focused on higher-order skill development and relied on student learning objectives that required them to (a) identify criteria, (b) analyze alternatives, (c) make a choice, (d) defend a choice, and (e) be active learners.

In order to achieve these solutions, LITEE set out to develop multimedia case studies. This type of instructional methodology appeared to be an appropriate solution because they allow faculty to present students with all of the discipline specific information required to engage in critical thinking and problem solving, regardless of one's background.

The design and development of the multimedia case studies required organizations who were willing to share actual problems and solutions from their own experiences. The LITEE team engaged in data collection with management and engineers from four organizations: Della Steam Plant, Crist Power Plant, NASA and MTI, and

AUCNET USA. Over the course of several months, students and faculty from Auburn formalized the case details and made iterative improvements with each organization. Following the fact gathering of the actual events, LITEE conducted research to assemble competency materials on topics appropriate to each case. In cooperation with the Auburn University Education/TV Services, videos were made to allow instructors to present students' recreations of events and examples of processes included in each case study. At the conclusion of this project, the Della Steam Plant was the only case to be entirely finalized and published as a multimedia case study, providing students with a CD-ROM that integrated videos, photographs, and texts. Although most were unfinished, each of the case studies was implemented during the course of this project.

In order to demonstrate and evaluate the case studies, the Della case study was implemented in both engineering and business classrooms. At the core of this implementation, students were required to work in groups. Each group then assumed one of the decision making roles in the plant, either plant manager or engineer. Students were faced with conflicting decisions that required critical thinking, analysis, and problem solving skills. Finally, students made recommendations and presented them to the class. The other three case studies were also implemented, either at Auburn or another educational institution.

An evaluation of the Della case was conducted at various institutions and during multiple semesters by an external evaluation team. Students were divided into control groups (i.e., no multimedia case study use), and experimental groups (i.e., use of multimedia case studies). Data were gathered from students in the form of surveys, consisting of Likert scale items ranging from one to five. In each data collection, the constructs represented in the instruments were found to have sufficient reliability. Constructs included perceived skill development, self-reported learning, intrinsic learning and motivation, communication skills, and ability to learn from fellow students. With the exception of communication skills, the median scores of each construct revealed positive results. In other words, the multimedia case study appeared to address the problems and goals of the project. During the evaluation, feedback was requested regarding improvements to the cases. This feedback included suggestions for future implementations of the cases. With regard to DSR, incorporation of feedback is vital if future iterations are to be developed.

Additionally, a longitudinal evaluation was conducted at Auburn University in which the grades of students in both experimental and control sections were observed during subsequent semesters. Initially, grades from students in the control group appeared higher, however, within two terms of the completion of this course, mean grade point averages for students in the experimental group were observed to be higher than the mean grade point averages of students in the control group. This could suggest that the skills acquired from use of multimedia case studies benefited students during the remainder of their degree program. The findings of this study were eventually published in the form of four case studies, as well as components of engineering textbooks.

**Funded Grant 9950514**

During the time frame between September 1999 and August 2003, LITEE conducted a study entitled Multi-Media Courseware Development to Bring Real-World Issues into Classrooms: A Research Project to Improve Engineering and Technological Education.

**Problem.** A review of the archival data from this project revealed that the predominant problem facing the LITEE team was a missing link between multimedia case study content and science, technology, engineering, and math (STEM) education and real world issues. Based on the extant research at the time of this study, policy makers were beginning to realize that STEM education was critical to America's future. Coupled with this was the growing retention problem in schools of engineering throughout the US. Additional problems included a lack of understanding regarding the effectiveness of multimedia case studies in higher education, and their adaptability for high school. The complex nature of this problem is yet another example of a wicked problem.

**Solution.** To address the disconnect between the existing multimedia case studies and STEM learning, LITEE members sought to improve the connection between the case studies and STEM by identifying specific topics and learning objectives that could be demonstrated using real world examples. Competency materials in a variety of STEM areas would need to be developed for existing and future cases so that students in engineering and business would be able to understand and analyze the cases based on their own background. In addition to improving the existing multimedia case studies, LITEE determined to establish new contacts with industrial partners who were willing to assist in the creation of new case studies. Overall, the goal of improving existing case studies and the creation of new materials was intended to address the STEM disconnect, while also allowing an opportunity for classroom implementation and a more rigorous evaluation of the case studies.

In total, seven cases were designed as new or improved multimedia case studies. These cases included Della Steam Plant, Chick-fil-a, Crist Power Plant, NASA STS 51-L, In Hot Water, AUCNET USA, and Lorn Textiles. The LITEE team was able to produce links to the following four competency areas for each of the seven multimedia case studies: science topics, technology and engineering topics, math topics, and business topics. After developing these competency areas for each study, LITEE members met with organization representatives to produce the appropriate multimedia materials necessary to illustrate real world examples of these concepts.

The resulting multimedia case studies were implemented in engineering classrooms at multiple universities to meet the objective of more rigorous tests of the case studies. To determine whether or not these cases could be adapted and implemented in high schools, the LITEE team implemented them in a high school physics class and via a special workshop for 4-H students in Birmingham, AL.

Once again, an external team of evaluators was tasked with examining the efficacy of these multimedia case studies. Surveys were used to measure student perceptions of their learning and to provide feedback about the case studies themselves. Both quantitative and qualitative results supported the objectives of the project. Students at multiple universities perceived the material to be relevant and useful for their disciplines. An additional form of evaluation was conducted via e-journals. Students replied to eight questions after each study that were used to identify dominant themes among the students. For example, common themes of students at Auburn revealed that the cases resulted in "improved interest in coursework, increased technical curiosity and technological awareness, development of personal skills, and better business skills." Findings were consistent across semester, and between two different courses.

High school students also completed questionnaires. The statistical results of these surveys revealed that students could see a connection between physics and the real world through examples in the multimedia case studies.

The results of this study were disseminated through a variety of channels. Numerous journal publications, conference presentations, and marketing materials through publishers were developed. However, in order to reach a wider audience, LITEE began holding workshops for faculty where they could discuss the results of this study and encourage faculty to adopt the multimedia case studies in their own classrooms.

**Funded Grant 0089036**

During the time frame between February 2007 and January 2008, LITEE conducted a study entitled Educating Engineers for the Information Age: A Real-World Case Studies Based Project.

**Problem.** Even with the success of the previous projects, and the resulting case studies that focused heavily on engineering and business, the multimedia case studies were still lacking with regard to certain disciplines. At their core, multimedia case studies rely on information technology (IT) to engage students; however, the case studies produced by LITEE to this point contained very limited material to teach content from the IT discipline. Therefore, the problem for LITEE in this project centered on how best to teach IT to engineering and business students. Extant research at the start of this study revealed that engineering was beginning to rely on IT for virtually every new product and process. In addition to this, the industry demand for employees knowledgeable in IT was drastically increasing. As an expansion of earlier projects, the complexity continued to grow. LITEE was beginning to experience the true meaning of a wicked problem.

**Solution.** To better prepare students, and to solve the aforementioned problem, LITEE decided to develop new case studies that could introduce students to the complexity of real-world problems and show how engineering companies work in the information age. This was to be done by creating or modifying the following case studies: Chick-fil-a, Powertel, Lorn manufacturing, Yuquyi motors, Superstar Corporation, Larsen & Toubro Limited, Wellborn Cabinets Limited, and Southern Nuclear. The addition of IT topics would need to be tested, so LITEE focused their evaluation on students' improvement of higher-level, cognitive-based problem solving abilities.

The implementation process for the aforementioned multimedia case studies was examined by external evaluators. This process allowed the validation of new instruments that provided both quantitative and qualitative feedback. Several publications resulted from this project in the form of conference proceedings and journal publications. These materials were subsequently implemented at several universities and high schools.

### Funded Grant 0442531

During the time frame between July 2010 and June 2011, LITEE conducted a study entitled National Dissemination of Multimedia Case Studies that Bring Real-World Issues into Engineering Classrooms.

**Problem.** To date, LITEE had produced a variety of multimedia case study instructional materials. However, a limiting factor of their work appeared to be their ability to share it with others. Positive results from the testing phases of earlier projects suggested that cases were effective at educating students in STEM and business disciplines, but these results needed to be shared with faculty and administrators in

STEM disciplines. Another wicked problem presented itself, this time, however, the solution did not appear to fit the requirement of educational IS.

**Solution.** To achieve broad dissemination, the LITEE team researched methods of publication and training of faculty. Ideas for dissemination included publishing a textbook, conducting workshops, and conference showcases to allow for one on one interaction with potential adopters of the cases. Training of faculty ensued in multiple countries and through a variety of venues.

Because the primary objective of this project was dissemination, several audiences benefited. First, a textbook was produced, benefiting students at several universities in the US, and extending LITEE case studies to an estimated 2,284 students during the time frame of this project. Second, regional and national workshops were able to reach faculty members from several schools. At the conference showcases, faculty representing over 400 schools gathered information from or spoke with members of the LITEE team. Finally, an instructor support system was developed to aid the adoption of new instructors, while also providing support to instructors who had already adopted LITEE case studies. Discussions revealed that multimedia case studies had the potential to make changes in engineering education, however, a rigorous evaluation of the dissemination process was not apparent in the archival literature for this case.

**Funded Grant 0736997**

During the time frame between April 2009 and March 2010, LITEE conducted a study entitled Capability-Focused Real-World-Based Technology-Enabled (CARTEL) Instructional Strategy: Development and Testing in Introductory Courses. Building on past research that resulted in the creation of multimedia case studies, LITEE began to focus on developing an appropriate pedagogy to implement the multimedia case studies.

**Problem.** To this point, LITEE had developed, implemented, and improved several multimedia case studies in a variety of courses. The major problem LITEE was seeking to address in this project, however, was the limited engineering related skills of freshmen engineering students. Specifically, LITEE sought to help students improve their teamwork skills, communications skills, engineering design skills, knowledge of safety and standards, integration of business issues and the design process, and application of math and science toward solving engineering problems. As noted in a previous project, multimedia case studies showed promise for increasing the retention of engineering students within the discipline. It makes sense, then, that the appropriate starting point for improvement of the aforementioned skills and increased retention begin with engineering students who are entering the field. The wicked problem, then, was the need for an appropriate instructional strategy (i.e., course map) to teach multimedia case studies.

**Solution.** To address this problems, LITEE decided to conduct a thorough experiment involving two sections of introduction to engineering courses across four semesters. The team gathered an experienced group of researchers from various disciplines and universities to act as an advisory committee. Members of the committee were to provide input regarding the course structure, implementation, and evaluation of the implementation. If successful, the implementation of case studies during each of these semesters would provide a measurable improvement in the skills of students enrolled in the experimental sections.

Members of the committee included faculty from engineering (i.e., content experts), and faculty from education. Input from committee discussions resulted in an experimental design for the implementation where one section of introduction to engineering students was taught using case studies, and the other section was taught using traditional lecture techniques. During the course of each semester, three phases of learning activities were to be carried out, preparation, application, and assessment. Pre-tests were to be given to measure the state of students' engineering knowledge upon entering the course, and then a follow up survey was to be given at the conclusion of the course.

The actual implementation of the material involved the use of control and experimental groups in introduction to engineering courses. Using the survey developed by members of the LITEE team, and refined by education faculty for use in this project, student feedback was gathered in both quantitative and qualitative forms. The questionnaire consisted of 36 evaluatory statements on a 5-point Likert scale. Slight modification of the questionnaire allowed it to be used for both pre- and post- questions. Additional open-ended questions were added to the survey to obtain student perceptions regarding the instructional material implemented in their respective section. In addition to the survey, focus groups were used to gather more in-depth responses from the students. The differences between the pre- and post- surveys were gathered and compared across control and experimental groups.

The project produced a detailed course map for introduction to engineering courses, guiding the use of multimedia case studies to influence skill development in certain areas relevant to freshmen engineering students. However, since the pre- and post-surveys did not result in useful findings, the LITEE team resorted to the use of a focus group. In the absence of clear findings, this wicked problem was unresolved.

**Funded Grant 0623351 & 0966561**

During the time frame between August 2007 and July 2011, LITEE conducted a study entitled IRES: US-India International Research, Education, and Industry Experiences for Students in Acoustics and Non-Destructive Evaluation.

**Problem.** The problem faced by LITEE in this project was two-fold. First, LITEE needed to provide a meaningful research opportunity for students, where they were also exposed to a foreign culture. As the world becomes more intertwined into a single global economy, it is increasingly important that engineers be able to interact with individuals from other countries and cultures. The ill-defined environmental context appears to fit the definition of a wicked problem.

**Solution.** In order to provide a research opportunity to students, while also exposing them to a dissimilar culture, the project required students to work either with business men and women in India or faculty members at Indian universities. Students had to work alongside faculty to document and solve problems faced on campus or in industry. The goal of this was to develop multimedia case studies.

Through this project, 40 undergraduate and graduate students travelled to India to meet the objectives set by the LITEE team. The trip consisted of a two month stay in India, where students engaged in the development of case studies. During the project, students presented their findings to the company executives and faculty members at IIT Madras, NIT Trichy, and Auburn University. The students also completed surveys at the conclusion of their trip. The survey consisted of 5-point Likert scale questions that measured students' difficulty collecting information for the case studies, difficulty adjusting to the culture,

Upon returning to Auburn University, the students who participated in the project made presentations to their faculty members and students in their colleges. The materials they gathered were then finalized into case studies that are currently being used at several universities. In addition, a workshop took place to stimulate thinking of the participants when using case studies. This project was later showcased at the 2008, 2009, 2010, and 2011 ASEE conferences. All case studies now appear on liteecases.com, and one particular case study, Mauritius Auditorium, is being used by a participating company to train their employees.

**Chapter Summary**

An examination of LITEE's work described in this chapter reveals that each of their projects attempted to address a wicked problem. In addition, the number of resources required by each project, and the resulting communication of results was significant, as evidenced in Table 4.3. Unfortunately, their attempts to address these problems lacked an overarching methodology, leading to results that sometimes failed to achieve desired outcomes. I contend that the application of the DSRM for wicked educational IS can provide the needed structure to solve many of the aforementioned wicked problems and I attempt to demonstrate its abilities in the following chapters.

Table 4.3. Overview of funded projects

| Grant / Years | 9752353 (1997-2000) | 9950514 (1999-2003) | 0089036 (2002-2008) | 0442531 (2004-2011) | 0736997 (2009-2010) | 0623351 (2007-2011) |
|---|---|---|---|---|---|---|
| Partners | | | | | | |
| Academic Institutions | 4 | 10 | 20 | 23 | 1 | 3 |
| Industry Partners | 5 | 7 | 9 | N/A | 1 | 5 |
| Students trained/taught | 2200 | 2800 | 3700 | 2284 | 300 | N/A |
| Research Participants | | | | | | |
| Senior Personnel | 4 | 5 | 9 | 31 | 3 | 5 |
| Post-doc | 2 | 3 | 3 | N/A | N/A | N/A |
| Graduate | 7 | 11 | 18 | 8 | 1 | 10 |
| Undergrad. | 17 | 14 | 12 | 2 | N/A | 6 |
| **Outcomes** | | | | | | |
| Training workshops | 12 | 25 | 45 | 9 | 1 | 2 |
| Conference Proceedings | | | | | 1 | |
| Journal Publications | 7 | 17 | 23 | 25 | 6 | 4 |
| One-time Publications | 6 | 11 | 4 | 4 | 3 | 11 |

# Chapter 5: Analyzing multimedia case studies using the DSRM

## Overview

The timeframe addressed by this project involves five consecutive semesters, beginning fall 2010 and ending spring 2012. Funding was awarded to LITEE by the NSF for a project titled Development and Testing of Presage-Pedagogy-Process-Product Model to Assess the Effectiveness of Case Study Methodology in Achieving Learning Outcomes. LITEE's Earlier projects predominantly focused on three areas: development of case studies through partnerships with business, use of multimedia case studies in technical disciplines (Bradley, Mbarika, et al., 2007), and dissemination of these case studies at other institutions. The primary focus of the current project was to make refinements to the implementation, evaluation, and communication of the multimedia case studies, providing further support for the their efficacy.

Hevner and Chatterjee (2010) noted that "the fundamental principle of DSR is that knowledge and understanding of a design problem and its solution are acquired in the building and application of an artifact." Further, Hevner et al. (2004) remind us that IT artifacts are broadly defined as constructs, models, methods, and functional instantiations. In this chapter, the processes, or methods, used by the LITEE team in the implementation and testing of multimedia case studies in engineering classrooms are presented as the artifact. The resulting quantitative and qualitative data provide a post-hoc view of these events and a starting point for the design and development of additional wicked educational IS. Archival data that were collected in the form of annual reports provided to the National Science Foundation, publications by LITEE team members submitted to conferences and peer reviewed journals, email exchanges, qualitative and quantitative survey responses, focus groups, course grades, and internal minutes from meetings were analyzed as data sources.

The first section in this chapter provides an overview of this project. In the following sections I document the implementation of multimedia case studies using the six steps of the DSRM for wicked educational IS. In addition to mere documentation, however, I synthesize the logic of the DSRM with the actions taken by LITEE. At the conclusion of the chapter, I describe the lessons learned from the application of the DSRM to this project and I conclude with a transition to future wicked educational IS developed by LITEE.

**Problem Identification**

According to Peffers et al. (2007), the initial step of DSR should define a specific research problem and justify the value of a solution. Therefore, this section documents the extant research that motivated LITEE to develop, implement, and test multimedia case studies for use in improving learning outcomes in engineering education. To accomplish this, I begin by examining the perceived problems that led to the implementation and testing of multimedia case studies. I provide additional support via citations from accrediting bodies and government organizations, the LITEE team's literature reviews and past research, and I provide my own examination of the problem situation addressed herein.

One of the earliest goals of LITEE was to develop new curricula using innovative applications of technology to improve engineering and technology education. A driving force for the development of case studies was the list of criteria presented by ABET (2008), suggesting that engineering students should be able to identify, formulate, and solve engineering problems by the end of their education. In their grant proposal, Raju and Sankar (2009) provide evidence to suggest that the engineering education landscape is an environment with an unknown future, where students from a variety of backgrounds must adapt to new situations and solve real-world problems. The problem herein lies in the absence of a technology that has been tested and proven as a means to prepare a diverse population of students for these real-world problems.

More recent literature appears to reinforce the propositions generated by Raju and Sankar (2009). In recent years, there has been great concern over the limited number of science, technology, engineering, and math (STEM) graduates entering the workforce and the disparities that exist between students of different genders and races. In an attempt to address these disparities within the United States, over 200 bills were introduced in the 20 years between the $100^{th}$ (1987-1988) and the $110^{th}$ (2007-2008) congresses (Gonzalez & Kuenzi, 2012). According to Gonzalez and Kuenzi (2012), legislative action has resulted in a federal investment between \$2.8 billion and \$3.4 billion annually. These monetary figures reinforce the existence of a problem that is of growing concern to both academicians and industry professionals. While the existence of a wicked problem is clear, researchers, administrators, and politicians have proffered a variety of solutions to solve this problem, ranging from changes in elementary and secondary schooling to changes in post-secondary education. When observing this situation from a design science perspective, the lack of a proven technology to address the needs of a diverse student body can certainly be classified as a wicked problem, and one that meets the criteria of being heretofore unsolved (Hevner et al., 2004). Therefore, an acceptable solution in the form of a tested education IS, with guidance for implementation, was needed for faculty and administrators.

### Objectives for a Solution

After clearly identifying a problem, the Peffers et al. (2007) DSRM calls for objectives for a solution based on what is possible and feasible. For reasons explained in detail below, LITEE believed that multimedia case studies were best suited as a solution, however, rigorous evaluation was required. The DSRM for wicked educational IS expands on the Peffers et al. (2007) model with a recommendation to develop a research based conceptual model, when theory exists to guide the research, in order to hypothesize the expected or desired relationships of a successful implementation. Such a model is defined below for the testing of multimedia case studies.

Although evaluation is discussed during a later stage in the DSRM, I posit that a plan for effective evaluation should contribute to the objectives for a solution, and should be given some consideration prior to initiation of the design and development stage. However, the amount of consideration given to evaluation at this stage depends on the type of artifact under development. In order to rigorously evaluate the artifact, one must first determine a method by which evaluation can take place (Hevner et al., 2004). With regard to LITEE, an instantiation, in the form of functioning multimedia case studies, had been developed and implemented in past studies. However, rigorous testing had not been conducted to provide academicians with a proven IS (i.e., multimedia case studies) for engineering students. By testing and refining the implementation and use of LITEE's multimedia case studies in engineering classrooms, there was potential to provide a proven wicked IS for educators, and a new DSR based artifact in the form of a method of implementation.

Since the problem described above focuses on developing a proven technology for teaching problem solving to engineering students, the first objective for a solution was to develop a conceptual model that was testable in the context of engineering students and their specific environment. For this model, LITEE determined that a focus on improving achieving outcomes for a diverse sample of students was also critical. In order to measure the desired outcomes, while considering the context of the environment and students, the team conducted an extensive literature review which revealed an existing model, the presage-process-product (3P) model, developed by Biggs and Moore (1993). The 3P model was then modified to allow more emphasis on the pedagogy of interest, multimedia case studies. The resulting model is titled the presage-pedagogy-process-product (4P) model (Raju & Sankar, 2009) and is displayed in Figure 5.1.

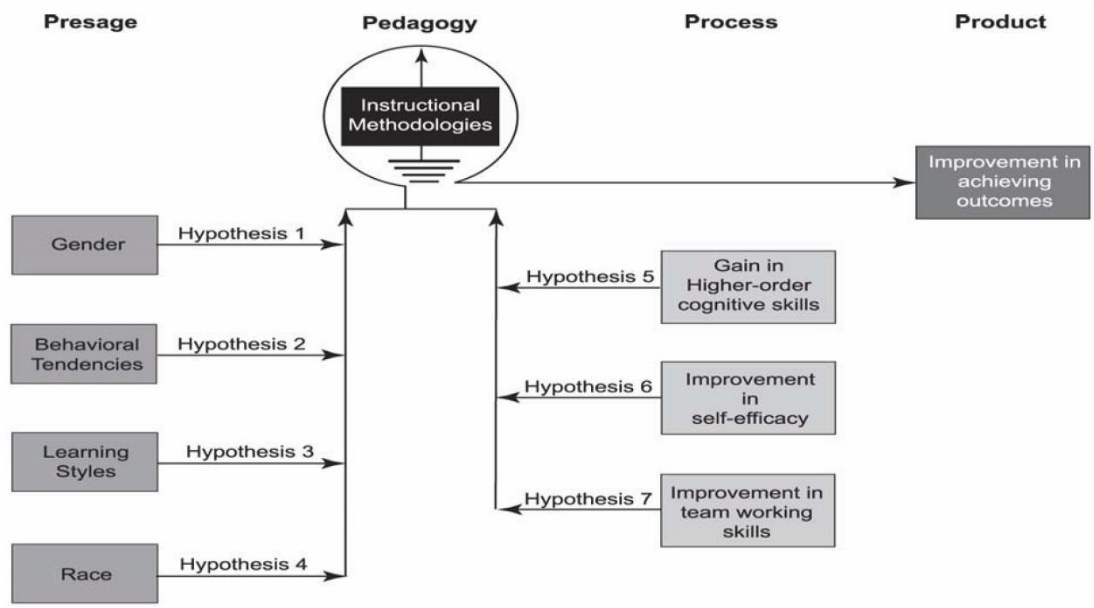



Figure 5.1. Initial Presage-Pedagogy-Process-Product (4P) Research Model

**Model description and hypotheses development.** The LITEE team's design of the 4P model hypothesizes two sets of relationships between independent and dependent variables. The first set of relationships is hypothesized to exist between presage factors and product factors, while moderated by pedagogy. The second set of relationships is hypothesized to exist between process factors and product factors, while moderated by pedagogy. Each of the constructs displayed in Figure 5.1 is described below, in addition to the seven specific hypothesized relationships that were tested during the evaluation stage of the DSRM.

In order to find support that multimedia case studies are superior to other instructional methodologies, it was first necessary to choose an instructional methodology to compare multimedia case studies to. Due to its traditional nature and common use in many disciplines, the LITEE team chose round table discussions as a comparison methodology. Round table discussions "utilize discussion, writing, verbal communication, and analytical thinking" (Nekvasil, 1998). At their core, round table discussions rely on applying knowledge that a student has acquired through his or her classes (Bond, Wang, Sankar, Raju, & Le, 2014). During the course of this project, the instructor led a discussion in which he or she presented questions to the students. The students then discussed and responded to the questions in a group setting. Round table discussions are not new to engineering. Flynn, Naraghi, Austin, Helak, and Manzer (2006) found that round table discussions reduced misunderstandings of engineering concepts and provided an opportunity for students to learn from both the instructor and peers.

***Presage.*** The first category of constructs included in the 4P model are presage factors. According to Biggs and Moore (1993), these are individual characteristics that exist prior to the learning process. With regard to the specific 4P model hypothesized in Figure 5.1, presage variables consist of gender, behavioral tendencies, learning styles, and race. Inclusion of the first variable, gender, is based on extant literature that observed the existence of differences between males and females with regard to learning in engineering classrooms. Additional studies reveal that females are underrepresented in STEM education as a whole (Chubin, May, & Babco, 2005; V. W. Mbarika, C. S. Sankar, & P. K. Raju, 2003a). The first hypotheses, therefore, relies on literature suggesting that disparities exist between males and females and that multimedia instruction has the potential to decrease that disparity (M. Zywno & Waalen, 2001).

*Hypothesis 1: The difference between improvements in achieving outcomes experienced by females compared to males will be decreased or even reversed when students are* *taught using the multi-media case study methodology rather than a round table discussion methodology.*

Behavioral tendencies, a type of personality trait, were included as a presage factor in this model because they exist within each student prior to entering the classroom. Several authors have found correlations between personality traits and performance on the job, some specific to engineering (Carr, de la Garza, & Vorster, 2002). In addition, literature suggests that an even balance of students with different behaviors in teams leads to successful performance (Smith, Sheppard, Johnson, & Johnson, 2005; M. S. Zywno, 2002), especially when teams are comprised of members with appropriate characteristics for the tasks to be accomplished (Carr et al., 2002).

*Hypothesis 2: The improvement in achieving outcomes based on behavioral characteristics will be stronger among students using the multi-media case study methodology than among students using a round table discussion methodology.*

The third presage factor, learning styles, is considered a relatively stable indicator of how students perceive and interact with their environment (Felder & Brent, 2005). Felder and Silverman explained that learning styles represent the way individuals take in and process information (1988), providing a good starting point for research into the effectiveness of new instructional methodologies. Because these multimedia case studies were designed to address specific learning preferences of the majority of engineering students, the LITEE team postulated that students will see a greater benefit from learning via multimedia case studies versus round table discussion.

*Hypothesis 3: The improvement in achieving outcomes based on certain learning styles will be stronger among students using the multi-media case study methodology than among students using the round table discussion methodology.*

The final presage factor in the 4P model is race. In the US, African-Americans represent one of the largest minorities that is also underrepresented in STEM education. There has been significant debate regarding the cause of this disparity between African-Americans and Caucasians (Banks, 1988; Chubin et al., 2005). A major reason cited involved differences in cognitive or learning styles of African-Americans versus other groups (Ramirez & Price-Williams, 1974; H. Witkin, 1974; H. A. Witkin, Dyk, Fattuson, Goodenough, & Karp, 1962). Other studies have expressed findings that suggest learning styles may be to blame for different learning outcomes (J. Anderson, 1988; J. A. Anderson & Adams, 1992). Therefore, LITEE's 4P model hypothesizes that this disparity may be due in part to individual motivation related to the instructional methodologies used in most engineering curricula.

