Design of an Educational Tool for Unmanned Air Vehicle Design and Analysis

Brian Sanders, Brent Terwilliger,
Ken Witcher, Mark Leary
Embry-Ride Aeronautical University
Daytona Beach, Florida
{Sanderb7, Terwillb, Witchea8,
Learym1;@erau.edu}

James Ohlman, Christina Tucker
Pinnacle Solutions
Huntsville, Alabama
{johlman, ttucker;
@pinnaclesolutionsinc.com}

ABSTRACT

Offering laboratories and team projects present significant challenges for delivering Science, Technology, Engineering, and Mathematics (STEM) courses in the online (asynchronous) modality. These interactive workspaces are important attributes since they provide forums for students to more deeply explore fundamental principles, exercise teamwork and planning to jointly overcome problems, and gain critical experience. The employment of online environments and interactive activities hold the potential to change how fundamental student outcomes measured by accreditation organizations are incorporated and treated in curricula, potentially improving the quality of the overall educational experience. To address this need Embry-Riddle Aeronautical University has teamed with Pinnacle Solutions to develop a realistic unmanned aircraft system (UAS) development, application, and evaluation simulation that educators can integrate into program curriculum. The research contained in this paper addresses simulation development and application starting with identification of basic educational objectives driving the need and how the simulation tool is envisioned to satisfy learning objectives. This will be followed by a description and examples of a multi-environment simulation framework designed to meet those needs. The first is a component test environment where students can investigate basic technical principles of operation and key performance metrics of standalone UAS components such as sensors, communications, and propulsion elements. The second is an integration facility, where students are provided the capability to apply knowledge gained in the previous laboratory to select and combine appropriate elements into a unified subsystem to meet prescribed mission parameters. The third is a flight test environment, where students experiment with development and execution of simulated flight profiles over common terrain environments (i.e., mountainous) to measure operational performance attributes of the completed UAS. The design is anticipated to provide the flexibility to implement each environment sequentially, as described above, or independently; ensuring a solution applicable to a broad range of courses, objectives, outcomes, and student capabilities.

ABOUT THE AUTHORS

Dr. Brian Sanders is an Assistant Professor at Embry-Riddle Aeronautical University-Worldwide and Program Chair of the AS in Engineering Fundamentals. His experience includes basic and applied research in high temperature composite materials for gas turbine engines and hypersonic flight vehicles, multifunctional structures, and unmanned aircraft system (UAS) concepts, such as morphing aircraft. His current research focus is on the design and application of virtual environments for application to engineering curriculum.

Dr. Brent Terwilliger is the Program Chair for the Master of Science in Unmanned Systems (MSUS) degree and an Assistant Professor of Aeronautics at ERAU-Worldwide. Dr. Terwilliger has coordinated proposals, led research and development efforts, authored peer reviewed publications, and performed editorial and acceptance review for topics associated with unmanned systems and application of training and simulation. He is currently working on several research publications detailing his work on application of unmanned aircraft systems (UAS) for emergency response, human-machine-interface (HMI), modeling and simulation, and situational awareness.

Design of an Educational Tool for Unmanned Air Vehicle Design and Analysis

Brian Sanders, Brent Terwilliger,
Ken Witcher, Mark Leary
Embry-Ride Aeronautical University
Daytona Beach, Florida
{Sanderb7, Terwillb, Witchea8,
Learym1;@erau.edu}

James Ohman, Christina Tucker
Pinnacle Solutions
Huntsville, Alabama
{johlman, ttucker;
@pinnaclesolutionsinc.com}

INTRODUCTION

Providing laboratory environments for use in asynchronous (online) science, technology, engineering, and mathematics (STEM) courses present significant challenges. The interactive workspaces inherent to such environments provide important attributes, such forums for students to more deeply explore fundamental principles, exercise teamwork and planning to jointly overcome problems, and gain critical experience.
Use of online learning environments creates unique challenges for delivery, such as addressing missing tactile and real-time cooperative and coordinated experimentation interaction available in an actual laboratory setting. However, the use and availability of online environments and subsequent interactive activities holds significant potential to change how fundamental student outcomes are incorporated and treated in curricula. While similar in nature to computer based training (CBT) in that it is a form of e-learning, the academic environment requires increased exploration of concepts in and outside of the classroom to support both synchronous and asynchronous educational goals over a longer course of academic study, while CBT tends to be more focused on comprehension of a subset of goals or requirements (Hafner, 1983). The availability of tools to incorporate such attributes may hold the key to improving the quality of the overall educational experience.

