Augmented Reality and User Interface for the Sustainable Product Architecture and Supplier Selection (S-PASS) Cyberlearning Tool

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Abstract

Various engineering design courses through cornerstone and capstone projects have been common in engineering curriculums due to their learning effectiveness. However, engineering students are often asked to design and manage multiple concurrent abstract tasks without any decision support tool to effectively guide and track their progress. To tackle this issue, this study aims to develop a design decision support tool for engineering students that provides enhanced learning through a cyberlearning application platform with an effective user interface. This study particularly focuses on transforming the current static learning environment of the Sustainable Product Architecture and Supplier Selection (S-PASS) tool into more dynamic learning environment to promote engineering students' learning for sustainable life cycle engineering; two enhanced versions of the S-PASS tool, 1) web-based without augmented reality and 2) web-based with augmented reality, are developed. Then, the current version and the new versions of the S-PASS tool are evaluated by undergraduate and graduate STEM students using pre- and post-user experience surveys along with eye tracking experiments to identify changes in usability, motivation, enjoyment, and understanding for the learning subjects. The results show that the cyberlearning platform with consideration of dynamic learning elements improves students' tasks and learning performance.

Keywords: Sustainability, Engineering, Education,Augmented Reality, User Interface Design

1.0 Introduction

Sustainable design has become increasingly important in recent years in light of diminishing resources and negative manufacturing effects on the environment. This is especially true in the field of engineering (Khan et al. 2017), where sustainable engineering can be described as the process whereby energy and resources are used in a way that does not compromise the natural environment or limit the ability of the future generations to meet their own needs (Brundtland, G. H., 1987).

As a result, introducing green engineering concepts into undergraduate curriculum is considered increasingly important (Criteria for accrediting engineering programs 2017, Hollar, K et al, 2002, Shiue, I. 2015) and the demand for environmentally conscious engineers is being driven by industry, the general population, government entities, and nonprofits.

[More specific examples of incorporating and suggesting sustainability into engineering education...]

However, sustainability courses and materials are not typically implemented until the senior undergraduate year or graduate level (Fisher, P. D., 2001, Hollar, K et al, 2002). Even then, many times they are optional (Fisher, P. D., 2001). This promotes the mindset that sustainability is an end of process treatment, rather than of fundamental design importance. By integrating principles of green engineering at the start of design processes, it is possible to help create products and processes of a sustainable future (Fisher, P. D., 2001).

One of the obstacles to engineering education in general is that most classes are still taught with traditional methods. However, research suggests these are less effective than more hands-on approaches such as constructionism, which is a variation of constructivist learning theory (Carew, A. L., & Mitchell, C. A., 2008, Khan, T. H., 2017, Rugarcia, A. 2000).

On the other hand, a constructionist approach engages learners in actively engaging in constructing, building or making artifacts in a cyclical approach. Learners first apply initial knowledge, which allows them to construct new knowledge, which in turn updates their old knowledge (Khan e al. 2017). Constructionism also strongly encourages autonomy in learning, which gives learners a sense of ownership over their ideas and creations (Khan et al. 2017).

In response to this complex problem, Iowa State, Penn State, Oregon State, and Wayne State University have worked in conjunction to create learning modules, jointly titled “Constructionism in Learning: Sustainable Life Cycle Engineering (CooL:SLiCE).” The Sustainable Product Architecture and Supplier Selection (S-PASS) tool is a module within the CooL:SLiCE learning platform to evaluate different product architectures and suppliers on their environmental sustainability.

In addition to the benefits of constructionism, research has also shown AR, especially mobile AR for e-learning, to be a viable educational tool (Dunleavy, M. and Dede, C. 2014, Bacca, J. et al. 2014, Ronging, Z., Yiran, S. et al. 2016, Sungkur, R. K., et al. 2016, Akçayıra, M. et al., Slykhuis, D. A. 2016, Kambona. K. et al 2013, Ramírez-Montoya, M.S. and García-Peñalvo, F.J. 2017, Fombona, J. et al 2017, Xu, H. et al 2017, Almenara, J. C., Días, V. M. 2017, Shiue, I. 2015).

[Briefly define AR, then discuss popularity, industry growth, cost, motivation, potential, accessibility, and limitations...]

Faculty and departments are often reluctant to change and to contribute resources to new educational endeavors (Rugarcia, A., 2000). To increase the likelihood of implementation, this study uses an online portal and augmented reality software in the S-PASS tool to minimize cost while maximizing accessibility.

Research has also shown user interface (UI) design to be extremely beneficial for website usability (references Santos, C. et al. 2016, Ferris, K. et al. 2016, Alberts et al, 2011, Johnson 2013, Garret 2011).