*Hypothesis 4: Under a round table methodology, the difference between improvement in achieving outcomes experienced by minorities compared to Caucasians will be decreased or even reversed when students are taught using the multi-media case study methodology.*

***Pedagogy.*** The second category of the 4P model refers to pedagogy. In the study conducted by the LITEE team, pedagogy is represented by one of two conditions, application of multimedia case studies or round table discussions. As noted in chapter four, multimedia case studies are those materials that include one or more types of media such as graphics, video, animation, images and sound, in addition to textual information (Beckman, 1996; Fetterman, 1997; V. W. Mbarika, C. S. Sankar, & P. K. Raju, 2003b).

Several authors have researched and debated the efficacy of multimedia instructional materials over the years, discovering that benefits of multimedia education exist (Bond, Sankar, & Le, 2010; Mbarika, 2000; McCuen & Chang, 1995). V. W. Mbarika et al. (2003b) and Mehta, Clayton, and Sankar (2007) emphasized the utility of multimedia case studies in enhancing students' learning and motivation, and, in turn, observed improvements in students' decision-making and problem-solving skills. The second instructional methodology, round table discussions, also involves problem-based learning. However, rather than hands on interactive learning, students meet with a group to generate discussion in the form of writing, verbal communication, and analytical thinking (Nekvasil, 1998). Round table discussion provides benefits from both individual work and the contributions of classmates. The LITEE team, therefore, chose multimedia case studies and roundtable discussions as the specific instructional methodologies to moderate the hypothesized relationships in the 4P model.

***Process.*** The third category of the 4P model contains process factors. Nemanich, Banks, and Vera (2009) explain that process factors incorporate the student's learning experience. The 4P model implemented in this study hypothesizes that these factors will differ based on the particular pedagogy implemented. Specific process factors included in the model are gain in higher-order cognitive skills, improvement in self-efficacy, and improvement in team skills. Higher-order cognitive skills typically refer to reasoning, critical thinking, decision making, problem identification, and problem solving. Research conducted prior to this NSF funded study produced positive results suggesting that multimedia case studies have the potential to increase higher order cognitive skills (Bradley, Sankar, Clayton, Mbarika, & Raju, 2007; V. W. Mbarika et al., 2003a).

Therefore, hypothesis five tests for observed differences in student outcomes between multimedia case studies and round table discussions.

*Hypothesis 5: The tendency for improvement in achieving outcomes being positively related to acquisition of higher-order cognitive skills will be more pronounced among students using the multimedia case study methodology than among students using a round table discussion methodology.*

The second process factor in the 4P model, improvement in self-efficacy, refers to a "belief in one's capability to organize and execute the courses of action required to produce given attainments" (Bandura, 1997). Several studies have found self-efficacy to be a reliable predictor of academic performance across disciplines (Zajacova, Lynch, & Espenshade, 2005), and in STEM education (Lent, Brown, & Larkin, 1984). Rittmayer and Beier (2009) discovered that higher levels of self-efficacy typically lead to higher performance and longer persistence within the discipline. When considering the appropriate match between the learning styles of engineering students and multimedia case study instruction, LITEE hypothesized the following relationship.

*Hypothesis 6: The relationship between students' improvement of improved self-efficacy and improvement in achieving outcomes will be stronger among students using a multi-media case study methodology than among students using the round table discussion methodology.*

The final process factor in the 4P model, improvement in team working skills, refers to a deep learning process that is also emphasized by employers and the ABET engineering criteria. Although many students have no prior experience working on teams, the multimedia case studies used herein require students to engage in problem solving as a group. Therefore, the seventh hypothesis is presented below.

*Hypothesis 7: The relationship between students' improvement of team working skills and improvement in achieving outcomes will be stronger among students using a multi-media case study methodology than among students using the round table discussion methodology.*

***Product.*** The final category of the 4P model refers to product variables. In the study conducted by the LITEE team, product variables are measured in the form of achieving learning outcomes. In the field of engineering, learning outcomes are a crucial measure of student achievement for the ABET accreditation process (ABET, 2011). Learning outcomes refer to statements or descriptions of what students are expected to know and be able to do at the end of a course. ABET refers to these as the knowledge, skills, and behaviors that students acquire via instruction during a course. The primary measure of student outcomes in this study was student grades on assignments, projects, and the overall course grade. Hart (1994) explains that student grades are a type of performance appraisal that is used to measure pre-operationalized abilities in a real-world setting.

Having documented the LITEE team's objectives for a solution, via a testable conceptual model, the DSRM for wicked educational IS dictates that a process for design and development should be attempted. In the following section, I document the process by which the LITEE team designed and developed the multimedia case study implementation for this project.

**Design & Develop**

The extensive work conducted by LITEE since its origins in 1996, as documented in chapter four, produced the multimedia case studies that were implemented in this project. Therefore, the design and development described in the following sections refers to the implementation and testing of multimedia case studies, rather than the design of the actual IS. In relation to the four types of IT artifacts described in the literature (i.e., constructs, models, methods, and instantiations), this particular example represents a method or development practice (Hevner et al., 2004). Therefore, the subsequent sections will document the LITEE team's development of a process for implementing and testing multimedia case studies. In order to complete this work, the LITEE team was awarded $284,000 in funding by the NSF for a three year project.

During the fall 2009 semester, the LITEE team began meeting via teleconferences, comprised of individuals at three universities, and onsite meetings, comprised of individuals at Auburn University, to decide the appropriate course of action needed to implement and test the multimedia case studies. For this project, the team consisted of two engineering professors from Hampton University, a Historically Black College and University (HBCU), a professor from the college of education at the University of West Georgia, two professors from the College of Business at Auburn University, a professor from the College of Engineering at Auburn University, and several master level and doctoral students at Auburn University representing business, engineering, and communications. The diversity of departments and backgrounds provided a significant advantage throughout the project. In order to more effectively address specific problems of smaller scope, the LITEE team also divided into smaller teams. The evaluation team met separately to discuss issues related to data collection and analysis, and the instructors and primary investigators met to plan the implementation of the actual case studies.

The LITEE team engaged in approximately four teleconferences during the fall 2009 semester that involved the entire team, followed by a meeting of all LITEE members on the campus of Auburn University on December 10, 2009. The following topics were the predominant focus of teleconferences: evaluation instruments, course textbook, and a common course syllabus and schedule to be used at both Auburn University and Hampton University, the two universities where the project was implemented. The textbook used for this class, Fundamental Leadership and Engineering Competencies (Raju, Sankar, & Le, 2010), was written and published by members of the LITEE team for use throughout the project.

At the meeting on December 10, 2009, the LITEE team broke into smaller groups to create a course schedule that was acceptable to professors at both universities, and to discuss and finalize a list of instruments for data collection. During the afternoon session, the team finalized the course schedule, instruments, and determined to implement multimedia case studies (i.e., the experimental sections) during the spring 2010 semester. The proposed list of instruments is available in Appendix B.

Over the course of the following semesters, teleconferences and meetings continued, increasing in frequency as the project continued. Discussions during these meetings focused on course schedule adjustments, changes to the data collection timetable for each semester, and student feedback in the form of focus group results and responses to online surveys. Table 5.1 below provides frequency counts, and the average number of days between meetings.

Table 5.1. Frequency of meetings during multimedia case study project

| Semester | Meeting Frequency | Average # days between meetings |
|---|---|---|
| Fall 2009 | 5 | 12.50 |
| Spring 2010 | 10 | 13.44 |
| Fall 2010 | 8 | 7 |
| Spring 2011 | 10 | 13 |
| Fall 2011 | 12 | 10.18 |
| Spring 2012 | 16 | 8.06 |

*Note.* Meetings listed above involved the entire project team (i.e., members from Auburn, Hampton, and the University of West Georgia).

With the growing number of meetings, it was clear that the implementation process was still unrefined at the beginning of the project. Instead, archival data support the notion that LITEE's implementation was more akin to a DSR process due to the iterative nature of the improvements applied to the implementation process.

**Case study Evaluation.** In order to test the hypothesized relationships displayed in the 4P model above, the LITEE team relied on a mixed methods approach. The team of researchers involved in this project represented a variety of disciplines, including engineering, education, communications, and management. The research evaluation team was comprised of individuals possessing both quantitative and qualitative expertise. Drawing on the expertise of the evaluation team, this study applied a mixed method technique referred to as concurrent triangulation, displayed in Figure 5.2 below. Creswell, Plano Clark, Gutmann, and Hanson (2003) describe this technique as a design in which researchers use multiple methods in an attempt to confirm, cross-validate, or corroborate findings within a single study. While several techniques for conducting mixed methods research are available, the current study required several aspects of mixed methods research that are specific to concurrent triangulation. For example, Creswell (2009) clarifies that a primary benefit of concurrent triangulation is to use separate quantitative and qualitative methods to offset the weaknesses of one method with the strengths of the other. The data collection for both quantitative and qualitative data occurs concurrently (i.e., in the same phase of the study), and are analyzed separately before being examined comparatively. Results are integrated at the time of discussion, typically in the form of one method presented before the next, where the results of one method confirm or disconfirm the other. In the context of the current study, results from quantitative data provide specific answers regarding the hypothesized relationships in the 4P model, while qualitative results provide additional insights regarding the preferences of students towards the overall implementation of multimedia case studies during the semester.

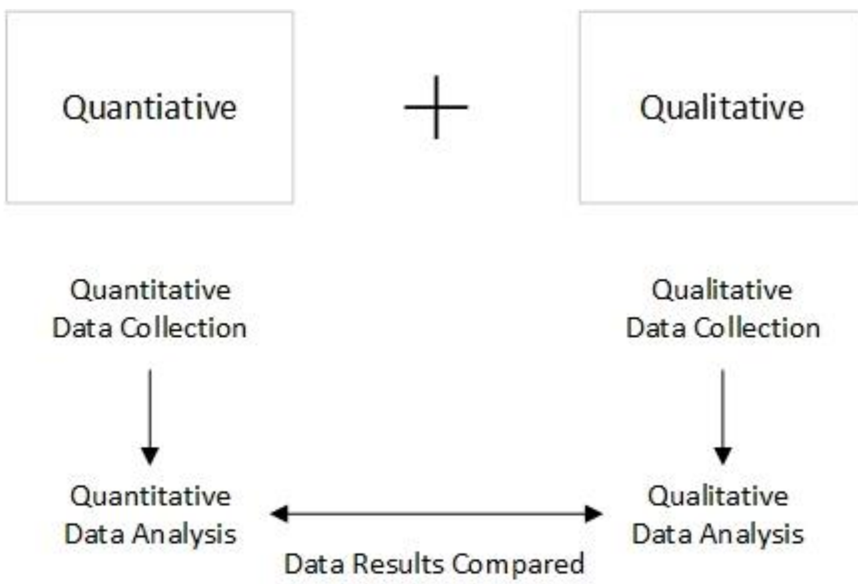



Figure 5.2. Concurrent Triangulation Design (Creswell et al., 2003).

**Experimental design.** The research project was a field study conducted during classroom lectures and lab sessions at Auburn University and Hampton University. An introduction to engineering course was chosen as the basis for acquiring the sample because it is a requirement for all engineering majors. Auburn University is a land grant university comprised of predominantly Caucasian students, while Hampton University is an HBCU comprised of predominantly African-American students. The LITEE team's plan for implementation involved one large class, containing approximately 80 students being taught each semester at Auburn University, and two smaller class sections, containing approximately 40 students, to be taught at Hampton University.

Because the experiment was scheduled to take place over the course of three years, semesters alternated between control and experimental designs, that is, the first semester of this study involved the use of multimedia case studies, and the following semester involved the use of round table discussions. Implementation of a single design each semester allowed closer collaboration and instructional alignment among instructors at the two universities. All tests and quizzes, course outlines, rubrics, lesson plans, instruction to students, assessments, strategies, attendance policy, and team-based projects were consistent across institutions in both the control and experimental sections (Raju & Sankar, 2009). In addition, the use of a single design per semester allowed for approximately equal division of students between control and experimental groups over the course of the study. Table 5.2 displays the breakdown of each semester's design.

Table 5.2. Experimental design by semester

| | **Semester** | **Design** |
|---|---|---|
| 1 | Spring 2010 | Experimental |
| 2 | Fall 2010 | Control |
| 3 | Spring 2011 | Control |
| 4 | Fall 2011 | Experimental |
| 5 | Spring 2012 | Experimental & Control |

During the semesters labeled experimental, instructors integrated three case studies into the course structure at each university, *Chick-fil-A, Della Steam Plant, and STS 51-L*. Each case study was carefully selected for its relevance to course objectives. Students in the experimental section were given access to the multimedia case studies online and asked to examine the case study's background and the engineering concepts involved during the first meeting. During the second meeting allotted for each case, students applied the technical and business information from each case towards a team-based oral presentation, requiring students to defend the role they were assigned to.

During each semester labeled control, students engaged in round table discussions. The first allotted class period included lecture aided by a textbook, occasional guest lectures, and the inclusion of real-world examples for certain topics. The second class required students to discuss the topic and their particular views on the subject in a round table discussion group that involved the other students in the class.

The remainder of each semester involved lecture and lab sections covering additional topics relevant to an introduction to engineering course. Three design projects were also included in every section, both control and experimental. The design projects included the design of a pasta tower, design and testing a paper parachute, and design and testing of a plastic boat. These projects were chosen to supplement lecture and provide additional hands-on problem-solving experience involving engineering concepts. Over the course of the implementation, the aforementioned teleconference meetings were scheduled to discuss course progress and allow coordination among instructors.

***Quantitative design.*** Several instruments were required to measure the constructs in the 4P model. Whenever possible, the LITEE team utilized existing instruments found during the literature review. Gender and race were recorded based on students' answers to a demographic section in one of the instruments. Learning styles were collected using the Index of Learning Styles, developed by Felder and Silverman (1988). This 44 item forced choice questionnaire allows researchers to classify student learning preferences within each of four dimensions: active-reflective, sensing-intuitive, visual-verbal, and sequential-global. Significant efforts have been made to examine the validity and reliability of this instrument (Felder & Spurlin, 2005; Hawk & Shah, 2007; Litzinger, Sang Ha, Wise, & Felder, 2007). The remaining presage factor, behavior tendency, was measured using the DiSC instrument. The DiSC profile is a nonjudgmental tool for understanding behavioral types and personality styles. Similar to the ILS, the DiSC also measures across four dimensions: dominance, influence, steadiness, and conscientiousness. The results of the DiSC profile reveal which dimensions an individual leans towards. This is done by having an individual respond to 79 adjectives on a five-point Likert scale, indicating how often the adjective describes them (EverthingDisc, 2011).

Two of the process factors, gain in higher order cognitive skills and improvement in team working skills, were measured using an instrument developed and tested by the LITEE team. This instrument has been shown to be a valid and reliable measure of both higher order cognitive skills (Bradley, Sankar, et al., 2007; V. W. Mbarika et al., 2003a) and team working skills (Sankar, Kawulich, Clayton, & Raju, 2010) when implemented with engineering students. Self-efficacy was measured using the Longitudinal Assessment of Engineering Self-efficacy (LAESE), developed by The Pennsylvania State University and University of Missouri, and funded by the National Science Foundation. The instrument was designed to measure the change in self-efficacy in classroom settings where a program or activity is undertaken related to student retention and student development (AWE, 2009). The LAESE was determined to have sufficient validity by external experts (Marra, Rodgers, Shen, & Bogue, 2009).

The final category, product factors, was based on improvement in achieving outcomes and focused on scores generated during classroom activities. Specifically, this measure included scores from tests and quizzes, scores related to the case studies, homework, group work, and any related scores derived from measures of student performance.

***Qualitative design.*** Following the mixed methods approach of concurrent triangulation, this study collected qualitative data in parallel to the quantitative data collection described above. In keeping with the qualitative tradition of posing guiding questions, three evaluation questions were created for this study.

1. *How do students perceive the value and nature of instructional methods used in this course?*
2. *How do students perceive the value and nature of group work in the course?*
3. *What strengths and areas of improvements do the students perceive are needed in the course, in general, and in the instructional methods, in particular?*

To arrive at substantive answers to these questions, qualitative data were gathered via two techniques, open ended survey questions and student focus groups. At the conclusion of each semester, students completed the evaluation instrument developed by the LITEE team. Strategically placed at the beginning of the instrument, so as not to be influenced by the quantitative questions, open ended questions gathered information related to prior experience in the field of engineering, preferred teaching styles, preference for group or individual work, suggestions for improving the course, and perceived opportunities to apply their course learning in the future.

Qualitative researchers from the college of education at the University of West Georgia, and primary contributors to this project, conducted focus groups at the conclusion of each semester in order to provide additional data necessary to answer the research questions above. To conduct the focus groups, the qualitative researchers were required to visit both Auburn University and Hampton University to facilitate the focus groups. Students were divided into groups consisting of 10-20 respondents, depending on class size in a particular semester. Students were then asked a series of predefined questions that evolved over the course of the project as responses from previous semester guided the inquiry.

### Demonstration

While the demonstration phase is technically an individual point within the DSRM, it represents a critical culmination of each of the aforementioned steps. In addition, the actions taken during demonstration will lead the researcher towards a successful artifact, or it can derail the project, causing invalid analyses and inappropriate findings. Therefore, a well-planned path for evaluation must be followed closely at this point. One process initiated by many institutions of higher education to insure that research is well planned and safe for all participants involved is the completion of an institutional review board (IRB) application for research. While this is not required in all institutions, it is highly recommended for the safety and benefits it provides to subjects and researchers. An IRB approval form associated with this project is available in Appendix G. With regard to the implementation of multimedia case studies, the extended time of the project resulted in multiple institutional review processes by Auburn University and Hampton University as the project progressed. The value of this process should not be ignored, as it provides protection for both researchers and participants, and may add rigor to the study. For these reasons, the IRB application process is explicitly incorporated in the DSRM for wicked educational IS.

During the spring semester of 2010, the LITEE team began their multimedia case study implementation by following an agreed upon course outline at both Auburn University and Hampton University. The aforementioned teleconferences and meetings began early in the semester to inform the research team of the progress of the implementation. At the beginning of each semester, instructors required students to complete an informed consent form, stating that they were aware of the risks and rewards associated with participation in the research. Prior to the collection of data, the course instructors generated a list of four-digit identification codes to allow students to complete each survey instrument anonymously, while also receiving extra credit for participation. Instructors maintained the list of identification codes, but never saw actual responses from the students. Evaluators were only provided the list of identification codes, without access to identifiable information.

**Quantitative data collection.** The data collection began in each of the five semesters with the administration of the ILS survey and the LAESE survey. In order to complete the ILS survey, students visited the official ILS webpage, located on North Carolina State University's website (Felder & Soloman, 1991). At the conclusion of the survey, each student was required to print their results and submit them to the instructor for extra credit; these pages were then given to an evaluator upon receipt by the instructor. The LAESE instrument was available through the LITEE team's Survey Monkey account, providing the evaluators with immediate access to student responses. After allowing sufficient time for all students to complete the LAESE survey, evaluators provided the instructors with a list of identification codes for those students who completed the survey as extra credit.

The remaining constructs, higher order cognitive skills and team working skills, were also collected using the LITEE team's online survey account. This instrument was administered near the conclusion of the semester in order to measure student perceptions related to the instructional methodology. Respondents were required to input their identification code at the start of the survey, and a list of identification codes was provided to instructors for purposes of administering extra credit.

After several repetitions involving the implementation and evaluation of multimedia case studies (i.e., the first three semesters), the model was refined to describe the relationships that were testable based on the classroom environment and initial findings. For example, both the self-efficacy instrument and the DiSC instrument did not appear to provide value in the early semesters, and the students were receiving what the LITEE team perceived to be an excessive amount of surveys. Thus, the self-efficacy and behavioral tendencies constructs were dropped from the initial model. The updated model is shown below in Figure 5.3.

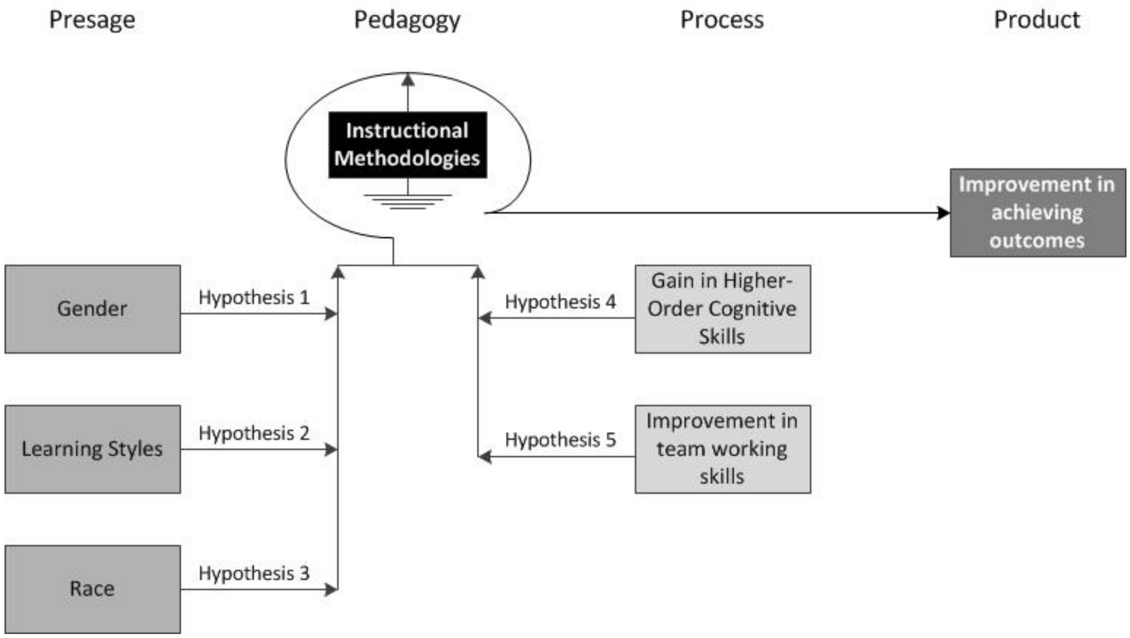



Figure 5.3. Updated 4P Model for Multimedia Case Study Project

**Qualitative data collection.** Qualitative data were gathered from open-ended questions at the beginning of the instrument developed by the LITEE team, and in the form of responses to focus groups at the conclusion of each semester.

**Feedback.** At the conclusion of each academic year, the LITEE research team met to present the results of quantitative and qualitative data analysis for the respective year, and to plan the implementation for the subsequent year. The principal investigator and co-principal investigator summarized results and provided an annual report to the National Science Foundation as a requirement for the grant.

## Evaluation

Several authors have suggested that a rigorous evaluation stage within DSR is what separates it from design. In particular, it is the evaluation phase that results in additional information gained from the construction of an artifact that is brought together and fed back to another round of development (Vaishnavi & Kuechler, 2007). It is critical, therefore, that the method of evaluation be appropriate for the problem and the artifact involved. In this study, the LITEE team relied on both quantitative and qualitative data analysis techniques to examine the research questions posed in the design stage.

Although data were collected throughout the three year project, analyses were completed at the end of each academic year (i.e., during the summer semester). Analyses involving an entire academic year allowed evaluators to analyze larger samples of data, while providing annual reports to the National Science Foundation. At the conclusion of the entire study, data from all sections were combined in order to make comparisons and conduct analyses regarding the potential differences between the two pedagogies.

**Quantitative analysis.** The sample for this study involved a total of 696 students enrolled in introduction to engineering courses during five consecutive semesters. Unfortunately, the data used in these analyses were subject to a number of missing data points. These missing data resulted from two sources. Several students provided no response to our surveys, and a small number of students used the incorrect identification code, preventing a match between their course grade and survey responses. Listwise deletion was applied in order to account for missing data points, removing a record entirely if a relevant data point was missing for a particular analysis. Therefore, the analyses used different sample sizes for each analysis, which limited the interpretation of the findings to some extent.

In order to test the hypotheses in Figure 5.3, both individual mean comparisons (i.e., independent *t*-tests) and a hierarchical multiple regression analyses were implemented. When conducting a hierarchical multiple regression analysis, the researcher, not the computer, determines the order of entry of variables. F-tests are used to compute the significance of each added variable (or set of variables) to the explanation of $R^2$ (Cohen, 1977). In each of the analyses, individual predictors were entered in the first block of analysis and interaction (i.e., moderating) variables were entered in the second block of analysis.

**Qualitative analysis.** The qualitative analyses conducted during the course of this project involved a thematic analysis approach (Braun & Clarke, 2006), where applicable; however, in instances where data were one or two word responses and thematic analysis was not possible, frequency counts were conducted to enable the team to provide some analytic discussion of the data. Braun and Clarke (2006) define thematic analysis as a method for identifying, analyzing, and reporting patterns (themes) within a dataset. In the current project, the qualitative evaluators applied thematic analysis to open ended responses from the LITEE developed survey, in addition to interview responses provided during the focus groups.

**Quantitative results.** The following section presents the results of the hypothesis testing for each relationship presented in Figure 5.3. Analyses were conducted after data were aggregated for all five semesters of the project.

***Hypothesis 1.*** *The difference between improvements in achieving outcomes experienced by females compared to males will be decreased or even reversed when students are taught using the multi-media case study methodology.*

Before testing hypothesis 1, I examined the mean grades of males and females, and the mean grades of individuals in both round table discussion and multi-media case study classrooms. The resulting means are shown in Table 5.3. The first independent *t*-test shows that females were significantly different from males on grades, ($p$=.000). Inspection of the two group means indicates that the average grade of female students (969.22) is significantly higher than the score for males (944.03). The second independent *t*-test shows that the overall mean grades of students in a classroom using multi-media case studies did not differ significantly from those of students in a classroom using round table discussions, ($p$=.506). The third independent *t*-test, representing the difference between multi-media case study use and round table discussion use for males, resulted in significantly higher grades in round table discussion (955.50) than in multi-media case study (929.67) classrooms, ($p$=.001). The fourth independent *t*-test, representing the difference between multi-media case studies and round table discussions for females, resulted in a non-significant result, ($p$=.656). The fifth independent *t*-test, representing the difference between males (929.67) and females (972.89) in a classroom using multi-media case studies resulted in a significant difference, ($p$=.000).

Table 5.3. Mean comparisons among variables of interest

| | Variable | *M* | *SD* | *N* | *t* | *Df* | *p* |
|---|---|---|---|---|---|---|---|
| 1 | Grades | | | | -3.59 | 509 | .000*** |
| | Males | 944.03 | 72.51 | 349 | | | |
| | Females | 969.22 | 75.96 | 162 | | | |
| 2 | Grades | | | | -.666 | 506 | .506 |
| | Multimedia | 918.17 | 134.09 | 269 | | | |
| | Lecture | 926.06 | 157.48 | 373 | | | |
| 3 | Males | | | | -3.36 | 347 | .001*** |
| | Multi-media | 929.67 | 74.39 | 155 | | | |
| | Round table | 955.50 | 69.03 | 194 | | | |
| 4 | Females | | | | .446 | 160 | .656 |
| | Multimedia | 972.89 | 83.62 | 56 | | | |
| | Round table | 967.28 | 71.93 | 106 | | | |
| 5 | Multimedia | | | | -3.60 | 209 | .000*** |
| | Males | 929.67 | 74.39 | 155 | | | |
| | Females | 972.89 | 83.62 | 56 | | | |
| 6 | Round table | | | | -1.39 | 298 | .165 |
| | Males | 955.50 | 69.03 | 194 | | | |
| | Females | 967.28 | 71.93 | 106 | | | |

*Note*. $*p<.05$, $**p<.01$, $***p<.001$

In order to test hypothesis 1, a hierarchical multiple regression analysis was used. Specifically, gender and instructional methodology were used to predict student grades, followed by a test for the interaction between gender and instructional methodology when predicting grades. The results of this analysis are shown in Table 5.4 below.