This paper contains a discussion of the development of a virtual laboratory, designed to support online/asynchronous education in the unmanned systems domain. The discussion includes the identification of basic educational objectives driving the need and a narrative of how such a simulation tool could be used to satisfy learning objectives, base concepts influencing the design, and end-use considerations that have been addressed in the development effort thus far. The design and implementation of this tool is anticipated to provide the necessary flexibility to implement a series of interactive experimentation and learning modules (environments) sequentially or independently to ensure a solution applicable to a broad range of courses, objectives, outcomes, and student capabilities is created and fielded.

BACKGROUND

Online learning environments have become an accepted approach for students to use in pursuit of higher education goals (Fursr, 2011; Hagg and Palais, 2002; Kullenberg, 2002; Whitttington et al., 1998), with a rapid change in the nature of education exhibited in traditional campuses to these venues as a result. As an example, the Embry-Riddle Aeronautical University (ERAU) Worldwide campus offers degrees and coursework specific to unmanned systems and engineering at the undergraduate and graduate levels using multiple delivery modalities (i.e., synchronous, asynchronous, and mixed-modality; e.g., classroom, online, and EagleVision). Delivery of education through such modalities works well for communication of basic information related to mathematics and theory. However, it lacks the element inherent to traditional laboratory settings and collaborative design experiences since these are typically not available to online (remote) students.

Laboratories and team projects are an important part of the practitioner's (e.g., engineer, analyst, researcher, or system designer) education since they provide forums for students to more deeply explore fundamental principles, while exercising teamwork and planning to jointly overcome problems. Kolb (1984) described the value of this active learning concept (Experimental Learning Cycle, depicted in Figure 1) as an alternative to the traditional lecture-exam approach. This approach illustrates a relationship between foundational (i.e., concrete) experience, reflective observation, and abstract conceptualization (Kolb, 1984). While there has been some dispute as to details of relating to specific personality types (Garner, 2000), this view has gained wide acceptance as a model toward understanding and explaining human learning behavior. This concept has been successfully applied to engineering courses (Abdulwahed & Hagy, 2009; Lagoudas et. al., 2000; Muscat & Mollicone, 2012) and used to demonstrate increased retention and understanding for courses in continuum mechanics, mechanics of materials, and laboratories. Although these applications were implemented in traditional university environments, the basic premise proposed by Kolb is paramount to the success of an online program and modeling and simulation (M&S) technologies can help address this need.