[Briefly define UI and describe benefits…]

This study has built on previous research to determine whether employing AR and UI design is effective for a specific learning niche, specifically a cyberspace learning environment for first, second and third year undergraduate engineering students in sustainable design.

To evaluate AR and UI, we have developed two enhanced versions of the S-PASS tool, 1) web-based without augmented reality and 2) web-based with augmented reality. This research provides how a learning tool can be effectively integrated with a cyberspace learning platform to enable college students to be better engaged in active learning of sustainable design.

The main goal of this research is to identify how do UI design and AR affect the UX of pedagogical engineering web applications and students' comprehension of subject material by 1) creating a user interfaces of the S-PASS tool based on different cyberspace learning environments and 2) investigating changes in students' learning performance and usability under the different user interfaces.

2.0 Methods

2.1 General Information

Using pre- and post-user experience surveys along with eye tracking experiments, we compared each version of S-PASS, including the current Excel-based version. This data allowed us to evaluate usability of the developed learning tool.

2.2 Selection of Participants

Participants were contacted through the email list of students from the IMSE department at Iowa State University (ISU) and the email list of program attendees from the Research Experience for Undergraduate (REU) program at ISU.

All participants were invited to participate in a drawing to win one of five prizes of Amazon e-gift certificates worth $30 each. Participants who complete the study will be able to enter a drawing three times. Participants who begin the study but do not complete it will enter a drawing only once.

Our study had ___ (breakdown of participant demographics). To ensure that vision problems or medical history of photosensitive epilepsy did not put students in unnecessary risk or skew eye tracking results, we excluded anyone with medical history of critical vision problems and with the symptoms.

2.3 Pre-study

Pre-survey items were created to gather base information about participants' demographic information, pre-existing knowledge and assumptions, and experience with the material we would be covering. We used the demographic information to split respondents into two groups in order to counterbalance learning effects in the study. In this way, we performed an appropriate sampling for the experiment. The experiment itself was conducted in the Iowa State UX Lab with a minimum of one research assistant in the room at all times. The lab resembles an individual testing center for students. The room itself relatively quiet with no significant distractions.

To create our new UI we needed a responsive, dynamic, and versatile toolset.

JavaScript is the most popular language of the web, however as it is used to write an increasing number of programs, it has become difficult to maintain (Kambona, Boix, & Meute, 2013). For this reason, this study used React.js as the front end framework. Node.js is used for the package management and connections. *[Explain why this is difficult before talking about how to make it easier...]* To make this process easier, a variety of other technology is used, including webpack, redux, mySQL, and express. Finally, A-Frame is used to incorporate the AR component. *[Explain why A-Frame was chosen...]*

2.4 Study—Part I

Our experiment was divided into three main parts: pre-evaluation questions, use and evaluation of the main tools, and finally the post evaluation questions. During each of these sections we collected data that we would use to determine the usability and user experience of the software.

To empirically determine the usability of the softwares we relied on the System Usability Scale(SUS). "The SUS score can and does provide a very useful metric for overall product usability" thus the scale is commonly used in determining suitability of a wide variety of systems (Bangor, Kortum, & Miller, 2008). We chose to use the SUS as well as additional questions that provided additional UX questions. The original version of the question list is available upon request.

We decided to include eye tracking in this study on the basis that we would be able to better determine the effect of a lingering gaze when pairing it with other qualitative data. Eye Tracking has already proved itself to be effective in assisting research when determining attention given to a specific point when actively focusing(Slykhuis, Wiebe, & Annetta, 2005)

This experiment was carried out by drawing from {the Iowa State summer Research Experiences for Undergraduates(REU) program} with a size of {n = ###}.

Upon arrival at the UX lab, participants were given 10 minutes to review the case study description and tasks. After the 10 minutes were up, they were asked to perform a pre-evaluation survey to identify their perceptions and general learning styles in product design activities. Questions for this survey were modified appropriately from a previous questionnaire by Wayne State University in a related study. Some questions were based on Autonomous Learning Scale, a scale used in education research to study how people learn. Participants were then given 25 minutes for practicing the three different tools freely.

The same questions were answered for the Excel version of the S-PASS tool, the web version of the S-PASS tool, and the web version of the S-PASS tool with AR. Additionally, all surveys were drafted, pilot tested and modified before the experiment.

2.5 Study—Part II

For the second portion of the study, participants interacted with the three tools through a Tobii eye-tracker T120 monitor and through a smartphone. Each participant underwent the Tobii calibration process as directed by the research assistant and as outlined by the official user guide. After practicing with the tools freely, the user completed the case study three times—once for each of the previously listed tools. The order of the versions which the participant used were randomly determined.