Table 5.4. Hierarchical moderated regression results predicting a difference in grade based on gender & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Gender | | .147*** |
| Instruction | | .109** |
| $\Delta R^2$ after step 1 | .037*** | |
| *Step 2:* | | |
| Gender X Instruction | | -.171* |
| $\Delta R^2$ after step 2 | .009* | |
| Overall $R^2$ | .046 | |
| Adjusted $R^2$ | .040 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant, $F$ (3, 507) = 8.067, $p < .001$. *$p<.05$, **$p<.01$, ***$p<.001$

The analysis consisted of the following steps. I entered gender ($\beta = .147$, $p = .001$) and instruction ($\beta = .109$, $p = .013$) in block one of the hierarchical analysis. The addition of these variables accounted for three percent of the variance in grades, ($\Delta R^2 = .037$, $p < .000$). Specifically, I found that both gender and instruction are significant predictors of grades. In step two of the hierarchical multiple regression analysis, I entered the interaction variable comprised of gender and instruction ($\beta = -1.71$, $p = .029$). The addition of the interaction variable also accounted for unique variance, ($\Delta R^2 = .009$, $p < .05$). In total, the regression model accounted for four percent of the variance in student grades. Based on these findings, an interaction effect does exist between gender and instruction as they predict student grades.

Following the analysis above, I generated Figure 5.4 to display the direction of the significant interaction. Specifically, grades of female students were significantly higher than grades of male students in classes taught with multi-media case studies, while grades of female students were not significantly higher than grades of male students in classrooms using round table discussions.

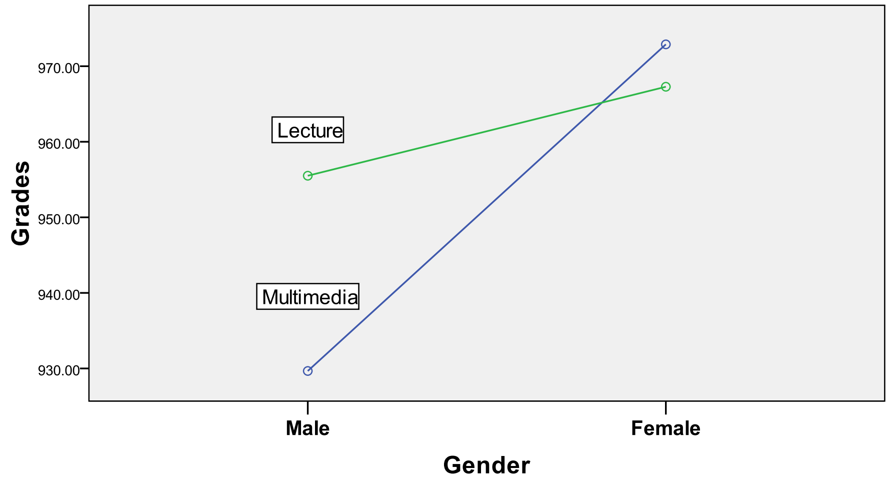



Figure 5.4. Interaction between gender and instructional methodology

Based on all analyses above, I fail to reject hypothesis 1. I did find that instructional methodology (i.e., round table discussions or multi-media case studies) moderates the relationship between gender and grades. Specifically, females perform better in classrooms using multi-media case studies than do males, with females receiving average grades of 972.89 (approximately 97%), and males receiving average grades of 929.67 (approximately 93%). Further, the mean scores of males differ significantly between control and experimental groups.

***Hypothesis 2.*** *The improvement in achieving outcomes based on certain learning styles will be stronger among students using the multi-media case study methodology than among students using a lecture methodology.*

Because hypothesis 2 is based on an individual's classification within a specific learning style, rather than the strength of an individual's preference for a learning style, I transformed each of the learning styles dimensions into dichotomous variables. Within each dimension, a student's preferred learning style is represented by a 0 or 1. For example, within the active-reflective dimension, 0 equals active and 1 equals reflective.

In preparation for testing hypothesis 2, I examined the descriptive statistics for each of the learning styles dimensions, and the mean grades for students within each of the eight learning styles dimensions. The resulting data are shown in Table 5.5. In contrast to my expectations, the independent *t*-tests did not reveal any mean differences within the data.

Table 5.5. Mean comparisons of student grades for each learning style

| | Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|
| 1 | Active | | | | -.806 | 314 | .421 |
| | Multimedia | 923.48 | 151.42 | 115 | | | |
| | Lecture | 935.92 | 119.63 | 201 | | | |
| 2 | Reflective | | | | .664 | 145 | .508 |
| | Multimedia | 962.11 | 74.64 | 49 | | | |
| | Lecture | 947.00 | 150.13 | 98 | | | |
| 3 | Sensing | | | | -.285 | 314 | .776 |
| | Multimedia | 935.95 | 128.81 | 118 | | | |
| | Lecture | 940.23 | 129.38 | 198 | | | |
| 4 | Intuitive | | | | -.301 | 146 | .764 |
| | Multimedia | 932.64 | 148.37 | 46 | | | |
| | Lecture | 940.01 | 133.21 | 102 | | | |
| 5 | Visual | | | | -.207 | 406 | .836 |
| | Multimedia | 935.48 | 117.80 | 144 | | | |
| | Lecture | 938.19 | 130.92 | 264 | | | |
| 6 | Verbal | | | | -.488 | 54 | .627 |
| | Multimedia | 931.67 | 223.33 | 20 | | | |
| | Lecture | 954.53 | 127.96 | 36 | | | |
| 7 | Sequential | | | | -.531 | 316 | .596 |
| | Multimedia | 933.83 | 140.39 | 110 | | | |
| | Lecture | 942.62 | 140.49 | 208 | | | |
| 8 | Global | | | | .150 | 144 | .881 |
| | Multimedia | 937.45 | 121.58 | 54 | | | |
| | Lecture | 934.58 | 104.81 | 92 | | | |

*Note*. $^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$

Based on the Table 5.5 above, it is evident that no statistically significant differences exist between multimedia and lecture for each of the eight learning styles. However, in order to fully test the hypothesis 2, I conducted a hierarchical multiple regression analysis. I entered the four variables representing each of the four learning styles dimensions in block one of the hierarchical analysis, in addition to the variable for instructional methodology. In step two of the analysis, I entered the variables representing the interaction between each dimension and instructional methodology. Neither of the steps in the analysis accounted for unique variance in grades. Table 5.6 provides the data resulting from this analysis.

Table 5.6. Hierarchical moderated regression results predicting a difference in grade based on learning styles & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Active-Reflective | | .071 |
| Sensing-Intuitive | | -.004 |
| Visual-Verbal | | .022 |
| Sequential-Global | | -.012 |
| Instruction | | .014 |
| $\Delta R^2$ after step 1 | .006 | |
| *Step 2:* | | |
| Active-Reflective X Instruction | | -.091 |
| Sensing-Intuitive X Instruction | | .018 |
| Visual-Verbal X Instruction | | .038 |
| Sequential-Global X Instruction | | -.053 |
| $\Delta R^2$ after step 2 | .004 | |
| Overall $R^2$ | .10 | |
| Adjusted $R^2$ | -.010 | |

*Note.* All tests are two-tailed. The overall model for the regression was not significant. $F$ (9, 453) = .498, $p$ > .05.

Based on the analysis above, I reject hypothesis 2, and suggest that a relationship is not present between learning styles and grades. In addition, the choice of instructional methodology did not moderate the relationship between learning styles and grades, meaning that changes in the relationship between learning styles and grades did not result when considering the difference between control and experimental groups. Therefore, I did not present a chart displaying an interaction effect.

***Hypothesis 3.*** *The improvement in achieving outcomes experienced by minorities compared to Caucasians will be decreased or even reversed when students are taught using the multi-media case study methodology.*

Before testing hypothesis 3, I examined the mean grades of Caucasians and minorities, and the mean grades of individuals in round table and multimedia classrooms. The resulting data are show in Table 5.7. The first independent *t*-test shows that Caucasians (945.19) scored significantly lower than minorities (965.27) on grades, ($p$=.022). The second independent *t*-test shows that Caucasian students' mean scores in a round table classroom (957.35) are significantly higher than Caucasian students' mean scores in multimedia classrooms (930.43), ($p$=.000). The third independent *t*-test shows that minority students' mean scores do not differ significantly between multimedia and round table discussions. The fourth independent *t*-test shows that minority students in a multimedia classroom (968.76) have significantly higher scores than Caucasians (930.43) in multimedia classrooms, ($p$=.022). The fifth independent *t*-test shows that minority students and Caucasian students do not differ significantly on mean scores in round table classrooms.

Table 5.7. Mean comparisons of student grades involving race

| | Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|
| 1 | Grades | | | | -2.31 | 204.83 | .022* |
| | Caucasian | 945.19 | 48.44 | 341 | | | |
| | Minority | 965.27 | 108.25 | 171 | | | |
| 2 | Caucasian | | | | -5.15 | 275.31 | .000*** |
| | Multimedia | 930.43 | 53.84 | 154 | | | |
| | Lecture | 957.35 | 39.70 | 187 | | | |
| 3 | Minority | | | | .301 | 169 | .763 |
| | Multimedia | 968.76 | 119.52 | 58 | | | |
| | Lecture | 936.48 | 102.49 | 113 | | | |
| 4 | Multimedia | | | | -2.35 | 65.90 | .022* |
| | Caucasian | 930.43 | 53.84 | 154 | | | |
| | Minority | 968.76 | 119.52 | 58 | | | |
| 5 | Lecture | | | | -.608 | 132.58 | .544 |
| | Caucasian | 957.35 | 39.70 | 187 | | | |
| | Minority | 963.48 | 102.49 | 113 | | | |

*Note*. *$p$<.05, **$p$<.01, ***$p$<.001

Based on these findings above, I progressed to the hierarchical multiple regression analysis. When conducting the hierarchical multiple regression analysis for hypothesis 3, I began by entering race ($\beta$ = .115, $p$ = .009) and instruction ($\beta$ = .112, $p$ = .011) in block one of the analysis. The addition of these variables accounted for 2.8 percent of the variance in grades, ($\Delta R^2$ = .028, $p$ < .001). In step two of the regression analysis, I entered the interaction variable comprised of race and instruction ($\beta$ = -1.79, $p$ = .024). The addition of the interaction variable also accounted for unique variance, ($\Delta R^2$ = .010, $p$ < .024). In total, the regression model accounted for 3.2 percent of the variance in student grades. The results of this analysis are shown in Table 5.8.

Table 5.8. Hierarchical moderated regression results predicting a difference in grade based on race and instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Race | | .115** |
| Instruction | | .112** |
| $\Delta R^2$ after step 1 | .028 | |
| *Step 2:* | | |
| Race X Instruction | | -.179* |
| $\Delta R^2$ after step 2 | .010 | |
| Overall $R^2$ | .038 | |
| Adjusted $R^2$ | .032 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant, $F$ (3, 507) = 8.067, $p <$ .001. *$p$<.05, **$p$<.01, ***$p$<.001

Following the analysis above, I generated Figure 5.5 to display the direction of the significant interaction. Specifically, grades of minority students were significantly higher than grades of Caucasian students in multimedia classrooms, while grades of minority students were not significantly higher than grades of male students in round table classrooms.

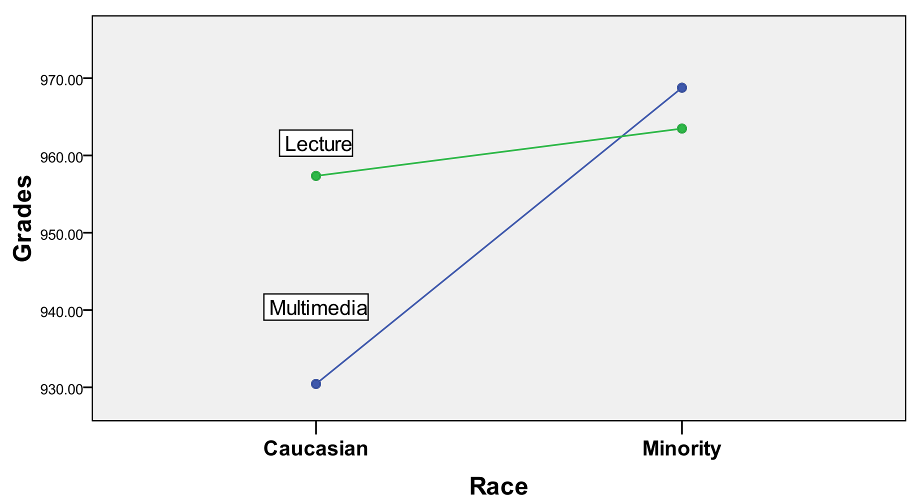



Figure 5.5. Interaction between race and instructional methodology

Based on all analyses above, I fail to reject hypothesis 3, and we note that a moderating effect does exist. Specifically, I found that instructional methodology (i.e., round table discussions or multimedia case studies) moderates the relationship between race and grades. Minorities perform better than Caucasians in multimedia classrooms, with minorities receiving average grades of 968.76 (approximately 97%) in multimedia classrooms, and Caucasians receiving average grades of 930.43 (approximately 93%). Further, the mean scores of Caucasians differ significantly between control and experimental groups.

***Hypothesis 4.*** *The tendency for improvement in achieving outcomes being positively related to acquisition of higher-order cognitive skills will be more pronounced among students using the multi-media case study methodology than among students using a round table methodology.*

Before testing hypothesis 4, I examined the mean Perceived Gain in Higher Order Cognitive Skills (HOCS) to determine if they differ across instructional methodology. The results of this analysis are available in Table 5.9. Based on the independent *t*-test, I find that Perceived gain in HOCS for multimedia classrooms (3.37) is significantly higher than perceived gain in HOCS for round table classrooms (3.12), ($p$=.001).

Table 5.9. Mean comparison of HOCS for multimedia and round table discussions

| | Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|
| 1 | Gain in HOCS | | | | 3.31 | 535 | .001*** |
| | Multimedia | 3.37 | .844 | 223 | | | |
| | Lecture | 3.12 | .889 | 314 | | | |

*Note*. *$p$<.05, **$p$<.01, ***$p$<.001

In order to test hypothesis 4, a hierarchical multiple regression analysis was used. Specifically, Gain in HOCS and Instructional Methodology were used to predict student grades, followed by a test for the interaction between Gain in HOCS and Instructional

Methodology when predicting grades. The results of this analysis are shown in Table 5.10.

My analysis consisted of the following steps. I entered Gain in HOCS ($\beta$ = .093, $p$ = .034) and Instruction ($\beta$ = .140, $p$ = .002) in block one of the hierarchical analysis. The addition of these variables accounted for 2.5 percent of the variance in grades, ($\Delta R^2$ = .025, $p < .01$). In step two of the regression analysis, I entered the interaction variable comprised of Gain in HOCS and Instruction ($\beta$ = .015, $p$ = .929). The addition of the interaction variable did not account for unique variance ($\Delta R^2$ = .000, $p$ = .929). The results of the regression model in step one suggest that perceived gain in HOCS and improvement in points obtained are significantly related. Specifically, I found that as perceived gains in HOCS increase, so do improvements in achieving outcomes. However, the aforementioned relationship does not differ across instructional methodology. Therefore, I reject hypothesis 4.

Table 5.10. Hierarchical moderated regression results predicting a difference in grade based on gain in HOCS and instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Instruction | | .140** |
| Gain in HOCS | | .093* |
| $\Delta R^2$ after step 1 | .025** | |
| *Step 2:* | | |
| Gain in HOCS X Instruction | | .015 |
| $\Delta R^2$ after step 2 | .000 | |
| Overall $R^2$ | .025 | |
| Adjusted $R^2$ | .019 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant, $F$ (3, 514) = 4.36, $p < .01$. *$p$<.05, **$p$<.01, ***$p$<.001

***Hypothesis 5.*** *The relationship between students' improvement of team working skills and improvement in achieving outcomes will be stronger among students using a multi-media case study methodology than among students using the round table methodology.*

Before testing hypothesis 5, I examined the mean perceived Gain in Team Skills to determine if they differ across instructional methodology. The results of this analysis are available in Table 5.11. Based on the independent *t*-test, I found that Perceived Gain in Team Skills for multimedia classrooms (3.54) is significantly higher than Perceived Gain in Team Skills for round table classrooms (3.32), ($p$=.004).

Table 5.11. Mean comparison of HOCS for multimedia and round table discussions

| | Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|
| 1 | Gain in Team Skills | | | | 2.85 | 513.76 | .004** |
| | Multimedia | 3.54 | .81 | 223 | | | |
| | Lecture | 3.32 | .93 | 314 | | | |

*Note*. **p*<.05, ***p*<.01, ****p*<.001

In order to test hypothesis 5, a hierarchical multiple regression analysis was used. Specifically, Gain in Team Skills and Instructional Methodology were used to predict student grades, followed by a test for the interaction between Gain in Team Skills and Instructional Methodology when predicting grades. The results of this analysis are shown in Table 5.12.

My analysis consisted of the following steps. I entered Gain in Team Skills ($\beta$ = .105, $p$ = .017) and Instruction ($\beta$ = .139, $p$ = .002) in block one of the hierarchical analysis. The addition of these variables accounted for 2.7 percent of the variance in grades, ($\Delta R^2$ = .027, $p < .001$). In step two of the regression analysis, I entered the interaction variable comprised of Gain in Team Skills and Instruction ($\beta$ = -.047, $p$ = .799). The addition of the interaction variable did not account for unique variance ($\Delta R^2$ = .000, $p$ = .799). The results of the regression model in step one suggest that perceived improvement in team skills and improvement in points obtained are significantly related. Specifically, I found that as perceived improvement in team skills increases, so do improvements in points obtained. However, the aforementioned relationship does not differ across instructional methodology. Therefore, I reject hypothesis 5.

Table 5.12. Hierarchical moderated regression results predicting a difference in grade based on gain in team skills and instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Gain in Team Skills | | .139** |
| Instruction | | .105* |
| $\Delta R^2$ after step 1 | .027*** | |
| *Step 2:* | | |
| Gain in Team Skills X Instruction | | -.047 |
| $\Delta R^2$ after step 2 | .000 | |
| Overall $R^2$ | .027 | |
| Adjusted $R^2$ | .022 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant, $F$ (3, 514) = 4.807, $p$ < .01. *$p$<.05, **$p$<.01, ***$p$<.001

***Summary of findings.*** My analyses of the hypotheses presented in the 4P model above revealed interesting results. Although some hypotheses were rejected either fully or in part, the results of the analyses produced relevant information.

The test of hypotheses 1 revealed that an interaction effect is present between gender and instructional methodology as they predict grades. Specifically, mean grades of females exceeded those of males overall and in multimedia classrooms. This is a positive result for both female students and the use of multimedia case studies as an instructional methodology in engineering. Additional studies should be conducted to confirm these findings and disseminate the results to the engineering community.

The test of hypothesis 2 revealed that not only is an interaction effect absent from the relationship between learning styles and instructional methodology as predictors of grades, learning styles do not display a significant relationship with grades. While the results involving learning styles are unexpected, it is important to note that the analysis may be limited by the use of a dichotomous variable for each of the four learning styles dimensions. However, the use of dichotomous variables was necessary to test the interaction effects proffered in the hypothesis. Further, discussion with the primary course instructor at Auburn revealed that he has adapted his teaching style, in both control and experimental groups, to match the predominant preferred learning styles of students. Therefore, the instructor's changes to his own teaching style may be partially responsible for the absence of significant findings with regard to the learning styles construct.

The test of hypothesis 3 revealed an interaction effect between race and instructional methodology as predictors for grades. Specifically, minorities displayed higher mean grades than Caucasians overall, and within multimedia classrooms. Similar to the finding in hypothesis 1, this is a positive result for both minorities and multimedia case studies as an instructional methodology in engineering. Further studies should also attempt to confirm these findings and disseminate the results to the engineering community.

The test of hypothesis 4 revealed the absence of an interaction effect between gain in HOCS and instructional methodology as predictors of grades. However, gain in HOCS displayed a strong positive relationship with grades. In addition, gain in HOCS was significantly higher in multimedia classrooms than in lecture classrooms. A possible explanation for this may be due to the higher reliance on HOCS in the problem-based learning environment created by multimedia case studies.

The test of hypothesis 5 revealed the absence of an interaction effect between gain in Team Skills and instructional methodology as predictors of grades. However, gain in Team Skills displayed a strong positive relationship with grades. Similarly to gain in HOCS, gain in Team Skills was significantly higher in multimedia classrooms than in lecture classrooms. A possible explanation for this may be the increased reliance on team work required to solve the problems associated with multimedia case studies.

**Qualitative results.** Results of the thematic analysis performed throughout this project resulted in the identification of numerous themes within each semester. Therefore, the current results are limited to themes that were observed across all five semesters or across semesters where a similar instructional methodology was implemented. Further, the qualitative data collection and analysis focused on answering three questions

1. *How do students perceive the value and nature of instructional methods used in this course?*
2. *How do students perceive the value and nature of group work in the course?*
3. *What strengths and areas of improvements do the students perceive are needed in the course, in general, and in the instructional methods, in particular?*

With regard to the first question, students at both Auburn University and Hampton University felt that lab activities were most helpful to their learning, by a margin of greater than fifty percent. Lab activities at Auburn represented themes from responses involving activities such as case studies, presentations, group work, hands on projects, robots, and projects. When asked specifically about the case studies in fall 2011, 74% of the students at Auburn and 82% of the students at Hampton found the case studies to be helpful. During the following semester, 70% of students at Auburn and 60% of the students at Hampton regarded the case studies as beneficial to their learning.

When answering the second qualitative research question, it is important to remember that team-working skills is a process variable in the 4P model. Responses to this question revealed that 80% of Auburn students in the fall 2011 semester found group work in the course to be beneficial, while 87% of the students at Hampton found group work to be beneficial. In the spring 2012 semester, 77% of Auburn students found it beneficial, while 78% of Hampton students found it beneficial.

With regard to the third qualitative question, the majority of suggested improvements involved the lack of connection between the lab and the classroom lecture material. Students at both universities enjoyed the hands on activities, however, the relationship between the lectures and those activities was weak. However, students found favor in all of the hands on activities, including the round table discussions, case studies, and projects simulating real world work experiences. Many students commented that the course enhanced their ability to work with others, and their problem-solving skills. Of particular note is that students felt the presentation portion of the case studies helped improve their communication skills. When describing the round table discussions, students generally had a positive experience. They felt that the group context of the discussions provided benefits such as creativity, problem solving, and shared ideas. However, the negatives associated with the round table discussion included a lack of structure that allowed students to "bluff" their way through the discussion.

**Discussion.** In order to meet the requirements of concurrent triangulation, quantitative and qualitative data were collected simultaneously, and data were analyzed separately before being compared. During each semester, qualitative data and quantitative data were collected via an online survey at the conclusion of the semester. Additional qualitative data was derived from focus groups conducted during the final week of each class.

Both qualitative and quantitative data were summarized and presented to the entire LITEE team at annual meetings. The results of the quantitative data consistently provided positive results regarding the use of multimedia case studies in the form of greater benefits for minorities and females when using the multimedia case studies verses the round table discussions. While the qualitative results did not provide such detailed explanation, it was apparent that the students at Auburn, who were predominantly Caucasian, enjoyed both multimedia case studies and round table discussions for their focus on group work.

One possible explanation for the increased benefits of minorities is that most of these students were at Hampton University in classrooms that were composed of a large population of non-engineering students or students with non-engineering backgrounds. When comparing the case studies to round table discussions, the case studies provide more detailed information for the students, while round table discussions require individual research by students.

**Communication**

The final stage of all DSR requires that knowledge from the design process be "presented effectively both to technology-oriented as well as management-oriented audiences" (Hevner et al., 2004). Peffers et al. (2007) provide detailed instructions for this phase, explaining that the problem and importance should be shared, in addition to the artifact, its utility and novelty, the rigor of the design, and its effectiveness. They even advocate the use of their paper as a template for communicating in scholarly research publications. Table 5.13 summarizes the communication efforts of the LITEE team at the time of this writing. An examination of Table 5.13 reveals that the current project has been disseminated in the form of eleven journal articles at the time of this writing.

Table 5.13. Summary of communication efforts resulting from multimedia case study implementation

| Author(s) | Title | Publication |
| --- | --- | --- |
| Bond et al. (2010) | Enhancing Minority Student Leadership Skills Using Case Studies | Journal |
| Clayson (2011) | Effectiveness of LITEE Case Studies in Engineering Education: A Perspective from Genre Studies | Journal |
| Halyo and Le (2011) | Results of Using Multimedia Case Studies and Open-ended Hands-on Design Projects in an 'Introduction to Engineering' Course at Hampton University | Journal |
| Kawulich (2011) | Learning from Action Evaluation of the Use of Multimedia Case Studies in Information Management Courses | Journal |
| Le (2012) | Implementation of Case Studies in an Introduction to Engineering Course for "LITEE National Dissemination Grant Competition" | Journal |
| Mbarika et al. (2010) | A Multi-Experimental Study on the Use of Multimedia Instructional Materials to Teach Technical Subjects | Journal |
| McIntyre (2011) | Effectiveness of Three Case Studies and Associated Teamwork in Stimulating Freshman Interest in an Introduction to Engineering Course | Journal |
| Sankar and Raju (2011) | Use of Presage-Pedagogy-Process-Product Model to Assess the Effectiveness of Case Study Methodology in Achieving Learning Outcomes | Journal |
| Sankar and Clayton (2010) | An Evaluation of Use of Multimedia Case Studies to Improve an Introduction to Information Technology Course | Journal |
| Sankar et al. (2010) | Developing Leadership Skills in Introduction to Engineering Courses through Multi-Media Case Studies | Journal |
| Sutton and Sankar (2011) | Student Satisfaction with Information Provided by Student Advisors | Journal |

## Chapter Summary

Positive results were observed by comparing the multimedia case study methodology to the round table discussion methodology, however, a need for improvement was evident in the methodology used to implement multimedia case studies in the classroom. During the five consecutive semesters involved in the abovementioned research project, qualitative and quantitative responses from students revealed that changes to the implementation and evaluation of the case studies were necessary.

While several details of the multimedia case study implementation were defined from the start of the project, the ensuing semesters revealed a need to adapt both the implementation and evaluation. By its nature, and without intention, this project took on a build-and-evaluate loop, typical of DSR (Markus et al., 2002). Examination of the minutes from teleconferences and meetings revealed that the frequency of the meetings increased as the project progressed, leading to greater communication among team members, and feedback from data analysis was given quicker towards the end of the project. Initial plans for this project relied on yearly evaluation presentations, however, discussions at the conclusion of the project revealed that results were not analyzed at the end of each semester over the course of the three year period. While the implementation did improve over the course of the project, the lack of timely feedback limited the amount of iterative improvements to the implementation and evaluation that were possible. Thus, recommendations for future projects included prompt feedback at the conclusion of each semester, and timely incorporation of feedback into subsequent course planning.