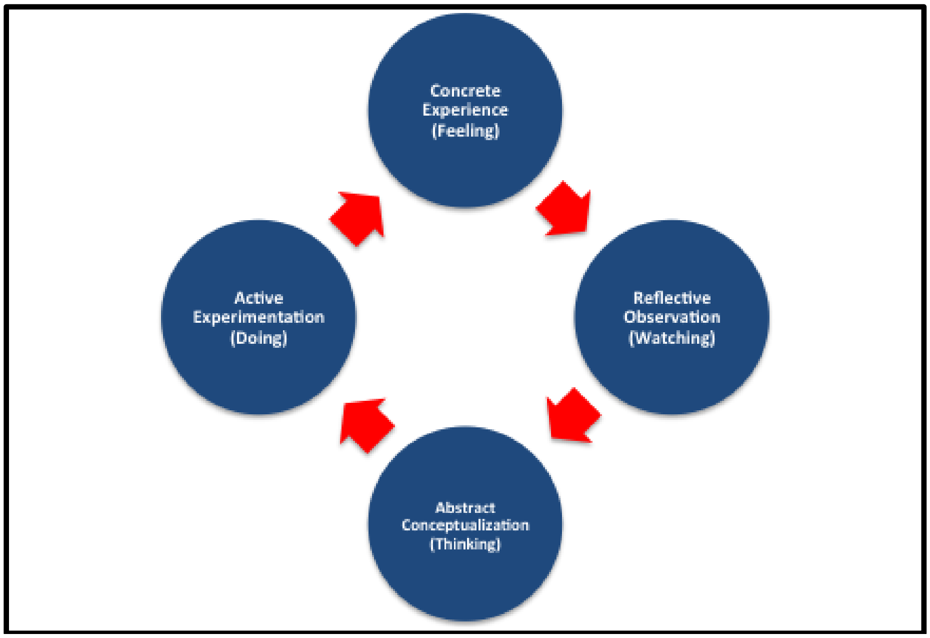

Figure 1. Adapted From Kolb's Experimental Learning Cycle (Kolb, 1984)

The overall quality of an educational program is assessed by organizations such as the Accreditation Board of Engineering and Technology (ABET; n.d.). These organizations conduct assessments with criteria that focus on students experience and learning outcomes (ABET, n.d., para. 3). Included in assessment criteria is an "ability to design and conduct experiments" (Engineering Accreditation Commission, 2014, p. 5). Recognizing the growth of distance learning programs and the resulting difficulty in offering this capability ABET sponsored an effort to investigate basic learning objectives of laboratories (Feisel & Peterson, 2002). The goal was to identify the educational objectives achieved by laboratory instruction and define attributes developed by the student in these experiences (Feisel & Peterson, 2002). These objectives and description used in this investigation are depicted in Table 1 below. Satisfying these objectives requires a combined approach of integrating tools and the learning management system (LMS). For example, as described in the table instrumentation, models, experiment, data analysis, design, and learn from failure can be met with the help of the simulation, while the others can be addressed through the design of the LMS.

Table 1. Laboratory learning objectives, adapted from Feisel and Peterson (2002, pp. 5-6)

Objective	Description
Instrumentaton	Apply appropriate sensors, instrumentation and/or software tools to make measurements of physical quantities.
Models	Identify the strengths and limitations of theoretical models as predictors of real world behaviors. This may include evaluating whether a theory adequately describes a physical event, and establishing or validating a relationship between measured data and underlying physical principles.
Experiment	Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system.
Data Analysis	Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments and know measurement unit systems and conversions.
Design	Design, build, or assemble a part, product or system including: using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.
Learn From Failure	Recognize unsuccessful outcomes due to faulty equipment, parts, code, construction, process or design, and then re-engineer effective solutions.
Creativity	Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.
Phychomotor	Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.
Safety	Recognize health, safety, and environmental issues related to technological processes and activities and deal with them responsibly.
Communications	Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.
Teamwork	Work effectively in teams, including: structure individual and joint accountability; assign roles, responsibilities and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.
Ethics in Laboratory	Behave with highest ethical standards, including reporting information objectively and interacting with integrity.
Sensory Awareness	Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.

Institutions offering online and remote courses need to address the laboratory challenge for their programs to receive accreditation and provide a quality learning experience to students. This gap can be overcome, to some degree, through arrangements with local institutions and remote laboratories (Nickerson et al., 2007; Velasco et al. 2009). However, these are not global solutions since they are not always available. Furthermore, they do not offer the break from traditional teaching strategies, such as Gamification (Kapp, 2012), that may be enabled by a technology-rich environment. To address a more global solution the College of Aeronautics of ERAU-Worldwide embarked on an initiative to bring interactive simulation to their academic programs. In 2013, the University began development of its first virtual learning environment, the Virtual Crash Lab, which was created through a partnership with Pinnacle Solutions (Tucker & Moore, 2014) and has been fielded across several ERAU-Worldwide safety and accident investigation courses. The experience gained from development and release of this first virtual laboratory environment was crucial for the development of the next virtual laboratory in the series, the Aerial Robotics-Virtual Lab (ARVL), which is the focus of this paper.

SIMULATION DEVELOPMENT AND DESCRIPTION

The development team for ARVL used a blended waterfall and agile method approach (Stocia et al., 2013). The blended approach is significant to align with waterfall method development practices (e.g., requirements definition, design development and revision, and validation, verification, and testing.), reducing the amount of potential rework and ensuring satisfactory completion of course objectives. The use of the agile method facilitated rapid prototyping, while enabling ERAU faculty opportunity to provide feedback earlier in the process than typically achievable using the waterfall method alone. A major challenge for this project was to develop a tool general enough to be applicable to a broad range of courses, yet with enough specificity to satisfy accreditation requirements and course specific learning objectives. The use of this hybrid approach ensured that clear connections were established and maintained among learning objectives, accreditation criteria, and necessary laboratory capabilities.