A smartphone was used to accommodate the augmented reality interface. Each participant was aided as necessary in using the augmented reality portion of the third tool. A smartphone was provided if they did not already have an AR capable device.

After the case study for each tool, participants took a post-evaluation survey without being tracked by the Tobii eye-tracker. This post-survey asked the learning effectiveness and usability of the three tools while performing the case study. After completing the study, we asked pre-evaluation survey questions again to use as a gauge for any change in confidence and knowledge.

Once calibration was complete, the user then proceeded to complete the case study using each tool. The Tobii eye-tracking system monitored where on the screen the participant was looking while simultaneously recording what was on their screen. Participants were asked to sit relatively still during the study to ensure optimal eye-tracking precision. Eye-tracking data was used to determine the number of times the participant looked at a certain area, the duration that the eyes spent in that spot, and how much distance the participants eyes covered.

The case study given to participants was completing a case study for quad- and hexa-copter design. Participants were asked to complete the study for each of the three different versions of S-PASS. The case study included tasks to determine a sustainable drone product design based on given information and guidelines in the description of the case study. Participants were required to derive design requirements and parameter values to input them in the learning tool to generate sustainable product architectures and their associate suppliers.

The case study was given to each participant as a hard copy with the purpose of the case study tasks clearly outlined at the top, as follows:

- Students will use multi-perspectives for product design, considering requirements, functions, modules, product architectures, and suppliers, to develop environmentally responsible products.
- Students will perform a design decision-making process to integrate environmental issues into selection of product concepts and suppliers through the S-PASS (Sustainable Product Architecture and Supplier Selection) tool.
- Students will formulate their own design problems for development of environmentally responsible products.

The Case study is summarized below.

> **Case Study:**
> Drones and multi-copters are very familiar to consumers. While children play with remote controlled toy versions, some adults expect deliveries by drones. Company X is currently selling two types of drones: hexa-copters and quad-copters (See Table 1). Due to global regulations regarding the environmental impacts of products and companies, Company X is planning to upgrade its existing products through environmentally responsible design. The main objective of environmentally responsible drone design at Company X is to determine new product architectures and their suppliers while considering their possible environmental impacts. New drones should satisfy design requirements for minimal energy use and reduction in hazardous by-products/pollutants both from the manufacturing process and throughout useful life of drones. Modules in new drones should be provided by suppliers that are environmentally friendly in their operations (i.e., manufacturing and logistics). Key modules and components of the existing drone designs are provided in Table 1.

> Company X has just signed a consulting agreement with your team to tap into your expertise in sustainable design and manufacturing. You are tasked with proposing new designs that are vastly improved in environmental sustainability performance over the current designs of drones. For facilitating the design task, your team will employ the Sustainable Product Architecture and Supplier Selection (S-PASS) tool provided in class (See Appendix). As a team, follow each phase outlined below and determine the input values to use within the S-PASS tool.

Furthermore, the case study outlined each phase of the S-PASS tool, describing the purpose of the phase and instructing the student on how to proceed each step of the way. This mimics how a project might be given to a student in an educational setting.

2.6 Study—Part III

Following the experiment, participants filled out a post-experiment survey where they provided feedback about their experiences and preferences. Parts of this end questionnaire repeated the initial survey to allow us to track the specific changes in opinion and learning that each version caused. Finally, participants also took the SUS. Additionally, after completion of the case study, participants answered the very common System Usability Survey (SUS) which provided a usability score for each tool. The SUS is comprised of 10-questions and a 5-point Likert scale ranging from “strongly disagree” to “strongly agree.” Generally, the whole of the experiment took about 45-60 minutes for all participants to complete.

2.7 Analyzing the Data

Data obtained from the pre- and post- evaluation surveys were statistically analyzed through ANOVA, t-Test, and descriptive statistics by sample groups (i.e., genders and majors) to identify differences in learning and usability among the different tools and between sample groups. The total number, the total distance, the total time spent in each location of eye movements measured by the Tobii eye tracking system was used to calculate task efficiency. ANOVA, t-Test, and descriptive statistics by sample groups (i.e., genders and majors) were also performed for the data obtained from the eye tracking system.

3.0 Results

Summary of methods
What was consistent?
What was divergent?

4.0 Discussion

5.0 Conclusion

Re-establish territory (draw on background, announce principal findings, preview content)
Frame findings (account for results, relate to expectations, address limitations)
Reference literature (supporting and countering with evidence)
Expand on comments (generalize results, broader implications, propose further research)

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