# Chapter 6: Using the DSRM to develop a serious game

As LITEE's work progressed, the results of each project affirmed that multimedia case studies were effective at achieving desired outcomes, however, data from focus groups continued to suggest that the IT artifact could benefit from additional improvements. With continued calls from ABET (2011) and AACSB (2012) to advance the professional skills of their students, there was continuous need for new innovations.

The advent of alternative educational information systems, as discussed in earlier chapters, has created interest in technologies such as serious games for use in higher education. These new instructional methods aren't limited to higher education, however. We can observe their application in corporations, primary schools, and the US military (Prensky, 2001). Therefore, the current chapter documents the LITEE team's most recent attempt to design and develop an IT artifact that expanded the capabilities of multimedia case studies, while still meeting the learning preferences of engineering students. This process was undertaken in partnership with an experiential learning provider, Toolwire, Inc. Once again, the DSRM for wicked educational IS is applied to the processes undertaken by LITEE and their industry partner.

This chapter proceeds as follows. I begin by providing an overview of serious games, their uses, and their growing demand in higher education. I then document the collaboration between LITEE and Toolwire as they began working to develop a serious game. The next six sections apply the DSRM for wicked educational IS to LITEE's work in developing this wicked educational IS. The final section provides a chapter summary.

## Overview

The use of digital games in all aspects of life has seen a significant increase over the last decade (Liu, Cheng, & Huang, 2011). Of specific interest to this study, however, is the increasing interest games have received from educators in recent years (Papastergiou, 2009). This is not a coincidence, but an attempt to combine two aspects of life that seldom overlap, learning and fun. Prensky (2001, p. 4) says it best, “The really large and potentially far-reaching opportunity is the combination of the entertainment business with learning, education, and training.”

Michael and Chen (2006) define serious games as “games that do not have entertainment, enjoyment, or fun as their primary purpose.” They clarify that serious games can still be fun, however, there is another purpose for serious games. Wouters and van Oostendorp (2013) state that serious games are computer games used in learning and instruction, and Sitzmann (2011) explains that while computer games have been used for educational purposes for decades, the term “serious games” was coined to refer to simulation games designed to address more complicated and thought provoking issues. One of the key benefits of serious games, as compared to some traditional instructional methodologies, is that they are designed to immerse learners and motivate them through interaction, typically via feedback regarding their progress (Prensky, 2001). Westera, Nadolski, Hummel, and Wopereis (2008) suggest that the main objective of using games is to present real-world situations without exposing students to the unwanted constraints and risks of the real world. When quoting John Lester, the developer of the game Second Life, Brown (2011) writes, “The real opportunities are the malleability of the space. You can make it look like anything you want.” In this scenario, Lester is referring to the unending possibilities available in a gaming environment, as opposed to a physical classroom environment.

The use of games in education dates back decades, when games such as *Oregon Trail* and *Where in the World is Carmen San Diego* were used to teach geography and history (Sitzmann, 2011). However, games have advanced to a point where students can experience in depth real-world simulations that present business and economics scenarios, such as *Simunomics* (Simunomics, 2008), where each player acts as the CEO of his or her own company to experience economic changes in real time. Other examples include the use of games to prepare for Cisco certifications (Cisco, 2010). As time progresses, the number of these wicked educational IS increases, providing new teaching and learning opportunities for students, faculty, and administrators in higher education.

**Smart Scenarios**

Based on their prior experiences, detailed in chapters four and five, LITEE recognized the opportunity for multimedia case studies to evolve into something more engaging. Specifically, LITEE observed that simply bringing real-world issues into the classroom wasn't enough, there was a need for more student engagement. Working in a collaborative effort with Toolwire, a three phase project was undertaken to develop a functioning serious game using existing case studies developed by LITEE. The first phase of the project consisted of a pilot study, which took approximately three months to develop and test two functioning IT instantiations during the fall semester of 2010, one used to teach engineering design and the other focused on communications. Although the end goal was to produce a serious game, these initial systems were still far from a game-like environment. Called Smart Scenarios, these systems adapted an existing multimedia case study into a more interactive environment. The design process involved students and faculty from Auburn University and Toolwire. Weekly teleconferences allowed the Auburn team, acting as content experts in communications and design, to assist the Toolwire developers and project managers. The entire LITEE team was not involved in development due to the hurried time frame required to implement the Smart Scenarios during the fall 2010 semester.

Students completing the Smart Scenarios took on the role of a new employee at a fictional organization, Lunar Aerospace, where they were guided through learning activities that both taught and evaluated. Screenshots of these Smart Scenarios are available in Appendix C. The Smart Scenarios were implemented at Auburn University and Hampton University in introduction to engineering courses. As a result of the hurried design and development process, a rigorous evaluation was not planned or conducted, and the only useful feedback was gathered from focus groups. The focus group responses were not positive, leading to changes in the direction of future builds. Suggestions from the focus group included changes to the navigation of the Smart Scenarios, and the need for more interaction. Student responses included the following comments: it’s too wordy, it should be more like a game, it was boring, make the characters talk (i.e., inclusion of audio), add videos, add a back button, improve the storyline, and make it more like an Xbox, PlayStation, or Wii game. On the positive side, most students preferred the Smart Scenarios to lecture, and suggested changes to the existing system, rather than starting over. For this reason, the results of the study acted as the catalyst for requesting the funding needed to develop a serious game.

Following the pilot study, LITEE and Toolwire applied for, and were awarded funding from the NSF for a project titled STTR Phase 1: Use of Serious Games to Improve Learning Outcomes in Engineering Programs. Funding for this project totaled $165,000 and was awarded in the summer of 2011.

**Learnscapes**

Following the implementation of the Smart Scenarios, LITEE and Toolwire collaborated to develop a new wicked educational IS that was more extensive in its capabilities. These were labeled Learnscapes and sought to educate students in the areas of communication, cross cultural communication, and engineering design.

The design process for the Learnscapes involved the collaboration of content experts from Auburn University working in small groups, followed by discussions of IS feasibility with Toolwire designers. There were two teams, based on the content of the Learnscapes being developed. The engineering design team was comprised of doctoral students from the college of engineering at Auburn University, led by faculty advisors from LITEE. The communications and cross-cultural communications teams were comprised of master's level students from the college of communications at Auburn University and myself, led by faculty advisors from LITEE. Each team met weekly to advance a storyline and specific learning objectives for their respective Learnscape. Additional weekly teleconferences allowed the teams to work with the designers and project managers at Toolwire. The design process took place during the fall semester of 2011, and the early months of the spring 2012 semester. However, finite resources and the need for input led the LITEE team to conduct a pilot test of the communication

Learnscape on March 5, 2012. Screenshots of the communication Learnscape are available in Appendix D.

The pilot test of the communication Learnscape involved fifteen students from an introduction to engineering course. Following the pilot test, the LITEE evaluation team conducted a focus group. Results of the focus group produced the following positive sentiments from students: easy to understand, clear audio, easy to navigate, would like to learn more concepts this way, good for visual learners, interesting historical content. Negative sentiments included: no back or refresh button, five of the fifteen students did not like learning in this manner, students were unsure if their responses were right or wrong, they did not understand the scoring system, the storyline was confusing, and students were unsure of the overall goal. Suggestions for improvement included: give students the ability to choose a direction within the Learnscape, make the topic more serious but have it interact like a game on Xbox, PlayStation, or Wii. Minutes from the meeting on March 9, following this pilot test, stated that the "pilot test did not go so well."

Analysis of the minutes from meetings during the design process revealed that several major shifts in the overall focus of the Learnscape may have resulted in its ultimate failure. Specifically, minutes from the December 1, 2011 meeting reveal a major shift in the direction of the communication Learnscape. Other possible explanations include changes in personnel at Toolwire and changes in the communications team at Auburn during the course of the design process.

As a result of the negative results garnered from the Learnscape pilot test, the team shifted its focus towards the development of serious game to teach engineering design. Rather than using technology that was familiar to Toolwire, the design game was built from scratch. By the time this third phase of this project began (i.e., serious game development), the LITEE project manager had determined that DSR was the most appropriate methodology for designing the game. The following sections document the design, implementation, and testing of the serious game.

**Problem identification**

According to the DSRM for wicked educational IS, the problem identification phase involves determining the need for wicked educational IS in the context of learning outcomes by reviewing extant literature. With regard to the project discussed in this chapter, the DSRM may benefit from an extension of this requirement. Specifically, a designer of wicked educational IS could determine the existence of a problem via discussion or interviews with current designers, or through interactions with users of existing IT. Since design science can also address wicked problems by improving or extending existing IT artifacts (Hevner et al., 2004), it seems reasonable to consider that researchers' inability to publish results could lead to the absence of extant literature's ability to define a problem on its own. Therefore, at the time this project was conducted, a portion of the problem identification process was driven by unpublished results from past studies, with additional support for the existence of the problem and the value of a solution coming from extant literature.

As an extension of previous LITEE projects involving multimedia case studies and smart scenarios, the problem under consideration was similar. Calls for increased engineering design skills by ABET (2011) were still a driving force in this development, but feedback from both the Learnscape and Smart Scenario development projects identified additional problems common to several existing wicked educational IS. When combining calls from ABET and data collected from previous studies conducted by LITEE, the problem became clear. There is a need for more immersive instructional materials focused on engineering design that are capable of achieving desired learning outcomes.

### Objectives for a solution

According to the DSRM for wicked educational IS, determining objectives for a solutions involves examining the environment and student learning styles, and creating a conceptual model with constructs of interest for evaluation. With the problem clarified, LITEE knew from past projects that engineering students are predominantly active-sensing-visual-sequential learners. Further, feedback from past focus groups confirmed that the engineering students took the course seriously and enjoyed learning through challenging hands on instructional methodologies.

In order to address the problem mentioned above, LITEE continued working with Toolwire to design and develop a serious game to teach the engineering design process. During an additional review of the literature, the evaluation team decided to continue using the 4P model to assess the effect of the serious game on learning outcomes. Improvement in higher order cognitive skills was retained in the model as a process variable, and new process variables were chosen based on their relationship to improvements in desired learning outcomes, as observed in extant literature. Figure 6.1 displays the 4P model used in the serious games study.

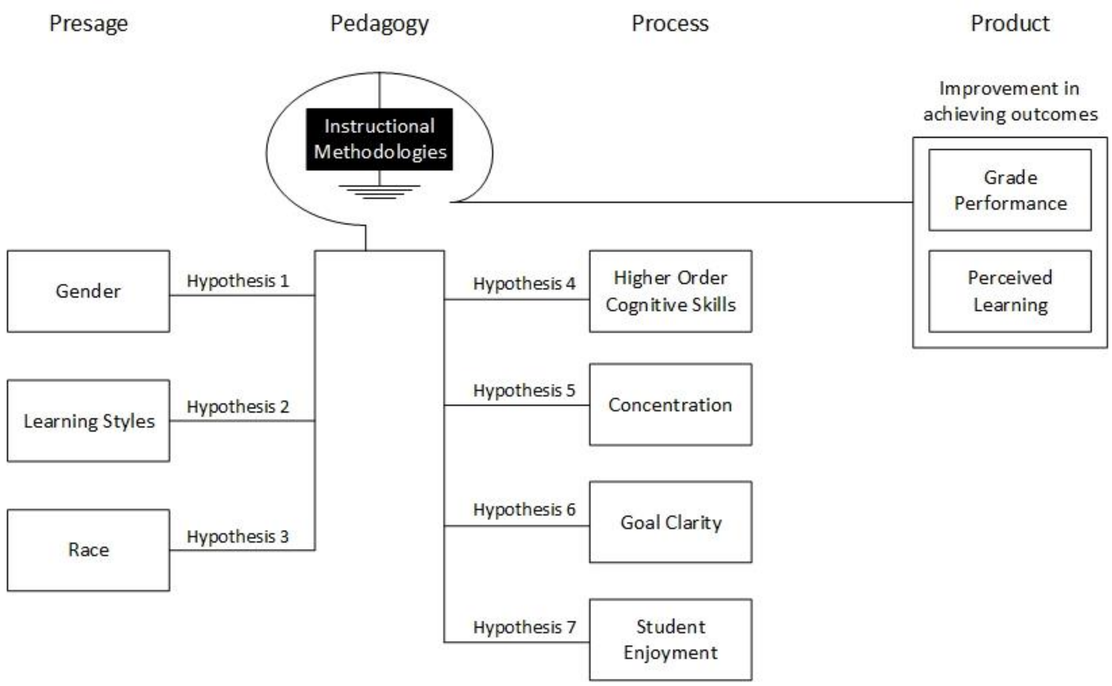



Figure 6.1. 4P model for serious games

**Model description and hypotheses development.** In this study, the 4P model hypothesized seven relationships. The first three relationships are hypothesized to exist between presage factors and product factors, while being moderated by pedagogy. Hypotheses four through seven suggest a relationship between process factors and product factors, while being moderated by pedagogy. Each of the presage, process, and product factors are defined below, in addition to an explanation of the seven hypothesized relationships.

***Presage factors.*** Three presage factors were considered in this model: gender, race, and learning style. Females have long been underrepresented in the field of engineering, with only 8.5 percent of engineers being women, and accounting for only 20% of enrollment in engineering schools (Goodman et al., 2002). For this reason, numerous researchers and administrators constantly seek methods to increase enrollment of females and retain those who are enrolled. With this in mind, the LITEE team was focused on student interactions with and responses to the serious game, and whether or not differences exist between male and female students. Historically, it has been shown that young males are more oriented towards video games and play games at a rate more than twice that of females (Greenberg, Sherry, Lachlan, Lucas, & Holmstrom, 2010). However, a study involving computer based assessments by Terzis and Economides (2011) revealed that both genders are more likely to use the computer based assessment if it is playful and its content is clear and relevant to the course. These findings suggest that differences may exist, but will depend on the content of the game.

*Hypothesis 1: The difference between improvements in achieving outcomes experienced by females compared to males will be decreased or even reversed when students are taught using a serious game methodology rather than a round table discussion methodology.*

The second presage factor of interest in this study is learning style. Both LITEE and others have observed that learning style relates to performance, especially when an appropriate instructional methodology is applied (Cegielski et al., 2011). Further, it has been observed by LITEE and others that the learning styles of engineering students are most often associated with the active, visual, sensing, and sequential learning dimensions. This was considered when deciding to develop a game, and during the design process. These data also reinforced the LITEE team's decision to implement specific characteristics of the game, such as multimedia, interactive elements, and the use of a story line. In order to measure this, the LITEE team hypothesized that the relationship between learning style and outcomes will be moderated by pedagogy.

*Hypothesis 2: The improvement in achieving outcomes based on certain learning styles will be stronger among students using the serious game methodology than among students using the round table discussion methodology.*

With regard to race, African Americans are one of the largest minority groups in the US, and also significantly underrepresented in engineering education. These results led Chubin et al. (2005) to suggest that engineering has a diversity problem. When considering race and games, statistics show that Caucasians represent a larger contingent of the gaming market than do African Americans, with Caucasians accounting for 79.3% of game play in online games and African Americans accounting for 8.9% of online game play (Corti, 2006). While this disparity doesn't represent ability, one could assume that Caucasians might be more comfortable with games used in the classroom. If this is true, and Caucasians appear to benefit more than minorities, the use of serious games in minority dominated classrooms might not prove beneficial. Therefore, LITEE hypothesized that the effect of race on learning outcomes will be moderated by pedagogy.

*Hypothesis 3: Under a serious game methodology, the difference between improvements in achieving outcomes experienced by minorities compared to Caucasians will be decreased or even reversed when students are taught using the round table discussion.*

***Pedagogy.*** During the serious game project, students were divided into control and experimental groups, based on their lab sections. The classes at Auburn met in a large lecture once each week, and then were split into several smaller lab sections, which also meet once each week. Students participating in the control group experienced the lecture and an active learning exercise. The active learning exercise consisted of a statistics lecture and applied data analysis. Students participating in the experimental group also experienced the lecture, however, this module completed the serious game. The two modules acted as control and experimental groups for the purpose testing hypothesized relationships in the 4P model.

***Process.*** Process factors relate to a student's learning experience (Nemanich et al., 2009). The factors chosen in this study were improvement in higher order cognitive skills, concentration, goal clarity, and student enjoyment. Higher order cognitive skills were chosen because extant research suggests that serious games can be used to address various cognitive aspects of learning by improving individuals' ability to process information. For this reason, LITEE hypothesized that the relationship between higher order cognitive skills and outcomes will be moderated by pedagogy.

*Hypothesis 4: The tendency for improvement in achieving outcomes being positively related to acquisition of higher-order cognitive skills will be more pronounced among students using the serious game methodology than among students using a round table discussion methodology.*

Concentration was chosen as a process variable because an individual's level of attention towards something, or level of concentration, has been shown to relate to the learning process (Yang & Chang, 2013). In addition, extant research suggests that participants who immerse themselves in game environments and digital activities have experienced an increased attention to tasks.

*Hypothesis 5: The tendency for improvement in achieving outcomes being positively related to increased concentration will be more pronounced among students using the serious game methodology than among students using a round table discussion methodology.*

When examining antecedents of performance in software developers, Rasch and Tosi (1992) found that goal clarity was a significant predictor of both effort and performance. With regard to games, Prensky (2001) suggests that achieving goals are a large part of what motivates players, resulting in greater achievements.

*Hypothesis 7: The tendency for improvement in achieving outcomes being positively related to goal clarity will be more pronounced among students using the serious game methodology than among students using a round table discussion methodology.*

Student enjoyment was shown to be a critical component of student motivation because it is required for effective learning (Cybinski & Selvanathan, 2005). Prensky (2001) explained that people typically enjoy difficult tasks more when they appear as play rather than work. When engaging in a game instead of a round table discussion, students will most likely perceive it as play, and, in turn, be motivated to reach greater achievements.

*Hypothesis 7: The tendency for improvement in achieving outcomes being positively related to student enjoyment will be more pronounced among students using the serious game methodology than among students using a round table discussion methodology.*

***Product.*** Product variables chosen for this study include an objective measure of performance, and perceived subject matter learning. Performance was to be a measurement of students' scores on a tower building exercise using pasta noodles that is commonly used in engineering (Verzat, Byrne, & Fayolle, 2009). Both control and experimental groups were assigned the tower building exercise after completion of their respective pedagogy (i.e., serious game or round table discussion). The tower building exercise consists of using spaghetti noodles to build a tower of at least twelve inches in height. A formula was used to calculate a student's score based on factors such as weight of supplies, tower height, and load supported by the tower. Higher scores are representative of superior towers.

The second product variable is a measure of students' perceived learning. According to Alavi, Marakas, and Yoo (2002), actual performance is not always a true measure of learning, since performance is an outcome comprised of many factors. Therefore, it may be of more value in some situations to examine an individual's mental model. For this reason, perceived subject matter learning was considered as an alternative achieving outcome to the aforementioned scored exercise.

**Design & Develop**

Following the direction of the DSRM for wicked educational IS, the focus was to design an artifact to maximize desired outcomes in a specific environment, according to the learning styles of students, with a focus on the constructs of interest. Knowing the preferred learning styles of students, and having determined to build a serious game to teach engineering design, the following process documents LITEE and Toolwire's efforts to produce an effective game and test it using the 4P model described above. Funding for this project was provided by NSF, in the amount of $165,000 for an 18 month period.

Teleconferences between LITEE and Toolwire, aimed at producing the engineering design serious game, began immediately following the March 2012 implementation and testing of the Learnscape. In addition to the teleconferences, the LITEE team had frequent meetings on the campus of Auburn University. New ideas and updates to the game were shared via email and the file sharing system Dropbox. All members of LITEE and Toolwire had access to the file sharing system, allowing the individuals developing the design game to collaborate and share updates with the entire group, while the individuals engaged in evaluation could also collaborate and share updates with the entire group. In order to more effectively address specific problems, the team was divided into several smaller groups. Among them were the external evaluation team, the project leaders from Toolwire and Auburn, the design team from Auburn, and the design team from Toolwire. Between March 2012 and October 2012, the two design teams worked together to produce several iterations of the game. Teleconferences involving the entire group supplied feedback to the two design teams and the project leaders. The frequency of meetings that occurred during the spring 2012 and summer 2012 semesters is documented in Table 6.1 below. Minutes from these meetings were used to document the design process in this dissertation.

Table 6.1. Meeting frequency during serious game design and development

| Semester | Meeting Frequency | Average # days between meetings |
|---|---|---|
| Spring 2012 | 4 | 15 |
| Summer 2012 | 8 | 11.71 |

*Note.* Meetings listed above involved the entire project team (i.e., members from LITEE and Toolwire)

On July 30, 2012, a prototype of the game was tested with a small group of students enrolled in a summer section of introduction to engineering at Auburn University. The goal of this test was to provide qualitative data that could be used to iterate to the next version of the game. In accordance with a design science perspective, this build-and-evaluate loop can be iterated a number of times before the final design artifact is generated (Markus et al., 2002). It was this very process that provided the team with specific guidance for the next iteration. Feedback from the focus group that followed the prototype implementation suggested that the design of the game was positive.

Approximately 20 students were in the focus group, and 17 of those students perceived it as a positive experience. Common positive themes from this focus group involved: fun, game-like, kept my interest. Common negative themes, and areas of improvement, were: need for better feedback, no specific learning objective, need precise calculations, introduction needed. In addition, several minor bugs and navigational details were noted for the design team.

Meetings continued during the fall 2012 semester, however, the advanced progress in game design precipitated a change to the meeting structure of the group. Individuals engaged in the actual design of the game continued to meet weekly, sometimes multiple times per week. Representatives from LITEE involved in the design provided updates to the group at Auburn via weekly in person meetings that continued throughout the fall 2012 semester. It was apparent that the smaller size of the group engaged in the design allowed for a more efficient meeting schedule and quicker improvements to the game.

The final version of the game followed a set of criteria comprised of ideas presented by members of LITEE and Toolwire. These ideas allowed the creation of an outline and specific learning objectives for the game. The outline began by presenting learning objectives and the need for the engineering design process that is used throughout industry whenever products are designed. The game then progressed through an introduction by presenting examples of failed bridges resulting from poor design. The game then provided an introduction and walkthrough that explained how to use the game controls and screen areas. Finally, students progressed to the main portion of the game, where they encountered three levels. The first level was a test tower where students were given constraints on the weight, cost, and load of their tower. The second level required students to build the structure, or frame, of a water tower that was required to hold a minimum load (e.g., water tank). The final level required students to build a train bridge across a canyon. The bridge also required the capacity to hold a minimum load (e.g., moving train). As students progressed through the game, the levels increased in difficulty. A grade was given to each student at the conclusion of the game. Screenshots of the engineering design serious game are available in Appendix E.

**Serious game evaluation.** In order to test the hypothesized relationships in the 4P model, LITEE relied on a mixed methods approach. Following the positive experience of the multimedia case study evaluation, concurrent triangulation was used once again (Creswell et al., 2003). During the course of the summer and fall 2012 semesters, the LITEE team developed a schedule for implementing and testing the serious games in October 2012. Table 6.2 shows a schedule of the evaluation in fall 2012.

Table 6.2. Serious game evaluation schedule for fall 2012

| Week | Date | Lecture | Lab | Experiment |
|---|---|---|---|---|
| 10 | 10/16-10/22 | Guest Lecture | Robot Project | Pretest |
| 11 | 10/23-10/29 | Engineering Design | Experiment/Control | Treatment & Posttest |
| 12 | 10/30-11/05 | Guest Lecture & Video | Pasta Towers | Pasta Tower |
| 13 | 11/06-11/12 | Unit Conversion | Measurement Lab | Focus Groups |

*Note.* The labs dictated that a week did not run Monday through Friday.

As noted in Table 6.2, the pasta tower exercise followed the treatment. This exercise was undertaken by both control and experimental groups. This design served two purposes in the context of the course. The first purpose was to provide an additional opportunity for students to experience design through active learning. The second purpose of the activity was for it to serve as a measure of performance in the experiment. In order to objectively score the pasta tower exercise, the instructor developed a formula that awarded points based on the square height of the tower multiplied by the maximum load supported without failure. This formula rewarded students for taking on the difficult design task of creating a taller tower, while also rewarding their ability to sustain a heavy load (Rajan, 2013). The formula used to calculate pasta tower performance is given as: Pasta tower performance factor = Tower height$^2$ x (Weight of supplies/Tower weight) x Load supported by tower.

Because the pasta tower required students to design a tower and receive a score, the evaluation team determined that it could serve as a proxy for learning. Scores from the pasta tower allowed evaluators to compare students' understanding of the engineering design process in the control group to those in the experimental group. One limitation associated with this score, however, is that students completed the project in a group. Therefore, all students working on a single tower received the same score. Fortunately, each group consisted entirely of students who shared the same treatment, either control or experimental.

### Demonstration

One of the components that is unique to the DSRM for wicked educational IS relates to the demonstration phase. The DSRM for wicked educational IS prescribes that research should research approval from an institutional review board. Therefore, prior to the demonstration of the serious game, an Institutional Review Board (IRB) application was submitted to and approved by the IRB at Auburn University. An IRB approval form associated with this project is available in Appendix H. The study participants included students enrolled in three semesters of an introduction to engineering course at Auburn University, beginning in the fall semester of 2012 and ending in the summer of 2013. The introduction to engineering course consists of two parts, lecture and lab. During each semester, the students were divided into several lab sections, consisting of smaller groups of students. While all students attended the same lecture, students attended the labs with only a small contingent of the overall class. This selection process occurred at the time of a student's registration. For this study, each lab section was classified as either experimental (i.e., participating in the game), or control. This division of students allowed for a comparison between experimental and control.

**Quantitative data collection.** The data collection involved survey items from a number of instruments. Higher order cognitive skills were measured using the same items implemented in the multimedia case study exercise. Learning styles were once again collected using the Index of Learning Styles measure (Felder & Silverman, 1988). Race and gender were collected as demographic data using a dichotomous male or female variable, and a specific measure of race that was later dichotomized into Caucasian or minority. The items measuring concentration were adapted from a scale used by Koufaris (2002), goal clarity measures were adapted from a scale used by Guo and Klein (2009), and student enjoyment measures were adapted from the scale used by Nemanich et al. (2009). The product variables consisted of perceived subject matter learning and scores on the pasta tower exercise. Perceived subject matter was measured using items adapted from Alavi et al. (2002).

**Qualitative data collection.** Qualitative data were collected during focus groups at the conclusion of each semester. The focus groups consisted of at least two members of the external evaluation team. A predetermined set of questions were asked at each focus group to allow comparison across semesters and interviewers.

## Evaluation

According to Gregor and Hevner (2013, p. 350), "research rigor is the driving goal for methods selection." Appropriately, then, the DSRM for wicked educational IS suggests that individuals engaged in the design and development of wicked educational IS should undergo a mixed methods approach, allowing for artifact improvement or validation, and to evaluate the artifact against the conceptual model. During the project, data were analyzed at the conclusion of each semester and shared with the design team. Over the course of the three semesters involved, quantitative data and qualitative data were combined after analysis and used to validate findings through concurrent triangulation. The following sections document the quantitative and qualitative analysis, followed by the results garnered from this project.