The first step in the design process identified relevant degree programs and accreditation criterion for use in development of derived and functional requirements. The applicable degree programs to feature use of this laboratory were identified; the Associates of Science in Engineering Fundamentals (ASEF), Bachelor of Science in Engineering Technology (BSET), BS in Aeronautics (BSA) with UAS minor, BS in Unmanned Systems Applications (BSUSA), Master of Science in Aeronautics (MSA) with UAS graduate specialization, and MS in Unmanned Systems (MSUS) degree. The outcomes, objectives, topics, and activities of these programs feature the incorporation and coverage of a broad range of academic principles, including detailed engineering concepts, predominant in ASEF and BSET degrees; architectural composition; system and application analyses; and system design experiences. Identifying, incorporating, and ensuring necessary coverage of these items required review of the early concepts and initial derived requirements by ERAU subject matter experts (SMEs), including program chairs and full time faculty members. A re-occurring dialog was initiated to brief these SMEs of the development of the baseline and evolving materials (e.g., requirements, storyboards, videos, and interactive demonstrations) and to elicit feedback regarding potential effectiveness and applicability to their discipline and specific program or learning outcomes. The SME feedback was in turn used to further refine or develop concepts or techniques featured in the evolving product or identify future areas for expansion or development (e.g., a Virtual Maintenance Lab).

Accreditation requirements, such as those determined by ABET discussed previously, include, but are not limited to demonstrating an ability to (1) conduct experiments, and analyze and interpret data, (2) design systems, components, or processes, and (3) select and apply knowledge of mathematics, science, engineering, and technology to engineering problems. These are a concrete needs that are clearly defined. A more abstract need is the desire to increase the role of experimentation in the learning process as described by Kolb (1984). This latter idea is more oriented toward how distance (online) learning will be transformed using virtual environments and will only become more apparent once application occurs. This led the team to conceptualize three basic modules to meet these needs and objectives; a Bench Test environment, an Integration and Assembly environment, and a Flight Testing and Analysis environment.

The first module, the Bench Test, introduces students to the form, function, and dependencies of individual UAS components (e.g., sensors, data-links, and propulsion sources) in a virtual (simulated) environment. This environment and the available subject components are envisioned to provide students with the ability to explore essential factors through interaction and experimentation. The ability to isolate, control, and capture parameters, such as acceleration, rotation, power, thrust, signal strength and propagation are included. The interactive environment and capability provided within this module will support investigation of behavior of an accelerometer, communication payloads, infrared sensors, and power plant performance. These systems are modeled with a degree of fidelity, which allows the student to explore a wide breath of input parameters to UAS components in a sterile environment and to export the data from their experimentation for further analysis. The use of a sterile lab environment eliminates outside influences (i.e., manage extraneous control parameters) to the system and allows the student to develop an understanding of the operating theory of UAS components, without the undue influence of outside factors (e.g., environmental factors or interference).

Example interactions are depicted below in Figure 2 for a communication payload and Figure 3 for a power plant option. In each scenario, the student has the ability to select the component and several test parameters, such as distance from propagation source (see Figure 2) or revolutions per minute (RPM; see Figure 3). The examination of individual elements and manipulation of variable controls is used to satisfy Laboratory Learning Objectives (requirements) depicted in Table 1. For example, the student will need to design an experiment to match a particular flight profile, analyze and interpret data, and compare the results with models presented in their course work included in the LMS.