**Quantitative Analysis.** The sample for this study involved 238 students enrolled in introduction to engineering courses at Auburn University. Data were collected over the course of three semesters: fall 2012, spring 2013, and summer 2013. As is common in most data collections, the resulting data were subject to missing data points. In the current study, missing data were the result of a participant's non-response to a question, or failure to use the identification code provided by the instructor. The identification code was used to link data from multiple survey measures to grades on the tower exercise. In response to missing data, analyses were conducted using listwise deletion, removing a record entirely if a relevant data point was missing during the analysis. For this reason, the *n* for all analyses are not identical. Table 6.3 displays the demographic data for respondents in this study.

Table 6.3. Respondent demographics during serious game implementation

| Semester | Males | Females | Caucasians | Minorities | Experimental | Control |
|---|---|---|---|---|---|---|
| Fall 2012 | 91 | 15 | 89 | 16 | 49 | 57 |
| Spring 2013 | 91 | 24 | 101 | 14 | 76 | 39 |
| Summer 2013 | 16 | 1 | 16 | 1 | 17 | 0 |
| Total | 198 | 40 | 206 | 31 | 142 | 96 |

*Note.* One student did not respond to the item about race.

Statistical methods used for this study include mean comparisons (i.e., *t*-tests), and hierarchical regression analyses. By using a hierarchical regression analysis, the researcher is able to determine the contributing predictive ability of variables added at different stages of the analysis. Specifically, this method of regression analysis determined whether interactions occurred between variables, as hypothesized in the 4P model, in addition to determining the existence of relationships between both presage and process variables and the outcome variables.

**Qualitative Analysis.** Results from the focus groups were presented to the LITEE team in a 65 page report, written by the evaluation team. When examining this report, it is clear that evaluators analyzed the results using techniques similar to those applied during the multimedia case study project. The qualitative analyses conducted during the course of this project also involved a thematic analysis approach (Braun & Clarke, 2006), where applicable; however, in instances where data were one or two word responses and thematic analysis was not possible, frequency counts were conducted to enable the team to provide some analytic discussion of the data. In the current project, the qualitative evaluators applied thematic analysis to interview responses provided during the focus groups.

**Quantitative Results.** The following section presents the results of the hypotheses testing for each relationship presented in the 4P model, Figure 6.1. Analyses were conducted after data were aggregated for the three semesters.

***Hypothesis 1.*** *The difference between improvements in achieving outcomes experienced by females compared to males will be decreased or even reversed when students are taught using serious games.*

Before testing hypothesis 1, we examined the mean scores of males and females on both the pasta tower exercise and their response for the perceived subject matter learning construct. These observations were provided for both the serious games sections and the traditional instruction sections. The resulting means related to tower scores are displayed in Table 6.4 while the resulting means for perceived subject matter learning are displayed in Table 6.5. A difference was not observed between males and females for pasta tower scores, however, a difference did appear in tower scores between the control and experimental groups, such that students enrolled in the serious games sections scored higher on the pasta tower exercise than did students in the traditional sections, ($p$<.01). Further examination revealed that this difference could be attributed mostly to females in the serious games section who scored higher on the pasta exercise than did their peers, ($p$<.01). When examining the perceived subject matter learning construct, no differences were observed between males and females.

Table 6.4. Mean comparisons using pasta tower scores

| Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|
| Pasta Tower Score | | | | -.396 | 221 | .692 |
| Males | 4699.66 | 3456.64 | 39 | | | |
| Females | 4458.06 | 3461.24 | 184 | | | |
| Pasta Tower Score | | | | -3.071 | 220.42 | .002** |
| Serious Games | 5188.11 | 3806.63 | 134 | | | |
| Traditional | 3858.37 | 2658.35 | 89 | | | |
| Males | | | | -1.901 | 181.98 | .059 |
| Serious Games | 5073.84 | 3869.11 | 109 | | | |
| Traditional | 4155.84 | 2682.13 | 75 | | | |
| Females | | | | -3.332 | 37 | .002** |
| Serious Games | 5686.31 | 3552.22 | 25 | | | |
| Traditional | 2264.74 | 1908.36 | 14 | | | |
| Serious Games | | | | .724 | 132 | .470 |
| Males | 5073.84 | 3869.11 | 109 | | | |
| Females | 5686.31 | 3552.22 | 25 | | | |
| Traditional | | | | .724 | 132 | .470 |
| Males | 5073.84 | 3869.11 | 109 | | | |
| Females | 5686.31 | 3552.22 | 25 | | | |

*Note*. $*p<.05$, $**p<.01$, $***p<.001$

Table 6.5. Mean comparisons using PSML

| Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|
| PSML | | | | -.085 | 88 | .933 |
| Males | 3.42 | .76 | 73 | | | |
| Females | 3.40 | .82 | 184 | | | |
| PSML | | | | 1.617 | 88 | .109 |
| Serious Games | 3.35 | .80 | 73 | | | |
| Traditional | 3.69 | .56 | 17 | | | |
| Males | | | | 1.352 | 71 | .181 |
| Serious Games | 3.36 | .79 | 59 | | | |
| Traditional | 3.67 | .61 | 14 | | | |
| Females | | | | .865 | 15 | .401 |
| Serious Games | 3.32 | .89 | 14 | | | |
| Traditional | 3.78 | .25 | 3 | | | |
| Serious Games | | | | -1.65 | 71 | .870 |
| Males | 3.36 | .79 | 59 | | | |
| Females | 3.32 | .89 | 14 | | | |
| Traditional | | | | .302 | 15 | .767 |
| Males | 3.67 | .61 | 14 | | | |
| Females | 3.78 | .25 | 3 | | | |

*Note*. *$p$<.05, **$p$<.01, ***$p$<.001

In order to test hypothesis 1a, a hierarchical multiple regression was used. Specifically, gender and instructional methodology were used to predict pasta tower scores, followed by a test for the interaction between gender and instructional methodology when predicting pasta tower scores. The results of this analysis are shown in Table 6.6 below.

Table 6.6. Hierarchical moderated regression results predicting a difference in tower score on gender & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Gender | | .034* |
| Instruction | | .190** |
| $\Delta R^2$ after step 1 | .037** | |
| *Step 2:* | | |
| Gender X Instruction | | -.363* |
| $\Delta R^2$ after step 2 | .018* | |
| Overall $R^2$ | .055 | |
| Adjusted $R^2$ | .042 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant, $F$ (3, 219) = 4.217, $p < .05$. $^*p<.05$, $^{**}p<.01$, $^{***}p<.001$

The analysis consisted of the following steps. I entered gender ($\beta = .034$, $p > .05$) and instruction ($\beta = .190$, $p < .01$) in block one of the hierarchical analysis. The addition of these variables accounted for almost four percent of the variance in pasta tower scores, ($\Delta R^2 = .037$, $p < .01$). However, we see that gender is not a significant predictor of pasta tower scores in step 1. In step two of the hierarchical multiple regression analysis, I entered the interaction variable comprised of gender and instruction ($\beta = -.363$, $p >.05$). The addition of the interaction variable did account for approximately two percent of the variance in pasta tower scores. Based on these findings, an interaction effect does exist between gender and instruction as they predict pasta tower scores. Therefore, hypothesis 1a was accepted. Figure 6.2 below provides a visual representation of the interaction.


Figure 6.2. Interaction between gender and instructional methodology for pasta tower

In order to test hypothesis 1b, a hierarchical multiple regression was also used. Gender and instructional methodology were used to predict perceived subject matter learning, followed by a test for the interaction between gender and instructional methodology when predicting perceived subject matter learning. The results of this analysis are shown in Table 6.7 below.

Table 6.7. Hierarchical moderated regression results predicting a difference in perceived subject matter learning on gender & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Gender | | .006 |
| Instruction | | -1.70 |
| $\Delta R^2$ after step 1 | .029 | |
| Overall $R^2$ | .029 | |
| Adjusted $R^2$ | -.004 | |

*Note.* All tests are two-tailed. The overall model for the regression was not significant. $F$ (2, 87) = 1.295, $p$ > .05

The analysis consisted of the following steps. I entered gender ($\beta$ = .006, $p$ > .05) and instruction ($\beta$ = .190, $p$ < .01) in block one of the hierarchical analysis. The addition of these variables accounted for three percent of the variance in pasta tower scores, ($\Delta R^2$ = .029, $p$ > .05). The combination of these predictors did not explain unique variance, therefore, no further analyses were conducted, and hypothesis 1b was rejected.

***Hypothesis 2.*** *The improvement in achieving outcomes based on certain learning styles will be stronger among students using the serious game methodology than among students using the round table discussion methodology.*

Because hypothesis 2 is based on an individual's classification within a specific learning style, rather than the strength of an individual's preference for a learning style, I transformed each of the learning styles dimensions into dichotomous variables. Within each dimension, a student's preferred learning style is represented by a 0 or 1. For example, within the active-reflective dimension, 0 equals active and 1 equals reflective.

In preparation for testing hypothesis 2, I examined the descriptive statistics for each of the learning styles dimensions, and the mean pasta tower grades for students within each of the eight learning styles dimensions. The resulting data are shown in Table 6.8. Consequently, students with preferences for Active, Sensing, Visual, and Sequential learning styles earned higher grades in the serious games sections than in traditional learning environments.

Table 6.8. Mean comparisons of pasta tower scores for each learning style

| Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|
| Active | | | | -2.713 | 71 | .008** |
| Serious Game | 5189.57 | 3614.32 | 43 | | | |
| Traditional | 3175.03 | 2222.18 | 30 | | | |
| Reflective | | | | -.996 | 39 | .325 |
| Serious Game | 5876.27 | 4447.48 | 25 | | | |
| Traditional | 4532.06 | 3813.07 | 16 | | | |
| Sensing | | | | -2.241 | 91 | .027* |
| Serious Game | 4951.94 | 3312.81 | 56 | | | |
| Traditional | 3549.99 | 2295.92 | 37 | | | |
| Intuitive | | | | -1.567 | 19 | .134 |
| Serious Game | 7729.14 | 5648.87 | 12 | | | |
| Traditional | 44045.99 | 4860.15 | 9 | | | |
| Visual | | | | -2.015 | 89 | .047* |
| Serious Game | 4791.04 | 3456.26 | 55 | | | |
| Traditional | 3471.84 | 2300.94 | 36 | | | |
| Verbal | | | | -2.004 | 21 | .058 |
| Serious Game | 8196.25 | 4689.04 | 10 | | | |
| Traditional | 4277.78 | 4596.25 | 13 | | | |
| Sequential | | | | -2.253 | 82 | .027* |
| Serious Game | 5554.48 | 4093.58 | 46 | | | |
| Traditional | 3771.82 | 2912.10 | 38 | | | |
| Global | | | | -1.500 | 28 | .145 |
| Serious Game | 5206.91 | 3618.45 | 22 | | | |
| Traditional | 3054.3713 | 3008.06 | 8 | | | |

*Note*. *$p<.05$, **$p<.01$, ***$p<.001$

In order to fully test hypothesis 2a, I conducted a hierarchical multiple regression analysis. I entered the four variables representing each of the four learning styles dimensions in block one of the hierarchical analysis, in addition to the variable for instructional methodology. In step two of the analysis, I entered the variables representing the interaction between each dimension and instructional methodology. Table 6.9 provides the data resulting from this analysis.

Table 6.9. Hierarchical moderated regression results predicting a difference in tower scores using learning styles and instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Active-Reflective | | .068 |
| Sensing-Intuitive | | .206* |
| Visual-Verbal | | .226* |
| Sequential-Global | | -1.26 |
| Instruction | | .275** |
| $\Delta R^2$ after step 1 | .172*** | |
| *Step 2:* | | |
| Active-Reflective X Instruction | | -.099 |
| Sensing-Intuitive X Instruction | | .156 |
| Visual-Verbal X Instruction | | .234 |
| Sequential-Global X Instruction | | -.077 |
| $\Delta R^2$ after step 2 | .028 | |
| Overall $R^2$ | .200 | |
| Adjusted $R^2$ | .130 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant. $F$ (9, 104) = 2.883, $p < .01$. *$p<.05$, **$p<.01$, ***$p<.001$

Only step one of the analysis above explained unique variance in pasta tower scores. Based on this analysis we see that a relationship is present between certain learning styles and pasta tower scores. However, the choice of instructional methodology did not moderate the relationship between learning styles and pasta tower scores, meaning that changes in the relationship between learning styles and pasta tower scores did not result when considering the difference between control and experimental groups. Therefore, I reject hypothesis 2a.

In order to test hypothesis 2b, I conducted a hierarchical multiple regression analysis. The dependent variable pasta tower scores was exchanged for perceived subject matter learning before conducting the analysis. The results of this analysis are displayed in Table 6.10 below.

Table 6.10. Hierarchical moderated regression results predicting a difference in PSML using learning styles & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Active-Reflective | | .396** |
| Sensing-Intuitive | | -.216 |
| Visual-Verbal | | -.301* |
| Sequential-Global | | .016 |
| Instruction | | .201 |
| $\Delta R^2$ after step 1 | .292** | |
| *Step 2:* | | |
| Active-Reflective X Instruction | | .588 |
| Sensing-Intuitive X Instruction | | .346 |
| Visual-Verbal X Instruction | | -.413 |
| Sequential-Global X Instruction | | -.101 |
| $\Delta R^2$ after step 2 | .083 | |
| Overall $R^2$ | .375 | |
| Adjusted $R^2$ | .235 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant. $F$ (9, 40) = 2.671, $p < .05$. *$p$<.05, **$p$<.01, ***$p$<.001

Just as was observed in the testing of hypothesis 2a, only step one of the analysis explained unique variance in perceived subject matter learning. Based on this analysis we see that a relationship is present between two of the four learning styles dimensions and perceived subject matter learning. However, the choice of instructional methodology did not moderate the relationship between learning styles and perceived subject matter learning, meaning that changes in the relationship between learning styles and perceived subject matter learning did not result when considering the difference between control and experimental groups. Therefore, I reject hypothesis 2b.

***Hypothesis 3.*** *Under a serious game methodology, the difference between improvements in achieving outcomes experienced by minorities compared to Caucasians will be decreased or even reversed when students are taught using the round table discussion.*

Before conducting a test of hypothesis 3, I examined the mean pasta tower scores of Caucasians and minorities in both the serious game sections and the traditional sections. The resulting data are shown in Table 6.11 below. While there were no observed differences in pasta tower scores between Caucasians and minorities, I did observe a difference between Caucasians enrolled in the serious games sections and those in the traditional sections. Specifically, Caucasians in the serious games section received higher scores on the pasta tower exercise, ($p < .01$). No other *t*-tests revealed significant differences.

Table 6.11. Mean comparisons of past tower scores for race

| | Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|
| 1 | Tower Scores | | | | 1.7 | 220 | .091 |
| | Caucasian | 4821.99 | 3531.95 | 195 | | | |
| | Minority | 3623.94 | 2571.34 | 27 | | | |
| 2 | Caucasian | | | | -2.633 | 193 | .009** |
| | Serious Games | 5357.52 | 3938.67 | 117 | | | |
| | Traditional | 4018.70 | 2640.04 | 78 | | | |
| 3 | Minority | | | | -1.553 | 25 | .133 |
| | Serious Games | 4244.39 | 2419.46 | 16 | | | |
| | Traditional | 2721.45 | 2626.41 | 11 | | | |
| 4 | Serious Games | | | | 1.100 | 131 | .273 |
| | Caucasian | 5357.52 | 3938.67 | 117 | | | |
| | Minority | 4244.39 | 2419.46 | 16 | | | |
| 5 | Traditional | | | | 1.527 | 87 | .130 |
| | Caucasian | 4018.70 | 2640.04 | 78 | | | |
| | Minority | 2721.45 | 2626.41 | 11 | | | |

*Note*. *$p$<.05, **$p$<.01, ***$p$<.001

The test of hypothesis 3a was conducted using a hierarchical multiple regression analysis. For this analysis, I began by entering race ($\beta$ = .113, $p$ > .05) and instruction ($\beta$ = .194, $p$ < .01) in block one of the analysis. The addition of these variables accounted for five percent of the variance in pasta tower scores, ($\Delta R^2$ = .051, $p$ < .01). In step two of the regression analysis, I entered the interaction variable comprised of race and instruction ($\beta$ = .014, $p$ > .05). The addition of the interaction variable did not explain unique variance. In total, the regression model accounted for 5.1 percent of the variance in pasta tower scores. Therefore, I reject hypothesis 3a. The results of this analysis are shown in Table 6.12.

Table 6.12. Hierarchical moderated regression results predicting a difference in tower scores using race & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Race | | -.113 |
| Instruction | | .194** |
| $\Delta R^2$ after step 1 | .051** | |
| *Step 2:* | | |
| Race X Instruction | | .014 |
| $\Delta R^2$ after step 2 | .000 | |
| Overall $R^2$ | .051 | |
| Adjusted $R^2$ | .038 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant. $F$ (3, 218) = 3.878, $p$ < .01. *$p$<.05, **$p$<.01, ***$p$<.001

The test of hypothesis 3b was conducted using a hierarchical multiple regression analysis. For this analysis, I began by entering race ($\beta$ = -.040, $p$ > .05) and instruction ($\beta$ = -.170, $p$ > .05) in block one of the analysis. Neither of these variables were related to perceived subject matter learning, therefore, I did not progress to the second model involving the interaction variable. For this reason, I reject hypothesis 3b. The results of this analysis are shown in Table 6.13.

Table 6.13. Hierarchical moderated regression results predicting a difference in perceived PSML using race & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Race | | -.040 |
| Instruction | | -.170 |
| $\Delta R^2$ after step 1 | .030 | |
| Overall $R^2$ | .030 | |
| Adjusted $R^2$ | .008 | |

*Note.* All tests are two-tailed. The overall model for the regression was not significant. $F$ (2, 87) = 1.367, $p$ > .05. *$p$<.05, **$p$<.01, ***$p$<.001

***Hypothesis 4.*** *The tendency for improvement in achieving outcomes being positively related to acquisition of higher-order cognitive skills will be more pronounced among students using serious games than among students using a traditional learning environment.*

Before conducting a test of hypothesis 4, I examined the mean gain in HOCS for students enrolled in the serious games sections and the control sections. The resulting data are shown in Table 6.14 below. Based on the *t*-test comparing the instructional methodologies, there was no difference between the HOCS of students in control versus those in the serious games section, ($p$ > .05).

Table 6.14. Mean comparisons between serious games and traditional instruction for HOCS

| | Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|
| 1 | Gain in HOCS | | | | .164 | 174 | .870 |
| | Serious Games | 3.43 | .789 | 114 | | | |
| | Traditional | 3.45 | .651 | 62 | | | |

*Note*. *$p$<.05, **$p$<.01, ***$p$<.001

In order to fully test hypothesis 4a, I conducted a hierarchical multiple regression analysis. I entered the variable representing instructional methodology and gain in HOCS in block one of the hierarchical analysis. In step two of the analysis, I entered the variable representing the interaction between instructional methodology and gain in HOCS. Table 6.15 provides the data resulting from this analysis.

Table 6.15. Hierarchical moderated regression results predicting a difference in pasta tower score using gain in higher order cognitive skills & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Instruction | | .235** |
| Gain in HOCS | | -.062 |
| $\Delta R^2$ after step 1 | .060** | |
| *Step 2:* | | |
| Gain in HOCS X Instruction | | .878 |
| $\Delta R^2$ after step 2 | .021 | |
| Overall $R^2$ | .082 | |
| Adjusted $R^2$ | .065 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant, $F$ (3, 161) = 4.774, $p < .01$, *$p<.05$, **$p<.01$, ***$p<.001$

Results of the test for hypothesis 4a revealed that instructional methodology is a significant predictor of tower scores when also considering gain in HOCS, ($\beta = .235$, $p < .01$), but gain in HOCS is not a significant predictor of tower scores, ($\beta = -.062$, $p > .05$). The addition of these variables accounted for six percent of the variance in pasta tower scores, ($\Delta R^2 = .060$, $p < .01$). In step two of the regression analysis, I entered the interaction variable comprised of instruction and gain in HOCS, ($\beta = .878$, $p < .05$). The addition of the interaction variable did not explain additional variance. Therefore, I reject hypothesis 4a.

In order to test hypothesis 4b, I conducted a hierarchical multiple regression analysis. The dependent variable, pasta tower scores, was exchanged for perceived subject matter learning before conducting the analysis. The results of this analysis are displayed in Table 6.16 below.

Table 6.16. Hierarchical moderated regression results predicting a difference in PSML using gain in HOCS and instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Instruction | | -.065 |
| Gain in HOCS | | .873*** |
| $\Delta R^2$ after step 1 | .779*** | |
| *Step 2:* | | |
| Gain in HOCS X Instruction | | -.159 |
| $\Delta R^2$ after step 2 | .001 | |
| Overall $R^2$ | .780 | |
| Adjusted $R^2$ | .772 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant. $F$ (3, 86) = 101.641, $p$ < .001. *$p$<.05, **$p$<.01, ***$p$<.001

Results of the test for hypothesis 4b revealed that instructional methodology is not a significant predictor of perceived subject matter learning when also accounting for gain in HOCS, ($\beta$ = -.065, $p$ > .05), but gain in HOCS is a significant predictor of perceived subject matter learning, ($\beta$ = .873, $p$ < .001). The addition of these variables accounted for seventy eight percent of the variance in perceived subject matter learning, ($\Delta R^2$ = .779, $p$ < .001). In step two of the regression analysis, I entered the interaction variable comprised of instruction and gain in HOCS, ($\beta$ = -.159, $p$ > .05). The addition of the interaction variable did not explain any additional variance in perceived subject matter learning. Therefore, I reject hypothesis 4b.

***Hypothesis 5.*** *The tendency for improvement in achieving outcomes being positively related to concentration will be more pronounced among students using serious games than among students using a traditional learning environment.*

Before conducting a test of hypothesis 5, I examined the mean concentration for students enrolled in the serious games sections and the control sections. The resulting data are shown in Table 6.17 below. Based on the *t*-test comparing the instructional methodologies, there was a significant difference between students in participating in serious games and those not participating in serious games, such that students undergoing the serious game treatment experienced higher levels of perceived concentration, ($p < .05$).

Table 6.17. Mean comparisons between serious games and traditional instruction for concentration

| | Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|
| 1 | Concentration | | | | -2.093 | 174 | .038* |
| | Serious Games | 3.72 | .761 | 114 | | | |
| | Traditional | 3.45 | .885 | 62 | | | |

*Note*. **p*<.05, ***p*<.01, ****p*<.001

In order to fully test hypothesis 5a, I conducted a hierarchical multiple regression analysis. I entered the variable representing instructional methodology and concentration in block one of the hierarchical analysis. In step two of the analysis, I entered the variable representing the interaction between instructional methodology and concentration. Table 6.18 provides the data resulting from this analysis.

Table 6.18. Hierarchical moderated regression results predicting a difference in pasta tower scores using concentration and instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Instruction | | .230** |
| Concentration | | .045 |
| $\Delta R^2$ after step 1 | .058** | |
| *Step 2:* | | |
| Concentration X Instruction | | -.244 |
| $\Delta R^2$ after step 2 | .002 | |
| Overall $R^2$ | .061 | |
| Adjusted $R^2$ | .043 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant. $F$ (3, 161) = 3.475, $p < .05$. *p<.05, **p<.01, ***p<.001

Results of the test for hypothesis 5a revealed that instructional methodology is a significant predictor of tower scores, when accounting for concentration, ($\beta = .230$, $p < .01$), but gain concentration is not a significant predictor of tower scores, ($\beta = .045$, $p > .05$). The addition of these variables accounted for six percent of the variance in pasta tower scores, ($\Delta R^2 = .058$, $p < .01$). In step two of the regression analysis, I entered the interaction variable comprised of instruction and concentration, ($\beta = -.244$, $p > .05$). The addition of the interaction variable did not explain additional variance in tower scores. Therefore, I reject hypothesis 5a.

In order to test hypothesis 5b, I conducted a hierarchical multiple regression analysis. The dependent variable pasta tower scores was exchanged for perceived subject matter learning before conducting the analysis. The results of this analysis are displayed in Table 6.19 below.

Table 6.19. Hierarchical moderated regression results predicting a difference in PSML using concentration & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Instruction | | .707*** |
| Concentration | | -.231** |
| $\Delta R^2$ after step 1 | .525*** | |
| *Step 2:* | | |
| Concentration X Instruction | | .334 |
| $\Delta R^2$ after step 2 | .004 | |
| Overall $R^2$ | .529 | |
| Adjusted $R^2$ | .513 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant. $F$ (3, 86) = 32.240, $p$ < .001. **p*<.05, ***p*<.01, ****p*<.001

Results of the test for hypothesis 5b revealed that instructional methodology is a significant predictor of perceived subject matter learning when also accounting for concentration, ($\beta = .707$, $p < .001$), and concentration is a significant predictor of perceived subject matter learning, ($\beta = -.231$, $p < .01$). The addition of these variables accounted for fifty two percent of the variance in perceived subject matter learning, ($\Delta R^2 = .525$, $p < .001$). In step two of the regression analysis, I entered the interaction variable comprised of instruction and concentration, ($\beta = .334$, $p > .05$). The addition of the interaction variable did not explain any additional variance in perceived subject matter learning. Therefore, I reject hypothesis 5b.

***Hypothesis 6.*** *The tendency for improvement in achieving outcomes being positively related to goal clarity will be more pronounced among students using serious games than among students using a traditional learning environment.*

Before conducting a test of hypothesis 6, I examined the mean goal clarity for students enrolled in the serious games sections and the control sections. The resulting data are shown in Table 6.20 below. Based on the *t*-test comparing the instructional methodologies, there was no significant difference between students participating in serious games and those not completing serious games, ($p > .05$).

Table 6.20. Mean comparisons between serious games and traditional instruction for goal clarity

| | Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|
| 1 | Goal Clarity | | | | .320 | 154.83 | .750 |
| | Serious Games | 3.55 | .815 | 113 | | | |
| | Traditional | 3.58 | .815 | 62 | | | |

*Note*. *$p$<.05, **$p$<.01, ***$p$<.001

In order to fully test hypothesis 6a, I conducted another hierarchical multiple regression analysis. I entered the variable representing instructional methodology and goal clarity in block one of the hierarchical analysis. In step two of the analysis, I entered the variable representing the interaction between instructional methodology and goal clarity. Table 6.21 provides the data resulting from this analysis.

Table 6.21. Hierarchical moderated regression results predicting a difference in pasta tower scores using goal clarity & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Instruction | | .239** |
| Goal Clarity | | .072 |
| $\Delta R^2$ after step 1 | .062** | |
| *Step 2:* | | |
| Goal Clarity X Instruction | | -.055 |
| $\Delta R^2$ after step 2 | .000 | |
| Overall $R^2$ | .062 | |
| Adjusted $R^2$ | .044 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant. $F$ (3, 161) = 3.524, $p < .05$. *$p$<.05, **$p$<.01, ***$p$<.001

Results of the test for hypothesis 6a revealed that instructional methodology is a significant predictor of tower scores, when accounting for goal clarity, ($\beta = .239$, $p < .01$), but goal clarity is not a significant predictor of tower scores, ($\beta = .072$, $p > .05$). The addition of these variables accounted for six percent of the variance in pasta tower scores, ($\Delta R^2$ = .062, $p$ < .01). In step two of the regression analysis, I entered the interaction variable comprised of instruction and concentration, ($\beta$ = -.055, $p$ > .05). The addition of the interaction variable did not explain additional variance in tower scores. Therefore, I reject hypothesis 6a.