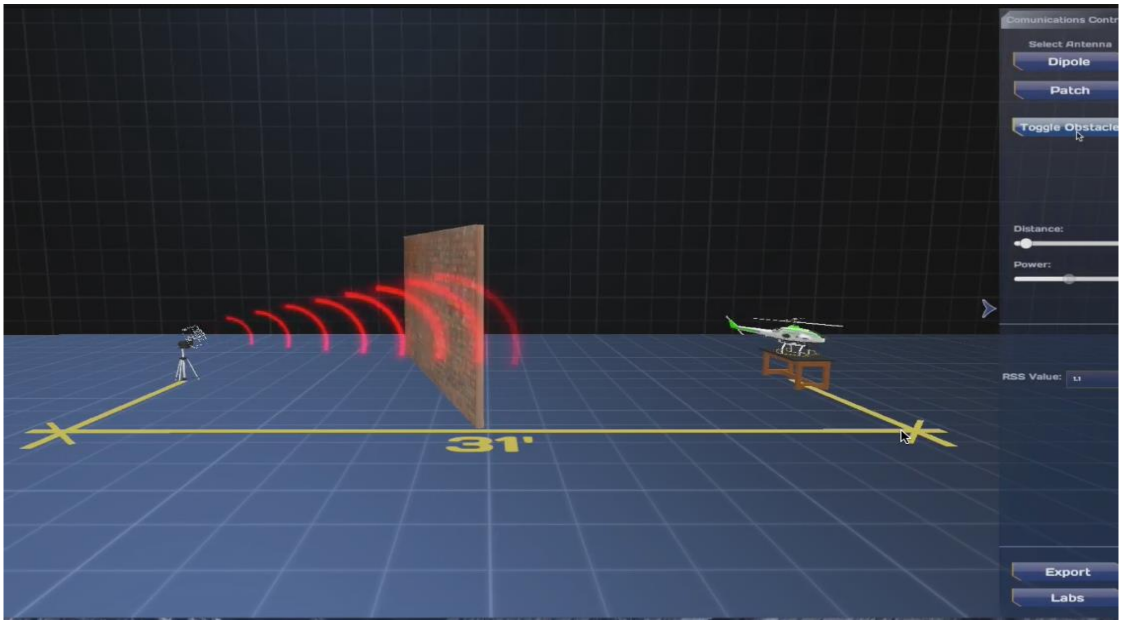

Figure 2. Communication experimentation in Bench Test environment

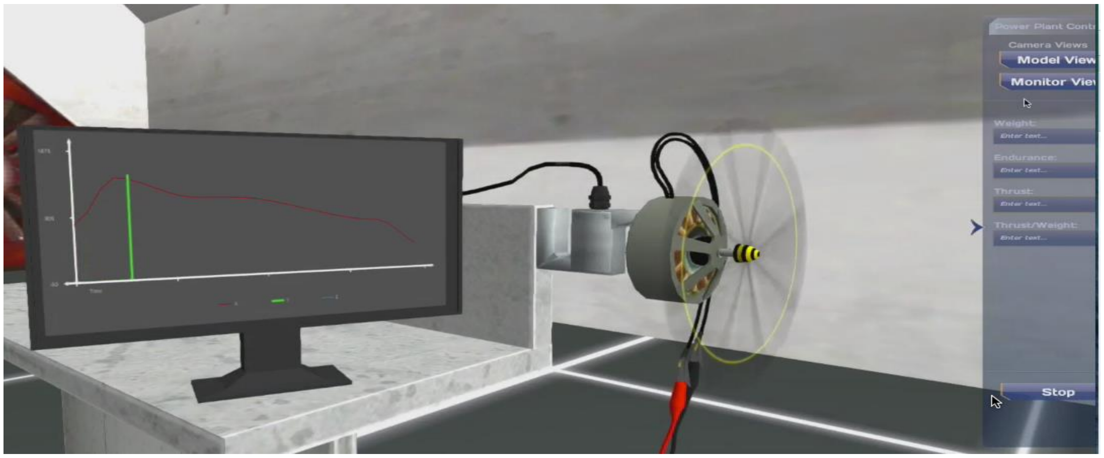

Figure 3. Power plant experimentation in Bench Test environment

The second module, Integration and Assembly, continues and expands experimentation capability through integration of individual elemental components and further manipulation of control parameters. Here the student selects elements of a basic aircraft subsystem configuration, such as the UAS power plant shown in Figure 4. Based on the performance requirements of a given project the student will select appropriate options to address propulsion, navigation, communication, and sensor needs. These can either be selected based on information gained in the previous model or as directed by the instructor. It will depend on the student's proficiency level (i.e., first year-undergraduate to graduate student) and project objectives. As depicted in the bottom of the figure, vehicle performance parameters are displayed. This module and the capabilities provided are used to address the design objective in Table 1 by enabling the student to conduct experimentation to gain an improved understanding of design trade-offs through exploration of the limits of the design space. As components are selected, metrics are displayed to the student relating their choice of components to the performance of the system as a whole. The selection of a particular power plant will affect performance parameters, such as range, speed, endurance,, and center of gravity. The selection of an electrical system (e.g., specific motor, speed control, and battery combination) will affect the ability of the system to simultaneously power a sensor suite and motor, decreasing the effective endurance and range of the system. The selection of components can be monitored by a virtual instructor or avatar. The avatar will provide guidance about components, based on the level of difficulty the environment has been launched in.

This guidance can range from preventing a mistake that would adversely affect the system, to no guidance at all. This instructor interaction provides a level of feedback crucial to learner success in a simulated environment, subject to specific rules and boundaries (e.g., game; Kapp, 2014).

Figure 4. Integration and Assembly environment