In order to test hypothesis 6b, I conducted a hierarchical multiple regression analysis. The dependent variable pasta tower scores was exchanged for perceived subject matter learning before conducting the analysis. The results of this analysis are displayed in Table 6.22 below.

Table 6.22. Hierarchical moderated regression results predicting a difference in PSML using goal clarity & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Instruction | | -.115 |
| Goal Clarity | | .699*** |
| $\Delta R^2$ after step 1 | .514*** | |
| *Step 2:* | | |
| Goal Clarity X Instruction | | -.289 |
| $\Delta R^2$ after step 2 | .001 | |
| Overall $R^2$ | .515 | |
| Adjusted $R^2$ | .498 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant, $F$ (3, 86) = 30.45, $p$ < .001. *$p$<.05, **$p$<.01, ***$p$<.001

Results of the test for hypothesis 6b revealed that instructional methodology is not a significant predictor of perceived subject matter learning when also accounting for goal clarity, ($\beta$ = -.115, $p$ > .05), but goal clarity is a significant predictor of perceived subject matter learning, ($\beta$ = .699, $p$ < .001). The addition of these variables accounted for fifty one percent of the variance in perceived subject matter learning, ($\Delta R^2$ = .514, $p$ < .001). In step two of the regression analysis, I entered the interaction variable comprised of instruction and goal clarity, ($\beta$ = -.289, $p$ > .05). The addition of the interaction variable did not explain any additional variance in perceived subject matter learning. Therefore, I reject hypothesis 6b.

***Hypothesis 7.*** *The tendency for improvement in achieving outcomes being positively related to student enjoyment will be more pronounced among students using serious games than among students using a traditional learning environment.*

Before conducting a test of hypothesis 7, I examined the mean student enjoyment for students enrolled in the serious games sections and the control sections. The resulting data are shown in Table 6.23 below. Based on the *t*-test comparing the instructional methodologies, there was no significant difference between students in participating in serious games and those not participating in serious games, ($p$ > .05).

Table 6.23. Mean comparisons between serious games and traditional instruction for student enjoyment

| | Variable | *M* | *SD* | *N* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|---|
| 1 | Student Enjoyment | | | | .592 | 88 | .555 |
| | Serious Games | 3.30 | .951 | 73 | | | |
| | Traditional | 3.44 | .675 | 17 | | | |

*Note*. *$p$<.05, **$p$<.01, ***$p$<.001

In order to fully test hypothesis 7a, I conducted a hierarchical multiple regression analysis. I entered the variable representing instructional methodology and student enjoyment in block one of the hierarchical analysis. In step two of the analysis, I entered the variable representing the interaction between instructional methodology and student enjoyment. Table 6.24 provides the data resulting from this analysis.

Table 6.24. Hierarchical moderated regression results predicting a difference in pasta tower score using student enjoyment & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Instruction | | .116 |
| Student Enjoyment | | .071 |
| $\Delta R^2$ after step 1 | .018 | |
| *Step 2:* | | |
| Student Enjoyment X Instruction | | -.497 |
| $\Delta R^2$ after step 2 | .008 | |
| Overall $R^2$ | .025 | |
| Adjusted $R^2$ | -.009 | |

*Note.* All tests are two-tailed. The overall model for the regression was not significant, $F$ (3, 84) = .728, $p >$ .05. *$p<.05$, **$p<.01$, ***$p<.001$

Results of the test for hypothesis 7a revealed that instructional methodology is not a significant predictor of tower scores, when accounting for student enjoyment, ($\beta$ = .116, $p$ > .05), and student enjoyment is not a significant predictor of tower scores, ($\beta$ = .071, $p$ > .05). The addition of these variables did not account for unique variance in tower scores. Therefore, I did not progress to the second stage of the analysis and <u>I reject hypothesis 7a</u>.

In order to test hypothesis 7b, I conducted a hierarchical multiple regression analysis. The dependent variable pasta tower scores was exchanged for perceived subject matter learning before conducting the analysis. The results of this analysis are displayed in Table 6.25 below.

Table 6.25. Hierarchical moderated regression results predicting a difference in PSML using student enjoyment & instructional methodology

| Variable | $\Delta R^2$ | $\beta$ |
|---|---|---|
| *Step 1:* | | |
| Instruction | | -.117* |
| Student Enjoyment | | .832*** |
| $\Delta R^2$ after step 1 | .719*** | |
| *Step 2:* | | |
| Student Enjoyment X Instruction | | .134 |
| $\Delta R^2$ after step 2 | .001 | |
| Overall $R^2$ | .719 | |
| Adjusted $R^2$ | .709 | |

*Note.* All tests are two-tailed. The overall model for the regression was significant. $F$ (3, 86) = 73.389, $p$ < .001. *$p$<.05, **$p$<.01, ***$p$<.001

Results of the test for hypothesis 7b revealed that instructional methodology is a significant predictor of perceived subject matter learning when also accounting for student enjoyment, ($\beta$ = -.117, $p$ < .05), and student enjoyment is also a significant predictor of perceived subject matter learning, ($\beta$ = .832, $p$ < .001). The addition of these variables accounted for seventy two percent of the variance in perceived subject matter learning, ($\Delta R^2$ = .719, $p$ < .001). In step two of the regression analysis, I entered the interaction variable comprised of instruction and student enjoyment, ($\beta$ = .134, $p$ > .05). The addition of the interaction variable did not explain any additional variance in perceived subject matter learning. Therefore, I reject hypothesis 7b.

***Summary of findings.*** The quantitative analysis applied the 4P model to determine the effectiveness of serious games for achieving learning outcomes. Although the majority of the hypotheses in the model were rejected, support was found for one interaction, hypothesis 1a, and mean comparisons provided several interesting findings.

Regarding hypothesis 1, an interaction was observed between gender and instructional methodology as predictors of pasta tower scores. The data suggested that while males perform better than females in a traditional classroom, females perform better than males when using a serious game. This result should cause one to question the common assumptions that males enjoy digital games more than females, and that males perform better at digital games than females, suggesting that academicians seeking to improve the performance of females in engineering should consider developing serious games. While hypotheses 2a and 2b were not supported, suggesting that an interaction does not exist between race and instructional methodology, an interesting finding appeared in a mean comparison. Specifically, the data revealed that Caucasians in the serious games sections performed better on the pasta tower than those in the traditional sections. This appears to support extant literature that suggest Caucasian males are the primary consumers of video games.

Learning styles were a primary component of this design, and hypotheses were developed to find the absence or existence of an interaction effect between learning styles and instructional methodology. We now see that data did not support these hypotheses, however, mean comparisons revealed that students who are active-sensing-visual-sequential learners (i.e., the most common profile of engineering students) appeared to score higher on the pasta tower exercise if they took part in the serious game exercise than did students fitting the same profile and taking part in the traditional classroom exercises.

When examining the mean comparison of concentration, data revealed that students in the serious games sections perceived higher levels of concentration when engaged in the game than did students completing the traditional active learning exercises.

In total, the quantitative results produced interesting findings, however, there is reason to wonder why the majority of hypotheses were rejected. It is possible that several individual characteristics of the study led to this situation. Specifically, the tower score was collected as a group score, and it was developed by the instructor for this particular exercise. The size of the class prohibited individuals from building their own towers, possibly reducing the power of the statistical analyses. In addition, several missing data points existed for students who failed to respond, and students who failed to provide their research identification number when completing surveys. Future research must be careful to consider these potential pitfalls during the research design process.

***Qualitative Results.*** Results from the qualitative analysis were garnered from responses given during the focus groups at Auburn University. The focus groups were conducted by two external evaluators from the University of West Georgia. The goal of the focus groups was to answer three questions.

1. To what extent is the computer simulation activity effective in promoting learning?
2. To what extent does use of the computer simulation activity among students in an introductory undergraduate engineering course improve student understanding of the engineering design process?
3. What are student perceptions of the computer simulation activity as an instructional method?

The computer simulation activity referred to in these questions is the serious game developed by LITEE and Toolwire. Students in both the serious game sections and the traditional sections had positive feedback for their experiences in their respective modules. However, many of the students in the serious games sections commented about the relevance of the content in the serious game for developing their pasta tower. Multiple students mentioned that it provided an opportunity for "trial and error," where this opportunity did not exist in the pasta tower exercise. Additional comments also supported the idea that the serious game promoted learning. One student commented about "how you have to have a bunch of different ideas and decide which works best for the task," while another said, "wisdom comes from experience, and I now have a better foundation of how to build a structure."

When asked about their desire to learn future concepts in this manner, most students responded in the affirmative. Common themes included: I prefer this to lecture, it was fun, more engaging than a textbook, this is a natural way of learning, and it was an overall positive experience. Additional support for this serious game was provided when several of the students in every focus group mentioned that they voluntarily play similar games for other courses.

**Discussion.** In order to provide an overall analysis of the experiment, it is necessary that the results are triangulated. As noted in the quantitative results, students with a preference for active-sensing-visual-sequential learning scored higher on the pasta tower if they participated in the serious game. Knowing that the game was designed around these students, this result provides strong support for the use of serious games in engineering courses. Further, student responses in the focus group revealed that the majority of students in the course, in both control and experimental sections, prefer to learn through hands on activities. The focus groups involving serious games participants referred to the game as a "natural way of learning," and "it's much better than someone telling you how to do something and a lot more interesting." When considering the higher levels of concentration among game participants revealed by the quantitative study, we find that these data were supported in the focus groups. Students explained that the game appeals to your need to win. Prensky (2001) noted that achieving our goals is a large part of what motivates us, and, in turn, push us to achieve and win.

Negative feedback was present for both modules, however, negative feedback in the gaming module centered on specific details about the game, rather than its capabilities as a learning tool. Regarding the quantitative results, future studies should consider the aforementioned limitations associated with the research design and analysis.

**Communication**

When explaining the details of the communications phase, Peffers et al. (2007, p. 56) explain that DS researchers must, "Communicate the problem and its importance, the artifact, its utility and novelty, the rigor of its design, and its effectiveness to researchers and other relevant audiences such as practicing professionals, when appropriate." In this instance, each of the things mentioned above should be shared via channels that inform academic researchers, academicians using the wicked educational IS, and industry developers seeking to develop wicked educational IS.

LITEE's initial attempt to communicate came in the form of the final project report to NSF at the conclusion of the funding period. In addition, one doctoral student has already completed a dissertation using data from this project. This dissertation will serve as one resource for communicating the results of this project through a DSR lens. Additional communications are documented in Table 6.26.

Table 6.26. Summary of communication efforts result from serious games project

| Author(s) | Title | Publication |
|---|---|---|
| Bond and Sankar (2011) | A Design Science Approach to Development of Educational IS | Conference |
| Rajan, Raju, and Sankar (2013) | Serious Games to Improve Student Learning in Engineering Classes | Conference & Journal |
| Rajan (2013) | Development and Testing of Innovative Instructional Materials to Improve Student Learning in Engineering Classes - Case Studies, Smart Scenarios and Serious Games | Dissertation |
| Y. Wang, Rajan, Sankar, and Raju (2014) | Relationships between Goal Clarity, Concentration and Learning Effectiveness when Playing Serious Games | Work in progress |
| Toolwire (Appendix F) | Toolwire and Auburn University Co-Create Immersive Scenarios for Engineering Programs | Press Release |

With the exception of the press release listed in table Table 6.26, all communications about this study are academic in nature, and predominantly quantitative. In order to truly communicate the results of this project to all interested audiences, it will be necessary for it to be shared among developers in industry, as well as in publications consumed by faculty seeking to implement new educational IS.

**Chapter Summary**

The projects documented in this chapter reveal a positive progression in the design methodology applied by LITEE and Toolwire. Specifically, the earliest collaboration between LITEE and Toolwire resulted in a Smart Scenario that was lacking in features and followed by only a basic evaluation. Several authors have suggested that a major difference between DSR and design lies in the rigor of the evaluation process (Hevner et al., 2004). The subsequent attempt at designing a Learnscape resulted in more positive feedback, but still had limited capabilities and was lacking a rigorous evaluation.

As the collaborative team advanced to the development of a serious game, several characteristics of the design process became apparent. Most notably, the LITEE team project manager determined to need for DSR prior to the serious game design. This decision led the team to apply the six stage process presented by Peffers et al. (2007) and the basis for the DSRM for educational IS that is applied in this dissertation. As a result, collaborative team of LITEE and Toolwire engaged in more communication throughout the six stages of the DSRM, leading to quicker feedback between evaluators and designers, and quicker iterations from the design team. Several other factors appear to have contributed to the improved design process, such as smaller groups working on specific tasks and reporting back to the overall group. During the late summer of 2012, and throughout the fall 2012 semester, the design team and the evaluation team worked independently from the overall group. These small groups of four to five individuals appear to have worked more efficiently than earlier teleconferences involving large numbers of participants.

As a result, a working serious game focused on the engineering design process was designed, implemented, and evaluated in approximately 18 months. Feedback from the final data analyses reveal that most of the early problems were alleviated by incorporating feedback into the iterative nature of the design. The resulting IT artifact has since been implemented in introduction to engineering courses at Auburn University and continues to generate positive feedback in focus groups.

Following this project, Toolwire developed a product they refer to as a "Gamescape" that is based on the results of this research. However, as a private company, Toolwire is positioning itself to be purchased and is no longer interested in developing additional games. LITEE is limited to use of this serious game in its current form, due to the large amount of financial and human resources required for further refinements, or the development of additional games.

## Chapter 7: Benefits of the DSRM and development of a modified DSRM

This dissertation was guided by the DSRM developed by Peffers et al. (2007). In order to apply their methodology for research in the area of educational IS, it was evident that alterations were necessary. The DSRM for wicked educational IS that was applied in this dissertation was the result of combining Peffers et al.'s model with specific recommendations that are unique to the development of educational IS. The resulting model, displayed in Figure 7.1 below, was applied to two projects conducted by LITEE at Auburn University.

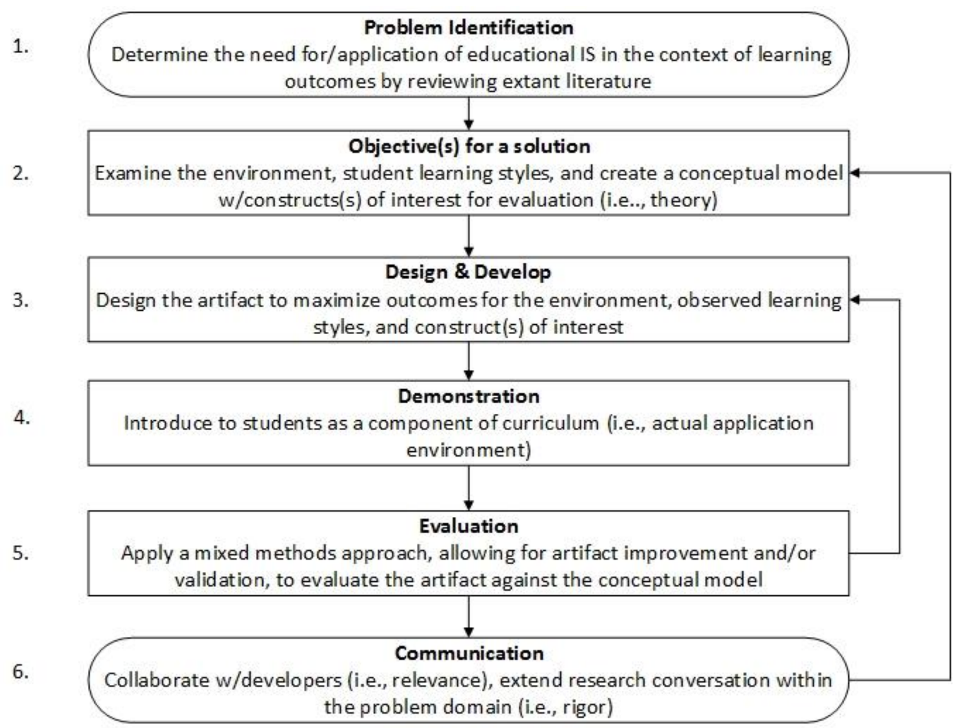



Figure 7.1. Re-presentation of the DSRM for developing wicked educational IS

The first project involved the application of the DSRM for educational IS in order to implement and evaluate multimedia case studies. This did not require the development of a new IT instantiation, however, it was used to design an effective implementation and evaluation of existing multimedia case studies (i.e., method). The second project involved the development of a serious game from the process of idea generation to implementation and evaluation. The post-hoc application of the DSRM for educational IS to each of these projects served to answer the question:

R1. How can design science research lead to effective development and implementation of wicked educational IS?

In order to answer this question, I documented the progression of each project by classifying the actions of the LITEE team into the six stages of the DSRM for wicked educational IS. The classification process served to highlight actions taken by the LITEE team that aligned with the DSRM and actions taken by the LITEE team that conflicted with the DSRM. By comparing the case study data within each application of the DSRM for educational IS to the research question above, an explanation for the effectiveness of the DSRM began to develop. Yin (2008) refers to this method of analyzing case study evidence as explanation building. The results of the analysis generated three themes, or characteristics, or the DSRM for wicked educational IS that can lead to effective development and implementation of wicked educational IS, and that can lead to improved outcomes.

**Planning**

Nearly all methodologies for design highlight the importance of planning. In the field of management, it is often noted that goals are rarely reached without an effective plan. The benefit provided by the DSRM for wicked educational IS, with regard to planning, lies in its detailed instructions for doing so. The first stage of the DSRM involves identifying a problem that requires wicked educational IS to achieve a learning outcome, and determining whether or not it has been solved in the extant literature. The second stage of the DSRM requires one to examine the environment, student learning styles, and create a conceptual model for the evaluation stages. Without specific guidance for doing so, most designers would not know how to undertake this depth of planning, nor would most commercial enterprises have the time to do so. In the projects documented in the dissertation, the LITEE team engaged in this depth of planning, but one factor influencing their decision to do so appears to be that each project was funded by NSF grants. In the process of developing a grant application, most of the details documented in the first two stages of the DSRM for wicked educational IS are required in order to receive funding.

**Communication**

The second characteristic of the DSRM for educational IS is the amount of communication that is required. It has been noted that design science is a build-and-evaluate process, based on communicating results of the evaluation to the designers for improvements in subsequent iterations of the artifact. In both the multimedia case study project and the serious games project, data reveal that increased communications had several effects on the overall project. Frequency counts of meetings during the course of the projects revealed that communications increased as the projects progressed. In each project, both the quality of the iterations and the speed of the iterations increased as the projects progressed, seemingly with the increased communication among team members.

Additionally, in the multimedia case study project, data were analyzed yearly in the early stages, and at the conclusion of each semester towards the end of the project. Conversations with LITEE team members and minutes from meetings revealed that increased communication of evaluation results improved design in the later semesters. Specifically, some of the evaluation instruments were found to be unnecessary and removed from the evaluation process in the last year of the project.

When examining communications during the serious game development, the frequency of meetings accelerated after the first semester, and the final semester of development restructured the teams for increased communication among the design team and the evaluation team. At the same time, it was apparent that the iterations of the serious game increased in number, while the time used to implement feedback decreased. Evaluation feedback from pilot tests was provided within weeks, rather than semesters, and updates to the evaluation schedule and process were communicated as soon as changes were made.

The improvements in communication appeared to be a major contributing factor to improvements in the artifact. The initial DSRM suggested that evaluation results be communicated for the next design process, and the final results of the project be communicated to provide objectives for solutions in the future, however, I proffer that channels of communication should be added throughout the DSRM. Specific additions include the need for an additional channel of communication at the objectives for a solution stage. During the serious game development, LITEE and Toolwire began their development of the Smart Scenarios with the goal of creating both design and communications exercises. As the project progressed, and after considering multiple pilot studies that did not involve a thorough evaluation, the group refined the objectives for a solution to only include the development of a serious game to teach the engineering design process. If the group had followed the original DSRM for wicked educational IS to its conclusion, the 4P model would have been used to examine Smart Scenarios and Learnscapes, leading to the consumption of additional time and resources before completing the final serious game. The second additional channel of communication was added to the design and development stage. In both projects documented herein, an observable increase in communications among the developers occurred during the design and development stage, and in both projects there was an observable increase in the speed of development that coincided with the additional communication. The final channel of communication that was added to the DSRM for wicked educational IS involves the demonstration stage. This is especially important when demonstrating educational IS because the nature of higher education enables researchers to demonstrate their artifact repeatedly. By communicating techniques applied during the demonstration phase, researchers have the ability to refine an artifact over time with a seemingly unlimited population of new student samples. For these reasons, I present the updated DSRM for wicked educational IS in Figure 7.2 below. Additional channels of communication are represented on the left side of the figure as dashed lines.

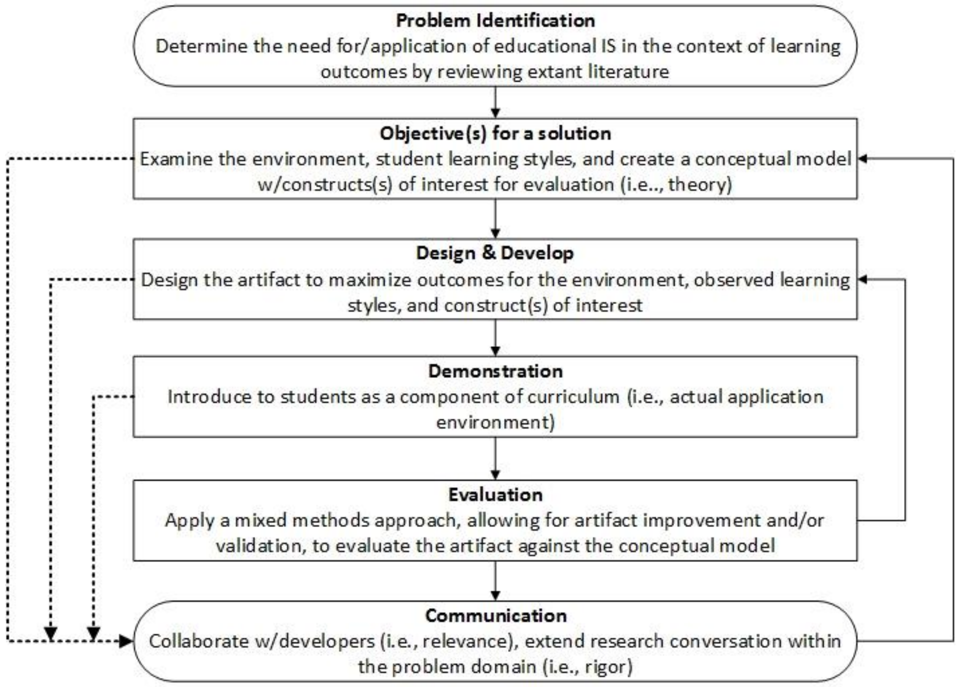



Figure 7.2. Updated DSRM for developing wicked educational IS

**Rigorous evaluation**

The final characteristic of the DSRM for wicked educational IS that serves to answer the research question is the requirement for a rigorous evaluation. Hevner et al. (2004) explain that the evaluation process in DSR sets it apart from design. The results of this study support this conclusion. Rather than simply producing artifacts based on collaboration alone, the DSRM for wicked educational IS suggests the use of a mixed methods approach, allowing for improvement or validation by using a predetermined conceptual model. Prior to the implementation of each iteration, research questions were developed to guide the evaluation. Across iterations, validated instruments were used for the quantitative data collection, and a pre-determined set of questions were asked in each focus group. The use of the 4P model provided guidance for a rigorous evaluation before the IT artifacts were completed and allowed data from multiple implementations to be compared. While the requirement of a rigorous evaluation is not unique to the DSRM for wicked educational IS, it distinguishes itself from typical design, where commercial entities are seldom trained in evaluation.

### Summary of Analysis

The case study described in this dissertation provided valuable insights by documenting two projects using the DSRM for wicked educational IS. Through the process of explanation building, the comparison of the actions taken by LITEE and Toolwire revealed three characteristics of the DSRM for educational IS that answer the research question. Specifically, the DSRM for educational IS leads to effective development and implementation through increased planning (i.e., stages 1 and 2 of the DSRM), increased communications, and rigorous evaluation. Finally, an updated DSRM for wicked education IS was developed to incorporate the requirements of increased communication during the process of finding objectives for a solution, design and development, and demonstration.

# Chapter 8: Limitations & Future Research

This chapter acknowledges and discusses the limitations of this research and future research opportunities. This study, like all academic pursuits, is not without limitations, and the contributions of this study should be considered while understanding the extent of its limitations. Future opportunities for research are plentiful because of the limited focus on design science in educational IS. Therefore, potential areas of research are presented below.

## Research Limitations

This research focuses on one organization and documents multiple projects using a case study methodology. The inherent nature of case studies relies on a single or limited sample to answering a research question or questions. Depending on the type of generalizations made, they can often be limited by the size of the study's sample. Therefore, it should be noted that while the organization chosen for this study was well suited for this research, the application of the DSRM for wicked educational IS may differ slightly when applied by individuals with limited resources, or organizations with seemingly unlimited resources.

Another limitation of this study involves the implementation and evaluation of the multimedia case studies and serious games. When designing the evaluation for each project, several elements of the quasi-experimental designs were limited by the number of students who enrolled each semester, and in each section, and several data points were lost due to non-response or identification errors.

With regard to the DSRM for wicked educational IS, there are limitations present due to its relatively limited number of applications. The DSRM for wicked educational IS was developed using extant literature and theory, however, needed updates became apparent after its application. Continued use of the DSRM for wicked educational IS will help refine it in future studies, while also increasing its effectiveness.

## Future Research

As the format of this case study is exploratory, the nature of this work leaves a great deal of the research agenda open for future exploration. Additional attempts to apply the DSRM for wicked educational IS to new IT artifacts began shortly after the serous games project described in this dissertation. The LITEE team began developing supplemental materials that were smaller in scope than a serious game. These supplemental materials took the form of concept tutors that focused on a single concept within a discipline. Unlike serious games, which can address several concepts and take vast amounts of time to master, a concept tutor is intended to be very pointed in its focus. Application of the DSRM for educational IS to a smaller project could prove worthwhile in both validating and advancing the methodology. Further, the results of the multimedia case study and serious game evaluations could be strengthened by comparing them to one another. Previous attempts by LITEE have only involved the comparison of traditional instructional methods (e.g., lecture) to active learning instructional methods (e.g., serious games).

Additional opportunities involve the use of the DSRM for wicked educational IS in other disciplines. The focus of the current study was engineering design, but the DSRM for educational IS should be tested in non-technical disciplines as well. Further, while the DSRM for wicked educational IS has shown to benefit new developments of IS, a successful implementation of the methodology in the improvement of existing IS could help it gain acceptance. Because many generic IT artifacts exist for use in education, the DSRM for wicked educational IS could be used by individuals with limited resources who only require minimal modifications to existing IS.

Although examples of the DSRM for wicked educational IS were provided in this research, it is possible that developers would benefit from a detailed flowchart to operationalize the modified DSRM for wicked educational IS. This flowchart could be used to design wicked educational IS, while also providing detailed decision points at critical steps of the process.

**Summary of Limitations and Future Research**

This chapter acknowledged certain limitations in this study and presented suggestions for future research. The limitations explained herein apply to the case study methodology, the relatively limited application of the DSRM for wicked educational IS, data collection techniques, and the results. It is important to note that these limitations may hinder the applicability of the findings, but they should not detract from the results. Each of these limitations can be improved in future research.

Areas of future research include replications of this study involving wicked educational IS in other disciplines, comparisons of the serious game documented herein to multimedia case studies developed by LITEE, the application of the DSRM for wicked educational IS in projects of varying scope, the extension or improvement of existing educational IS, and the development of a flowchart designed to allow developers of wicked educational IS to operationalize their ideas. Addressing any of these areas will allow researchers to expand the application of DSR in the area of wicked educational IS, and it will advance the DSRM for wicked educational IS.

# Chapter 9: Contributions & Conclusion

The current study has implications for multiple constituents. First, this study will benefit DSR by extending its reach into the area of wicked educational IS. To date, the application of DSR has primarily focused on information systems designed for commercial businesses. With the exception of research centering on workplace training, there is a paucity of DSR focused on educational IS. At the same time, administrators in higher education are faced with meeting accreditation demands through measurable improvements. It was noted that IS in higher education are abundant, however, not all systems were designed with a clear problem in mind. For this reason, administrators and faculty should consider wicked educational IS as a means to address problems facing higher education. It is possible that commercial designers can also benefit from the findings of this dissertation. The paucity of wicked educational IS offers an unexploited market where quality and effectiveness are required.

## Contributions

This dissertation has three contribution to the literature. First, this dissertation provides a modified DSRM for wicked educational IS that is based on the DSRM presented by Peffers et al. (2007). I analyzed two examples of wicked educational IS to determine that increased communication can lead to a more robust wicked educational IS. Specifically, academicians developing wicked educational IS can benefit from increased communication during earlier stages of the design process. Therefore, the updated DSRM requires increased communication at three specific stages: objectives for a solution, design and development, and demonstration. My findings show that the design process can benefit from clarity associated with detailed documentation and enhanced communication in the early stages of the design process, as much as from a rigorous evaluation. The dashed lines on the left side of Figure 9.1 represent the new channels of communication.

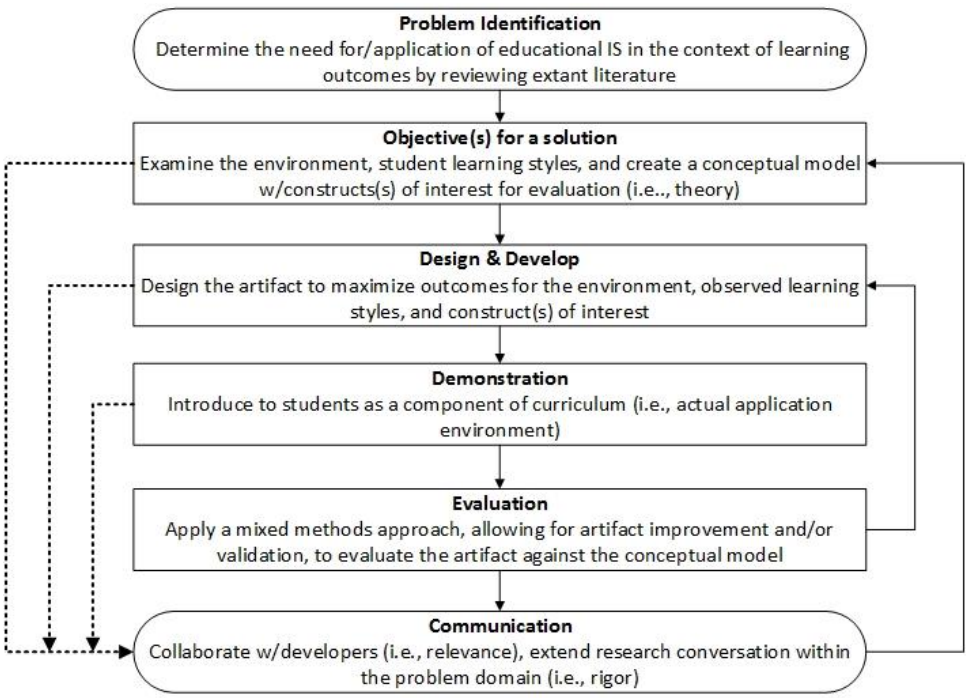



Figure 9.1. Re-presentation of the updated DSRM for developing wicked educational IS

The second contribution of this dissertation is that it distinguishes between standard educational IS and wicked educational IS. Much of the existing educational IS digitizes current processes or information, such as converting textbooks to an electronic format. However, the use of wicked educational IS can solve ill-defined problems that require entirely new processes, such as new learning processes associated with playing serious games. STEM education is faced with several challenges, such as the need for improved outcomes. The results in chapters five and six show that wicked educational IS can improve the learning effectiveness of students in STEM areas.

The third contribution is that this dissertation provides a step-by-step description of how a modified DSRM can be applied to guide the development of wicked educational IS. Using a case study methodology, chapter five applies the DSRM process to analyze the implementation and testing of multimedia case studies, and chapter six uses the DSRM process to develop, implement, test, and evaluate serious games. These two case studies provide detailed examples that can help other researchers conduct similar experiments.

The funds spent on educational IS for higher education have grown exponentially in recent years, but their application is not always aimed at improving learning outcomes. As universities move towards online education, and they seek to benefit from technological improvements in the classroom, the desire for new innovations will continue to grow. When considering these points, it is apparent that commercial entities with the skillset to develop wicked educational IS are positioned to experience the most profound benefits.

As this dissertation explains, the cost of developing wicked educational IS can be substantial. However, extant literature involving business strategy explains that differentiation is a successful method for gaining competitive advantage. The DSRM for wicked educational IS can potentially assist commercial entities in their desire to differentiate based on quality. As the market for educational IS becomes flooded with products, and academic institutions compete for the brightest and most motivated students through the quality of their programs, commercial developers will be required to produce wicked educational IS that are both desirable and effective at achieving learning outcomes. Application of the DSRM for wicked educational IS can assist such businesses in their attempts to meet these new market needs.

## Conclusion

This dissertation adapted the DSRM presented by Peffers et al. (2007) for use in the development of wicked educational IS. A research question was posed to determine how the DSRM for wicked educational IS can be used to develop and implement wicked educational IS. In order to answer this question, the DSRM for wicked educational IS was applied to the documentation of two efforts conducted by LITEE: the implementation and evaluation of multimedia case studies; and the design, implementation, and evaluation of a serious game. Using a case study methodology, each of the aforementioned projects were documented in order to identify a pattern of benefits associated with the DSRM. As a member of the LITEE team, I participated in many aspects of each project. However, many details of this dissertation were collected from archival data. The final collection of data was then analyzed in the context of the research question.

A synthesis of the case study findings gathered from both projects revealed that application of the DSRM for educational IS can result in effective IT artifacts and improved outcomes. Generally, benefits from the DSRM appear in three major forms: enhanced planning before the project, improved communication throughout the project and after completion, and the use of a rigorous evaluation. While these characteristics require the addition of time and effort in certain stages of a design project, they can also reduce the overall time of developing wicked educational IS, while also improving the quality of the final artifact.

This dissertation offers detailed guidelines that help develop wicked educational IS by using the DSRM stages of problem identification, determining objectives for a solution, design and development, demonstration of the IS, evaluation, and communication processes. By illustrating the methodology with two implementations, this dissertation makes it possible for potential developers of wicked educational IS to replicate the processes herein.

References

AACSB. (2012). Eligibility procedures and accreditation standards for business accreditation. Tampa, FL: AACSB International - The Association to Advance Collegiate Schools of Business.

ABET. (2008). Criteria for accrediting engineering programs. Baltimore, MD: ABET Engineering Accreditation Commision.

ABET. (2011). Criteria for accrediting engineering programs. Baltimore, MD: ABET Engineering Accreditation Commission.

Ackoff, R.L. (1967). Management misinformation systems. *Management Science*, 147-156.

Alavi, M., Marakas, G.M., & Yoo, Y. (2002). A comparative study of distributed learning environments on learning outcomes. *Information Systems Research, 13*(4), 404-415.

Anderson, J. (1988). Cognitive styles and multicultural populations. *Journal of Teacher Education, 39*(1), 2.

Anderson, J.A., & Adams, M. (1992). Acknowledging the learning styles of diverse student populations: Implications for instructional design. *New directions for teaching and learning, 1992*(49), 19-33.

AWE. (2009). Longitudinal assessment of engineering self-efficacy. Retrieved October, 2009, from http://www.engr.psu.edu/awe/secured/director/diversity/efficacy.aspx#desc

Bandura, A. (1997). *Self-efficacy: The exercise of control*: Worth Publishers.

Banks, J.A. (1988). Ethnicity, class, cognitive, and motivational styles: Research and teaching implications. *Journal of Negro Education*.

Beckman, M. (1996). The web goes interactive. *Macworld-Boulder, 13*(7), 92-101.

Benbasat, I., & Zmud, R.W. (2003). The identity crisis within the is discipline: Defining and communicating the discipline's core properties. *MIS Quarterly*, 183-194.

Biggs, J., & Moore, P. (1993). *The process of learning* (3rd ed.). Australia: Prentice Hall.

Bond, J.L., & Sankar, C.S. (2011). *A design science approach to development of educational is.* Paper presented at the European Design Science Symposium, Leixlip, Ireland.

Bond, J.L., Sankar, C.S., & Le, Q. (2010). Enhancing minority student leadership skills using case studies. *Journal of Computer Information Systems, 51*(1), 82.

Bond, J.L., Wang, Y., Sankar, C.S., Raju, P.K., & Le, Q. (2014). Female and minority students benefit from use of multimedia case studies. *International Journal of Engineering Education, 30*(2), 1-17.

Bradley, R.V., Mbarika, V.W., Sankar, C.S., Raju, P.K., & Kaba, B. (2007). Using multimedia instructional materials in mis classrooms: A tutorial. *Communications of AIS, 2007*(20), 260-281.

Bradley, R.V., Sankar, C.S., Clayton, H.R., Mbarika, V.W., & Raju, P.K. (2007). A study on the impact of gpa on perceived improvement of higher-order cognitive skills. *Decision Sciences Journal of Innovative Education, 5*(1), 151-168.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology, 3*(2), 77-101.

Brohman, M.K., Piccoli, G., Martin, P., Zulkernine, F., Parasuraman, A., & Watson, R.T. (2009). A design theory approach to building strategic network-based customer service systems*. *Decision Sciences, 40*(3), 403-430. doi: 10.1111/j.1540-5915.2009.00242.x

Brown, R.H. (2011). Virtual world, mobile tech finding use as innovative education tools. Retrieved March, 2013, from http://www.bizjournals.com/boston/blog/mass-high-tech/2011/03/virtual-world-mobile-tech-finding-use.html

Burgos, D., Tattersall, C., & Koper, R. (2007). Re-purposing existing generic games and simulations for e-learning. *Computers in Human Behavior, 23*(6), 2656-2667.

Carr, P., de la Garza, J., & Vorster, M. (2002). Relationship between personality traits and performance for engineering and architectural professionals providing design services. *Journal of Management in Engineering, 18*(4), 158-166. doi: doi:10.1061/(ASCE)0742-597X(2002)18:4(158)

Cegielski, C.G., Hazen, B.T., & Rainer, R.K. (2011). Teach them how they learn: Learning styles and information systems education. *Journal of Information Systems Education, 22*(2), 135-146.

Chubin, D., May, G., & Babco, E. (2005). Diversifying the engineering workforce. *Journal of Engineering Education, 94*(1), 73-86.

Cisco. (2010). Gaming: The new elearning. Retrieved February, 2014, from https://learningnetwork.cisco.com/blogs/games_on/2010/11/24/gaming-the-new-elearning

Clayson, A. (2011). Effectiveness of litee case studies in engineering education: A perspective from genre studies. *Journal of STEM Education: Innovations & Research, 12*(7), 15-31.

Cohen, J. (1977). *Statistical power analysis for the behavioral sciences*: Academic Press New York.

Corti, K. (2006). Games-based learning; a serious business application. *Informe de PixelLearning, 34*(6), 1-20.

Creswell, J.W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches*: Sage Publications, Inc.

Creswell, J.W., & Plano Clark, V.L. (2011). *Designing and conducting mixed methods research* (2nd ed.): SAGE Publications, Inc.

Creswell, J.W., Plano Clark, V.L., Gutmann, M.L., & Hanson, W.E. (2003). Advanced mixed methods research designs. *Handbook of mixed methods in social and behavioral research*, 209-240.

Csikszentmihalyi, M. (1991). *Flow: The psychology of optimal experience*: Harper Perennial.

Cybinski, P., & Selvanathan, S. (2005). Learning experience and learning effectiveness in undergraduate statistics: Modeling performance in traditional and flexible learning environments. *Decision Sciences Journal of Innovative Education, 3*(2), 251-271. doi: 10.1111/j.1540-4609.2005.00069.x

DeSantis, N. (2012). A boom time for education start-ups. Retrieved May, 2012, from http://chronicle.com/article/A-Boom-Time-for-Education/131229/

Dick, G., Case, T., Ruhlman, P., Van Slyke, C., & Winston, M. (2006). Online learning in the business environment. *Communications of the Association for Information Systems, 17*(1), 895-904.

EverthingDisc. (2011). Research report for 79-item assessment: Inscape Publishing.

Felder, R.M., & Brent, R. (2005). Understanding student differences. *Journal of Engineering Education, 94*(1), 57-72.

Felder, R.M., & Silverman, L. (1988). Learning and teaching styles in engineering education. *Engineering Education, 78*(7), 674-681.

Felder, R.M., & Soloman, B. (1991). Index of learning styles questionnaire. Retrieved November, 2009, from http://www.engr.ncsu.edu/learningstyles/ilsweb.html

Felder, R.M., & Spurlin, J. (2005). Applications, reliability and validity of the index of learning styles. *International Journal of Engineering Education, 21*(1), 103-112.

Fetterman, R. (1997). *The interactive corporation: Using interactive media and intranets to enhance business performance* (1st ed.). New York, NY: Random House.

Flynn, A.M., Naraghi, M.H., Austin, N., Helak, S., & Manzer, J. (2006). Teaching teachers to teach green engineering. *Journal of STEM Education: Innovations & Research, 7*.

Gibbert, M., & Ruigrok, W. (2010). The ‘‘what’’ and ‘‘how’’ of case study rigor: Three strategies based on published work. *Organizational Research Methods, 13*(4), 710-737. doi: 10.1177/1094428109351319

Gibson, D., Aldrich, C., & Prensky, M. (2007). *Games and simulations in online learning: Research and development frameworks*. Hershey, PA: Information Science Publishing.

Gonzalez, H.B., & Kuenzi, J.J. (2012). *Science, technology, engineering, and mathematics (stem) education: A primer*. (R42642). Congressional Research Service.

Goodman, I.F., Cunningham, C.M., C, L., Thompson, M., Bittinger, K., Brennan, R.T., & Delci, M. (2002). Final report of the women's experiences in college engineering (wece) project. Cambridge, MA: Goodman Research Group, Inc.

Greenberg, B.S., Sherry, J., Lachlan, K., Lucas, K., & Holmstrom, A. (2010). Orientations to video games among gender and age groups. *Simulation & Gaming, 41*(2), 238-259.

Gregor, S., & Hevner, A.R. (2011). Introduction to the special issue on design science. *Information Systems and e-Business Management, 9*(1), 1-9.

Gregor, S., & Hevner, A.R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly, 37*, 337-A336.

Guo, Y.M., & Klein, B.D. (2009). Beyond the test of the four channel model of flow in the context of online shopping. *Communications of the Association for Information Systems, 24*(1), 48.

Halyo, N., & Le, Q. (2011). Results of using multimedia case studies and openended hands-on design projects in an 'introduction to engineering' course at hampton university. *Journal of STEM Education: Innovations & Research, 12*(7), 32-35.

Hart, D. (1994). *Authentic assessment: A handbook for educators. Assessment bookshelf series*: ERIC.

Hawk, T.F., & Shah, A.J. (2007). Using learning style instruments to enhance student learning. *Decision Sciences Journal of Innovative Education, 5*(1), 1-19.

Hayes, J., & Allinson, C.W. (1993). Matching learning style and instructional strategy: An application of the person-environment interaction paradigm. *Perceptual and Motor Skills, 76*(1), 63-79.

Hayes, J., & Allinson, C.W. (1996). The implications of learning styles for training and development: A discussion of the matching hypothesis. *British Journal of Management, 7*(1).

Hevner, A., & Chatterjee, S. (2010). Design research in information systems: Theory and practice (Vol. 22, pp. 9-22): Springer US.

Hevner, A., March, S.T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly, 28*(1), 75-105.

Hevner, A., & Zhang, P. (2011). Introduction to the ais thci special issue on design research in human-computer interaction. *AIS Transactions on Human-Computer Interaction, 3*(2), 56-61.

Holmström, J., Ketokivi, M., & Hameri, A.-P. (2009). Bridging practice and theory: A design science approach. *Decision Sciences, 40*(1), 65-87. doi: 10.1111/j.1540-5915.2008.00221.x

Kachra, A., & Schnietz, K. (2008). The capstone strategy course: What might real integration look like? *Journal of Management Education, 32*(4), 476-508. doi: 10.1177/1052562907300811

Kawulich, B.B. (2011). Learning from action evaluation of the use of multimedia case studies in management information systems courses. *Journal of STEM Education: Innovations & Research, 12*(7), 57-69.

Kolb, D.A. (1981). Experiential learning theory and the learning style inventory: A reply to freedman and stumpf. *The Academy of Management Review, 6*(2), 289-296.

Koufaris, M. (2002). Applying the technology acceptance model and flow theory to online consumer behavior. *Information Systems Research, 13*(2), 205-223.

Krippendorff, K. (2004). *Content analysis: An introduction to its methodology*. Thousand Oaks, California: Sage Publications, Inc.

Kuechler, W., & Vaishnavi, V. (2008). The emergence of design research in information systems in north america. *Journal of Design Research, 7*(1), 1-16.

Le, Q. (2012). Implementation of case studies in an introduction to engineering course for "litee national dissemination grant competition". *Journal of STEM Education: Innovations & Research, 13*(4), 12-17.

Lee, A.S. (1989). A scientific methodology for mis case studies. *MIS Quarterly, 13*(1), 33-50.

Leidner, D.E., & Jarvenpaa, S.L. (1995). The use of information technology to enhance management school education: A theoretical view. *MIS Quarterly, 19*(3), 265-291.

Lent, R.W., Brown, S.D., & Larkin, K.C. (1984). Relation of self-efficacy expectations to academic achievement and persistence. *Journal of Counseling Psychology, 31*(3), 356-362.

LITEE. (2012). Laboratory for innovative technology and engineering education. Retrieved July, 1, 2012, 2012, from www.litee.org

LITEE. (2014). Laboratory for innovative technology and engineering education. Retrieved May, 2014, from http://www.liteecases.com

Litzinger, T.A., Sang Ha, L., Wise, J.C., & Felder, R.M. (2007). A psychometric study of the index of learning styles©. *Journal of Engineering Education*, *96*(4), 309-319.

Liu, C.-C., Cheng, Y.-B., & Huang, C.-W. (2011). The effect of simulation games on the learning of computational problem solving. *Computers & Education*, *57*(3), 1907-1918.

March, S.T., & Smith, G.F. (1995). Design and natural science research on information technology. *Decision Support Systems*, *15*(4), 251-266.

March, S.T., & Storey, V.C. (2008). Design science in the information systems discipline: An introduction to the special issue on design science research. *MIS Quarterly*, *32*(4), 725-730.

Markus, M.L., Majchrzak, A., & Gasser, L. (2002). A design theory for systems that support emergent knowledge processes. *MIS Quarterly*, *26*(3), 179-212.

Marra, R.M., Rodgers, K.A., Shen, D., & Bogue, B. (2009). Women engineering students and self-efficacy: A multi-year, multi-institution study of women engineering student self-efficacy. *Journal of Engineering Education*, *98*(1), 27-38.

Martocchio, J.J., & Webster, J. (1992). Effects of feedback and cognitive playfulness on performance in microcomputer software training. *Personnel Psychology*, *45*(3), 553-578.

Mbarika, V.W. (2000). Importance of learning-driven constructs on perceived skill development when using multimedia instructional materials. *Journal of Educational Technology Systems, 29*(1), 67-87.

Mbarika, V.W., Bagarukayo, E., Shipps, B.P., Hingorani, V., Stokes, S., Kourouma, M., & Sankar, C.S. (2010). A multi-experimental study on the use of multimedia instructional materials to teach technical subjects. *Journal of STEM Education: Innovations & Research, 11*(2), 24-37.

Mbarika, V.W., Sankar, C.S., & Raju, P.K. (2003a). Identification of factors that lead to perceived learning improvements for female students. *Education, IEEE Transactions on, 46*(1), 26-36.

Mbarika, V.W., Sankar, C.S., & Raju, P.K. (2003b). Perceived role of multimedia instructional materials on multicriteria technology and engineering decisions. *Decision Sciences Journal of Innovative Education, 1*(2), 225-257. doi: 10.1111/j.1540-4609.2003.00019.x

Mbarika, V.W.A., Sankar, C.S., & Raju, P.K. (2003). Perceived role of multimedia instructional materials on multicriteria technology and engineering decisions. *Decision Sciences Journal of Innovative Education, 1*(2), 225-257.

McCuen, R.H., & Chang, P.C. (1995). Multimedia-based instruction in engineering education: Evaluation. *Journal of professional issues in engineering education and practice*, *121*(4), 220-224.

McIntyre, J.S. (2011). Effectiveness of three case studies and associated teamwork in stimulating freshman interest in an introduction to engineering course. *Journal of STEM Education: Innovations & Research, 12*(7), 36-44.

Mehta, A., Clayton, H., & Sankar, C.S. (2007). Impact of multi-media case studies on improving intrinsic learning motivation of students. *Journal of Educational Technology Systems, 36*(1), 79-103. doi: 10.2190/ET.36.1.f

Michael, D., & Chen, S. (2006). *Serious games: Games that educate, train, and inform*. Mason, OH: Course Technology, Cengage Learning.

Nekvasil, N.P. (1998). Using round table labs to complement didactic lectures and experimental labs. *Adv Physiol Educ, 19*(1), S68-S73.

Nemanich, L., Banks, M., & Vera, D. (2009). Enhancing knowledge transfer in classroom versus online settings: The interplay among instructor, student, content, and context. *Decision Sciences Journal of Innovative Education, 7*(1), 123-148.

Nguyen, L., Barton, S.M., & Nguyen, L.T. (2014). Ipads in higher education—hype and hope. *British Journal of Educational Technology*, n/a-n/a. doi: 10.1111/bjet.12137

Nunamaker, J.F., Chen, M., & Purdin, T. (1991). Systems development in information systems research. *Journal of Management Information Systems, 7*(3), 89-106.

Orlikowski, W.J., & Iacono, C.S. (2001). Research commentary: Desperately seeking "it" in it research - a call to theorizing the it artifact. *Information Systems Research, 12*(2), 121-134.

Palvia, P., En Mao, P., Salam, A.F., & Soliman, K.S. (2003). Management information systems research: What's there in a methodology? *Communications of AIS, 11*, 289-308.

Pan, S.L., & Tan, B. (2011). Demystifying case research: A structured–pragmatic–situational (sps) approach to conducting case studies. *Information and Organization, 21*(3), 161-176.

Papastergiou, M. (2009). Exploring the potential of computer and video games for health and physical education: A literature review. *Computers & Education, 53*(3), 603-622. doi: http://dx.doi.org/10.1016/j.compedu.2009.04.001

Peffers, K., Tuunanen, T., Rothenberger, M.A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems, 24*(3), 45-77.

Prensky, M. (2001). *Digital game-based learning*. New York: McGraw-Hill.

Rajan, P. (2013). *Development and testing of innovative instructional materials to improve student learning in engineering classes - case studies, smart scenarios and serious games.* (Doctor of Philosophy), Auburn University, Auburn, AL. Retrieved from http://etd.auburn.edu/handle/10415/3839

Rajan, P., Raju, P.K., & Sankar, C.S. (2013). *Serious games to improve student learning in engineering classes*. Paper presented at the 120th ASEE Annual Conference & Exposition, Atlanta, GA, USA.

Raju, P.K., & Sankar, C.S. (2009). Development and testing of presage-pedagogy-process-product model to assess the effectiveness of case study methodology in achieving learning outcomes. Auburn, AL: National Science Foundation.

Raju, P.K., Sankar, C.S., & Le, Q. (2010). *Fundamental leadership and engineering competencies* (1 ed.): Tavenner Publishers.

Ramirez, M., & Price-Williams, D.R. (1974). Cognitive styles of children of three ethnic groups in the united states. *Journal of Cross-Cultural Psychology, 5*(2), 212-219.

Rasch, R.H., & Tosi, H.L. (1992). Factors affecting software developers' performance: An integrated approach. *MIS quarterly, 16*(3).

Reinecke, K., & Bernstein, A. (2013). Knowing what a user likes: A design science approach to interfaces that automatically adapt to culture. *MIS Quarterly, 37*(2), 427-A411.

Rittmayer, M.A., & Beier, M.E. (2009). Self-efficacy in stem. *Applying Research to Practice (ARP) Resources.* Retrieved November, 2009, from http://www.engr.psu.edu/AWE/ARPresources.aspx

Rockinson- Szapkiw, A.J., Courduff, J., Carter, K., & Bennett, D. (2013). Electronic versus traditional print textbooks: A comparison study on the influence of university students' learning. *Computers & Education, 63*(0), 259-266. doi: http://dx.doi.org/10.1016/j.compedu.2012.11.022

Sankar, C.S., & Clayton, H. (2010). An evaluation of use of multimedia case studies to improve an introduction to information technology course. *International Journal of Information and Communication Technology Education (IJICTE), 6*(3), 25-37.

Sankar, C.S., Kawulich, B., Clayton, H., & Raju, P.K. (2010). Developing leadership skills in introduction to engineering courses through multi-media case studies. *Journal of STEM Education: Innovations & Research, 11*(3/4), 34-60.

Sankar, C.S., & Raju, P.K. (2011). Use of presage-pedagogy-process-product model to assess the effectiveness of case study methodology in achieving learning outcomes. *Journal of STEM Education: Innovations & Research, 12*(7), 45-56.

Siggelkow, N. (2007). Persuasion with case studies. *Academy of Management Journal, 50*(1), 20-24.

Simon, H.A. (1996). *The sciences of the artificial*: the MIT Press.

Simunomics. (2008). Simunomics: The ultimate business simulation game. Retrieved February, 2014, from http://www.simunomics.com/

Sitzmann, T. (2011). A meta-analytic examination of the instructional effectiveness of computer-based simulation games. *Personnel Psychology*, *64*(2), 489-528. doi: 10.1111/j.1744-6570.2011.01190.x

Smith, K.A., Sheppard, S.D., Johnson, D.W., & Johnson, R.T. (2005). Pedagogies of engagement: Classroom-based practices. *Journal of Engineering Education, 94*(1), 87-101.

Sutton, K.L., & Sankar, C.S. (2011). Student satisfaction with information provided by academic advisors. *Journal of STEM Education: Innovations & Research, 12*(7), 71-85.

Takeda, H., Veerkamp, P., & Yoshikawa, H. (1990). Modeling design process. *AI magazine, 11*(4), 37.

Terzis, V., & Economides, A.A. (2011). Computer based assessment: Gender differences in perceptions and acceptance. *Computers in Human Behavior, 27*(6), 2108-2122.

Trigwell, K., Prosser, M., Ramsden, P., & Martin, E. (1998). Improving student learning through a focus on the teaching context. *G Gibbs, Improving Student Learning. Oxford: Oxford Centre for Staff Development*.

Vaishnavi, V.K., & Kuechler, W.L. (2007). *Design science research methods and patterns: Innovating information and communication technology*. Boca Raton, FL: Auerbach Publications.

Venable, J. (2011). Incorporating design science research and critical research into an introductory business research methods course. *Electronic Journal of Business Research Methods, 9*(2), 119-129.

Verzat, C., Byrne, J., & Fayolle, A. (2009). Tangling with spaghetti: Pedagogical lessons from games. *Academy of Management Learning & Education, 8*(3), 356-369.

Wang, M., Vogel, D., & Ran, W. (2011). Creating a performance-oriented e-learning environment: A design science approach. *Information & Management, 48*(7), 260-269. doi: 10.1016/j.im.2011.06.003

Wang, Y., Rajan, P., Sankar, C.S., & Raju, P.K. (2014). *Relationships between goal clarity, concentration and learning effectiveness when playing serious games*.

Westera, W., Nadolski, R.J., Hummel, H.G.K., & Wopereis, I.G.J.H. (2008). Serious games for higher education: A framework for reducing design complexity. *Journal of Computer Assisted Learning, 24*(5), 420-432. doi: 10.1111/j.1365-2729.2008.00279.x

Witkin, H. (1974). Psychological differentiation: Studies of development: L. Erlbaum Associates;[distributed by Halsted Press Division, Wiley, New York (Potomac, Md).

Witkin, H.A., Dyk, R.B., Fattuson, H., Goodenough, D.R., & Karp, S.A. (1962). Psychological differentiation: Studies of development.

Wouters, P., & van Oostendorp, H. (2013). A meta-analytic review of the role of instructional support in game-based learning. *Computers & Education, 60*(1), 412-425. doi: http://dx.doi.org/10.1016/j.compedu.2012.07.018

Wu, J.-H. (2009). A design methodology for form-based knowledge reuse and representation. *Information & Management, 46*(7), 365-375. doi: 10.1016/j.im.2009.06.004

Yang, Y.-T.C., & Chang, C.-H. (2013). Empowering students through digital game authorship: Enhancing concentration, critical thinking, and academic achievement. *Computers & Education, 68*(0), 334-344. doi: http://dx.doi.org/10.1016/j.compedu.2013.05.023

Yin, R.K. (2008). *Case study research: Design and methods* (Vol. 5): Sage Publications, Incorporated.

Zajacova, A., Lynch, S.M., & Espenshade, T.J. (2005). Self-efficacy, stress, and academic success in college. *Research in Higher Education, 46*(6), 677-706. doi: 10.1007/s11162-004-4139-z

Zott, C., Amit, R., & Donlevy, J. (2000). Strategies for value creation in e-commerce: Best practice in europe. *European Management Journal, 18*(5), 463-475.

Zywno, M., & Waalen, J. (2001). *The effect of hypermedia instruction on achievement and attitudes of students with different learning styles*.

Zywno, M.S. (2002). *Instructional technology, learning styles and academic achievement.* Paper presented at the Proceedings, 2002 ASEE Conference and Exposition.

Appendix A: Sources for Data Collection

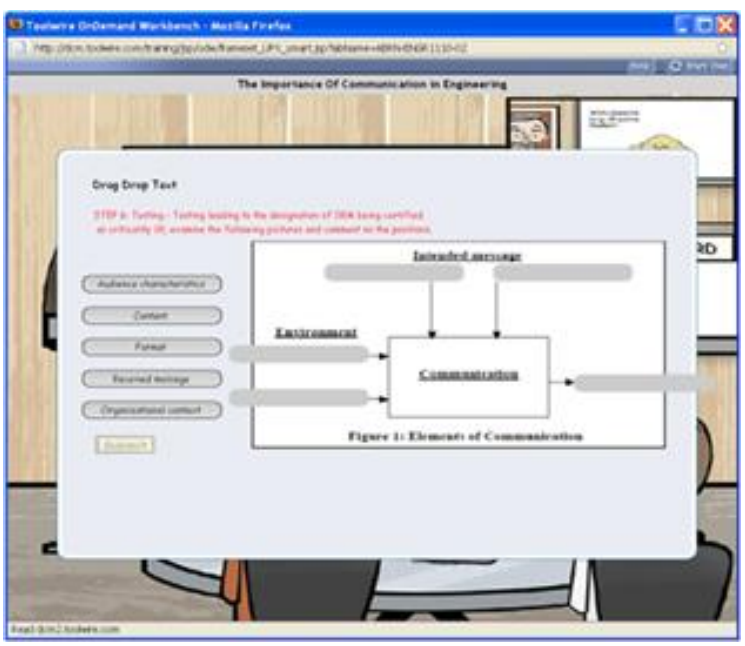
| Steps 1-6 | Multimedia Case Studies | Serious Games |
|---|---|---|
| Problem Identification | NSF Proposal<br>Journal Articles<br>Conference Proceedings<br>Lit. Review | MMCS findings<br>NSF Proposal<br>Lit. Review |
| Objectives for a Solution | NSF Proposal<br>Journal Articles<br>Conference Proceedings<br>Lit. Review<br>Team Emails<br>Meeting Minutes | NSF Proposal<br>Lit. Review<br>Input from previous iteration(s)<br>Team Emails<br>Meeting Minutes |
| Design & Develop | Project Journal Articles<br>Conference Proceedings<br>Meeting Minutes<br>Team Emails<br># Teleconferences & Meetings | Team Emails<br>Meeting Minutes<br># Teleconferences & Meetings<br>Input from previous iteration(s) |
| Demonstration | Meeting Minutes<br>Journal Articles<br>Annual Reports<br>Instructor Reports | Meeting Minutes<br>Annual Reports<br>Instructor Reports |
| Evaluation | Survey Responses<br>Focus Groups<br>Course Grades | Survey Responses<br>Focus Groups<br>Scores from IS |
| Communication | Annual Reports<br>Journal Articles<br>Conference Proceedings<br>Poster Presentations<br>Internal Meetings | Annual Reports<br>Journal Articles<br>Conference Proceedings<br>Poster Presentations<br>Internal Meetings |

*Note*. MMCS refers to the multimedia case study project

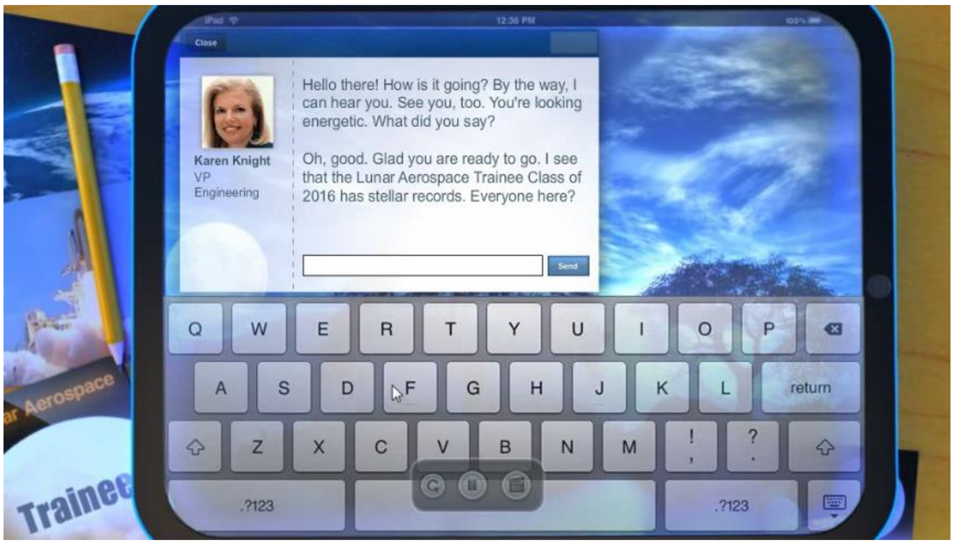
## Appendix B: Proposed Measures for the Variables

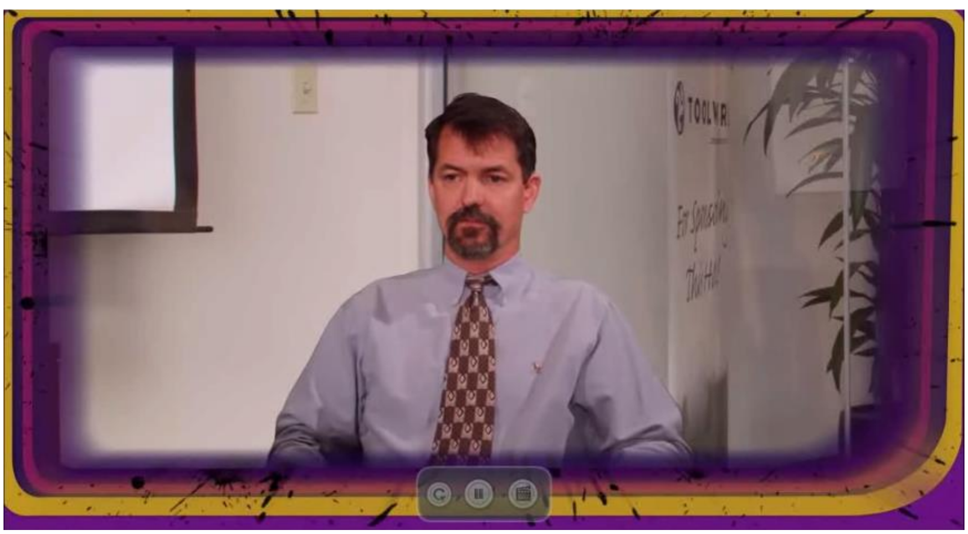
| Variables: | Demonstrated Measures | Observed Measures | Perceived Measures |
|---|---|---|---|
| In charge of assessment | Evaluators/ Instructor/ GTA | Instructor/ GTA | Evaluators |
| *Process Variable: Gain in higher-order cognitive-based problem solving skills of students.* | (1) Critical Thinking Assessment Test (CAT): Pre and post (TN Tech)<br>(2) Answers to tests administered in classroom (Instructor)<br>(3) Evaluations at the end of case study/ project presentations (Instructor/ GTA) | (1) types of questions asked in class/lab<br>(2) performs analysis<br>(3) ability to synthesize results<br>(4) Ability to solve problems | (1) Items used in a questionnaire with items such as decision making, interrelate, alternatives, problem solving skills, relevant, applying concepts.<br>(2) To what extent do you feel you have a working knowledge of ____?<br>(3) To what extent where the texts helpful in gaining proficiency in ___?<br>(Home-grown questionnaire) |
| *Process Variable: Improvement in self-efficacy* | (1) Quality of project (Instructor/ GTA)<br>(2) Integration of engineering concepts in the project (Instructor/ GTA)<br>(3) Interest in subsequent courses (Evaluators: Not measured)<br>(4) Intention to stay in engineering (exit interview) (Focus Group) | (1) shows excitement (posture)<br>(2) participates in class<br>(3) interacts constructively with others (respectful)<br>(4) comes prepared/did homework<br>(5) takes notes<br>(6) asks questions | (1) Longitudinal Assessment of Engineering Self-Efficacy (LAESE; FREE)<br>(2) Items used in questionnaire such as trouble, discipline, no idea, frustrated, stress, insecure.<br>(Home grown questionnaire) |
| *Process Variable: Improvement in team-working skills* | (1) Quality of team work in the project (Instructor/ GTA)<br>(2) Ability to resolve conflicts during project presentation (Instructor/ GTA) | Measures of improvement in team working in class using Besterfield-Sacre et al., (2007) instrument<br>• working together<br>• disrupting distractions<br>• coming to conclusions<br>• reporting results<br>• managing team<br>• working individually | Items used in questionnaire such as interpersonal, listening to others, consensus, share ideas, interaction; measure teaming skills in a practical problem solving scenario. (home grown questionnaire) |
| *Product Variable: Improvement in achieving outcomes* | (1) Scores on the tests and quizzes (Instructor/ GTA)<br>(2) Score on a pre-test for each case study (only a small sample of the post-test question) (N/A)<br>(3) Exit interview questions (longitudinal) (Focus Group)<br>(4) tests (Instructor/ GTA)<br>(5) homework (Instructor/ GTA)<br>(6) Other products of group work (write ups and rubrics) (Instructor/ GTA) | Understanding of concepts of (TESTS)<br>(1) standards<br>(2) safety<br>(3) legal issues<br>(4) gear design<br>(5) lubrication<br>(6) design<br>(7) ethics<br>(8) propulsion<br>(9) joint rotation<br>(10) field joint<br>(11) operating systems,<br>(12) entrepreneurship,<br>(13) joint application development,<br>(14) ergonomics | Items used in questionnaire related to expected outcomes<br>(1) To what extent do you feel prepared for advanced work in ____?<br>(2) To what extent do you feel you have a working knowledge of ___?<br>(3) To what extent did you gain knowledge of the relationship between ___ and engineering solutions?<br>(home grown questionnaire) |

Appendix C: Smart Scenario Screenshots

Appendix D: Learnscape Screenshots



Appendix E: Serious Games Screenshots


Appendix F: Toolwire Press Release

FOR IMMEDIATE RELEASE

Toolwire and Auburn University Co-Create Immersive Scenarios for Engineering Programs
Virtual, "Day-in-the-Life" Environments Based on Auburn's Challenger Space Shuttle Case Study Designed to Enhance Engagement and Skill Development

Pleasanton, CA – November 14, 2010 - Auburn University's Laboratory for Innovative Technology and Engineering Education (LITEE) – www.litee.org - and Toolwire – www.toolwire.com - have partnered to design immersive scenarios for first year engineering students based on LITEE's case study, Space Shuttle STS 51-L (Challenger). Through this collaboration, Toolwire's experiential learning technology and instructional design expertise will be combined with LITEE's professorial excellence and experience in mechanical engineering and its instructional material development and evaluation expertise.

Engineering programs in the U.S. are struggling to engage and retain students. According to a 2008 study of nine institutions, retention rates of engineering majors ranged from 38 to 66%. LITEE's response to statistics such as these was to make engineering instruction more authentic and relevant by developing 18 multi-media case studies based on situations faced by actual companies. Still, Auburn studies on student engagement showed that there was room for improvement. "To match the learning style of the students in our program, we needed to introduce a new learning modality that would provide a more hands-on and visual experience. Toolwire's immersive scenarios were the perfect solution," commented Auburn's Dr. PK Raju, Thomas Walter Distinguished Professor of Mechanical Engineering and Director of LITEE. "Bringing together our university resources and experts in industry will no doubt provide the optimal approach to develop learning games that will best serve our students."

Based on LITEE's Space Shuttle STS 51-L (Challenger) case study, the scenarios focus on two over-arching learning objectives: understanding key engineering design principles and mastering engineering communication. During these scenarios, students take on the role of a newly hired mechanical engineer with a fictitious company, Lunar Aerospace, to participate in trainings, discussions, conversations, and presentations as they learn about their new company and what it means to be an engineer. Along the way, "Natural Assessments" allow students to demonstrate command of the key topics in the same way that they would in real-life situations by communicating with their virtual "boss," colleagues, or others within the scenario. All information provided by students in the assessment elements is captured and formatted for delivery to the course instructor for grading purposes and builds a feedback loop for further analysis and course improvements over time.

Initial results are encouraging for the pilot scenarios, which were co-created over the summer and introduced to students during the fall semester. 70% of the students have expressed interest in working with such instructional material in the future. An Auburn instructor commented, “Overall, this is another huge improvement to the case study. The students demonstrate genuine interest in the Toolwire scenarios. We believe that the interactive computer format provided deeper engagement in the material than that of a lecture session.”

Auburn’s scenarios for Engineering are delivered to students via the Internet. “What Toolwire does for universities is not easy – it requires a centralized data center, 24x7 customer service, installation and maintenance staff, dynamic hardware deployment platforms, and software licensing,” commented Michael Watkins Toolwire’s Director of Instructional Design and Technology. “We take ownership of the challenge to deliver state-of-the-art experiential learning for students through anytime access to real hardware and software that makes the experience easy, transparent and scalable.”

“Instructional environments such as these immersive scenarios are undeniably on the threshold of cutting-edge technology in education and professional training,” commented Dr. Chetan S. Sankar, an expert on case study development, pedagogy, and research at Auburn University who will be part of a team that closely studies how these virtual, “day-in-the-life” scenarios affect student performance and engagement. “Through this partnership, we will conduct research to fully understand the best ways to utilize this technology in the classroom.”

“Toolwire was founded 15 years ago on the belief that students learn best by doing and have been deeply committed to developing a highly reliable, scalable infrastructure to deliver authentic, experiential learning solutions ever since then,” commented John Valencia, CEO and President of Toolwire. “Combining these capabilities with Auburn/LITEE’s subject matter and educational expertise creates a unique partnership with unlimited potential to significantly enhance higher education engineering instruction.”

About Toolwire
Toolwire is a learning solutions provider specializing in products and services for experiential learning. Bridging the gap between education and experience, Toolwire's LiveLabs, Scenarios, and Immersive Learning Environments provide on-demand, personalized practice to best meet the dynamic needs of the learner. “Learning by doing” provides the quickest and most effective way to develop skills and ensure ongoing learning, knowledge retention and competency. Toolwire’s award winning solutions “bring knowledge to life”. For more information, please visit www.toolwire.com

About Auburn University's Laboratory for Innovative Technology and Engineering Education

•The Laboratory for Innovative Technology and Engineering Education (LITEE) at Auburn University has established a strong reputation for developing, testing, and disseminating innovative instructional materials for use by engineering and business students. Using funding received from six different NSF grants, LITEE has developed eighteen multi-media case studies that describe problems that happened in actual companies and are available from www.liteecases.com. A major finding from the previously funded research projects is that the case studies serve to improve higher-order cognitive skills, team working skills, and attitude of students towards engineering subjects. LITEE case studies have been widely recognized by national organizations and have received numerous awards recognizing leadership in Engineering Education.
For more information about LITEE, please visit www.litee.org and www.liteecases.com.

Media Contact:

Peyton Williams
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Appendix G: IRB Approval for Multimedia Case Study Research

AUBURN UNIVERSITY

COLLEGE OF BUSINESS

DEPARTMENT OF MANAGEMENT

The Auburn University Institutional Review Board has approved this document for use from 12/14/09 to 12/13/10. Protocol # 09-303 EP 0912

**(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)**

**INFORMED CONSENT for a Research Study entitled "Phase 2: Development & Testing of Presage-Pedagogy-Process-Product Model to Assess the Effectiveness of Case Study Methodology in Achieving Learning Outcomes"**

**You are invited to participate in a research study** to evaluate the effectiveness of multi-media case studies. The study is being conducted by Dr. Chetan S. Sankar and Howard Clayton in the Auburn University Department of Management. You were selected as a possible participant because you are a student in this course and are age 19 or older. If you are 19 and younger, please use the parental consent form.

If you decide to participate in this study, you will be asked to complete several questionnaires and a journal concerning your beliefs and attitudes about learning and your course experiences. You total time commitment will be approximately 30 minutes and you can obtain extra credit of 5 points. During class sessions, teaching assistants will observe and document your response to instruction and your level of participation in the class. You are also being asked to allow the investigators to obtain your scores on tests and exams in this course. All information about you will be recorded using a code number and the evaluators will ensure this information remains confidential.

**If you change your mind about participating,** you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University, the Colleges of Business or Engineering. **Any data obtained in connection with this study will remain confidential.** Information collected through your participation may be *published in a professional journal, and/or presented at professional meetings.* **If you have questions about this study,** *please ask them now or* contact Dr. Chetan S. Sankar at 844-6504 (sankacs@auburn.edu). A copy of this document will be given to you to keep.

**If you have questions about your rights as a research participant,** you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE IF YOU WANT TO PARTICIPATE IN THIS RESEARCH PROJECT. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

Chetan S. Sankar Date Participant's Signature Date

415 W. MAGNOLIA AVENUE
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AUBURN, AL 36849
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AUBURN
UNIVERSITY

# COLLEGE OF BUSINESS

DEPARTMENT OF MANAGEMENT

**(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)**

**PARENTAL PERMISSION/CHILD ASSENT**
**for a Research Study entitled**
**"Phase 2: Development & Testing of Presage-Pedagogy-Process-Product Model to Assess the Effectiveness of Case Study Methodology in Achieving Learning Outcomes"**

**Your child is invited to participate in a research study** to evaluate the effectiveness of multi-media case studies. The study is being conducted by Dr. Chetan S. Sankar and Howard Clayton in the Auburn University Department of Management. Your child was selected as a possible participant because he or she is a student in this course. Since your child is age 18 or younger we must have your permission to include him/her in the study.

**What will be involved if your child participates?** If your child decides to participate in this study, he/she will be asked to complete several questionnaires and a journal concerning his/her beliefs and attitudes about learning and course experiences. Your child's total time commitment will be approximately 30 minutes and he/she can obtain extra credit of 5 points. During class sessions teaching assistants will observe and document your child's response to instruction and his/her level of participation in the class. Your child is also being asked to allow the investigators to obtain his/her scores on tests and exams in this course. All information about your child will be recorded using a code number and the evaluation will ensure this information remains confidential.

The Auburn University
Institutional Review Board
has approved this document for use
from 12/14/09 to 12/13/10
Protocol # 09-303 EP 0912

**If you (or your child) change your mind about participating,** your child can withdraw at any time during the study. Your child's participation is completely voluntary. If your child chooses to withdraw, that data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your (or your child's) future relations with Auburn University, the Colleges of Business or Engineering. **Any data obtained in connection with this study will remain confidential**. Information collected through your child's participation may be *published in a professional journal, and/or presented at professional meetings.* **If you have questions about this study,** *please ask them now or* contact Dr. Chetan S. Sankar at 844-6504 (sankacs@auburn.edu).

**If you have questions about your child's rights as a research participant,** you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu. **HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH FOR YOUR CHILD TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO ALLOW YOUR CHILD TO PARTICIPATE. YOUR CHILD'S SIGNATURE INDICATES HIS/HER WILLINGNESS TO PARTICIPATE.**

| | |
|---|---|
| Participant's signature Date | Investigator's Signature Date |
| Printed Name | Chetan S. Sankar<br>Printed Name |
| Parent/Guardian Signature Date | |
| Printed Name | |

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# Appendix H: IRB Approval for Serious Game Research

AUBURN
UNIVERSITY

COLLEGE OF BUSINESS

DEPARTMENT OF AVIATION
AND SUPPLY CHAIN MANAGEMENT

**(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)**

The Auburn University Institutional Review Board has approved this document for use from 12-29-11 to 12-28-12
Protocol # 11-386EP 1112

**INFORMED CONSENT**
**for a Focus Group Research Study entitled**
**"The Design and Testing of Serious Games in Technical Disciplines"**

You are invited to participate in a research study to determine the extent to which serious games, as an instructional methodology, improve student outcomes, motivate students to persist in their current discipline, and provide benefits beyond traditional instructional methodologies. The study is being conducted by Chetan S. Sankar in the Auburn University Department of Aviation & Supply Chain Management. You were selected as a possible participant because you are enrolled in an engineering course or another technical course and are age 19 or older.

If you decide to participate in this research study, you will possibly be asked to participate in a focus group. Your total time commitment will be approximately 45 minutes.

The risk associated with participating in this study is a potential breach of confidentiality. To minimize this risk, we will separate all of your identifiable information from your focus group responses and store them, electronically, on two separate computers in password protected files. All identifiable information will be kept confidential and will not be made available to any third parties for any reason. While the participants involved in the focus groups will be encouraged to keep discussion information private, we cannot guarantee the confidentiality of discussions.

If you participate in this study, you can expect to receive feedback regarding the results of this study, if requested.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University, the researchers involved in this study, or the Department of Aviation & Supply Chain Management.

415 W. MAGNOLIA AVENUE
SUITE 403
AUBURN, AL 36849
TELEPHONE:
334-844-4908
FAX:
334-844-4927
www.auburn.edu

Participant's initials ______

Page 1 of 2

Any information obtained in connection with this study will remain confidential. Information obtained through your participation may be used to fulfill an education requirement, published in a journal, or presented at a professional meeting.

If you have questions about this study, please ask them now or contact Chetan S. Sankar at sankacs@auburn.edu, or Justin L. Bond at justin.bond@auburn.edu. A copy of this document will be given to you to keep.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

The Auburn University Institutional Review Board has approved this document for use from 12-29-11 to 12-28-12 Protocol # 11-380 EP 1112

**HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE. YOU MAY PROCEED TO SIGN THE FORM.**

| | |
|---|---|
| Participant's signature Date | Investigator obtaining consent Date |
| Printed Name | Chetan Sankar<br>Printed Name |
| | Co-Investigator Date |
| | Justin Bond<br>Printed Name |

AUBURN
UNIVERSITY

COLLEGE OF BUSINESS

DEPARTMENT OF AVIATION
AND SUPPLY CHAIN MANAGEMENT

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| | |
|---|---|
| Participant's signature Date | Investigator obtaining consent Date |
| Printed Name | CHETAN S. SANKAR<br>Printed Name |

The Auburn University Institutional Review Board has approved this document for use from 2/8/13 to 12/28/13
Protocol # 11-380 EP 1112

Page 2 of 2

Appendix I: LITEE Team Members

| Name | Affiliation | Position | Project |
|---|---|---|---|
| P.K. Raju | Auburn U. | Faculty & P.I. | 0934800 & 1110223 |
| Chetan S. Sankar | Auburn U. | Faculty & Co-P.I. | 0934800 & 1110223 |
| Howard Clayton | Auburn U. | Faculty & Senior Personnel. | 0934800 |
| Joseph McIntyre | Auburn U. | Doctoral Student | 1110223 |
| Pramod Rajan | Auburn U. | Doctoral Student | 0934800 & 1110223 |
| Ashok Manoharan | Auburn U. | Doctoral Student | 0934800 & 1110223 |
| Justin Bond | Auburn U. | Doctoral Student | 0934800 & 1110223 |
| Eliza Banu | Auburn U. | Doctoral Student | 0934800 & 1110223 |
| Ashley Clayson | Auburn U. | Master's Student | 0934800 |
| Kristen Billy | Auburn U. | Master's Student | 0934800 & 1110223 |
| Anna Hewlett | Auburn U. | Undergrad. Student | 1110223 |
| Barbara Kawulich | U. of West GA | Faculty | 0934800 & 1110223 |
| Kim Huett | U. of West GA | Doctoral Student | 1110223 |
| Kelly Williams | U. of West GA | Doctoral Student | 1110223 |
| Qiang Le | Hampton U. | Faculty & P.I. | 0934800 & 1110223 |
| Nesim Halyo | Hampton U. | Faculty | 0934800 |
| Stephen Lynch | Toolwire Inc. | Employee & P.I. | 1110223 |
| Peyton Williams | Toolwire Inc. | Employee | 1110223 |
| Michael Watkins | Toolwire Inc. | Employee | 1110223 |
| Juzen Toy | Toolwire Inc. | Employee | 1110223 |
| Mary Schenck-Ross | Toolwire Inc. | Employee | 1110223 |
| Deirdre Cohen | Toolwire Inc. | Employee | 1110223 |
| Dayvid Jones | Toolwire Inc. | Employee | 1110223 |

*Note*. EEC #0934800 is the Multimedia Case Study Project. IIP#1110223 is the Serious Games Project