The third module, Flight Testing and Analysis, provides a unified simulated environment to perform flight testing, evaluation, and observation of the UAS performance as it relates to ability to operate as intended and configured. Figure 5 illustrates the flight test design space (i.e., experiment design as labeled in Table 1). The student is able to prescribe flight parameters, such as direction, speed, and waypoints featuring specific locations and altitudes, connected sequentially, within the available operating environment. System capabilities are based on vehicle and sensor payload performance and mission requirements. Static performance parameters of system components match those available to the student in the previous laboratory and assembly environments. Dynamic performance parameters, such as electrical draw, are calculated as the flight progresses and are based on the system configuration and use of the attached components. Figure 6 illustrates what the student sees when the flight test is in progress. In addition to elements such as experiment, described in Table 1, this activity addresses the "Learn from Failure" element since the prescribed flight plan may or may not meet the objectives. As learning to control a UAS system is not an objective of this module, all control of the UAS is conducted through an automatic waypoint system. The student chooses waypoints on a map view and sets an altitude and speed for each. The student can analyze a graph view of terrain height above mean sea level (MSL) and their flight plan (in MSL) to adjust inputs and retest accordingly.

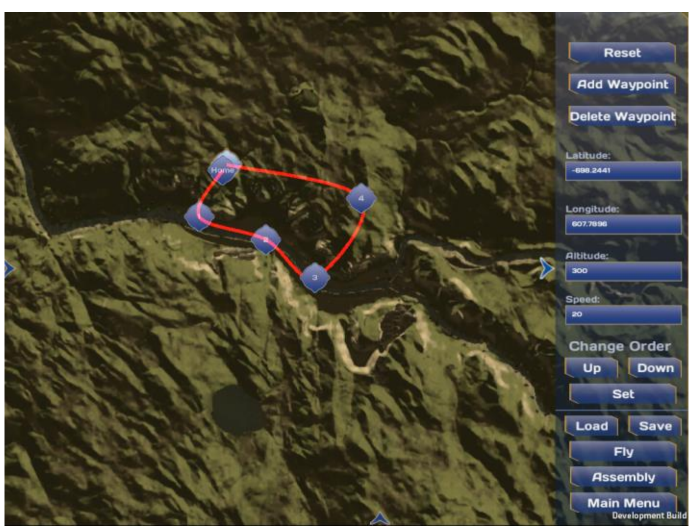

Figure 5. Flight planning in the Flight Testing and Analysis environment

Figure 6. Payload camera view and controls in the Flight Testing and Analysis environment

After the automatic flight plan has been completed the student is provided an opportunity to launch the UAS in the flight environment. Collision detection is implemented to detect flight into terrain or obstacles that would result in a crash indication to the student. The aircraft flight model navigates the selected waypoints using dead reckoning and applies smoothing to changes in aircraft heading and rotation. An exceedance of the flight envelope of the airframe will result in a crash indication to the student. As the aircraft flies the prescribed route the student is able to control the sensor package of their platform. The student can also toggle between optical sensors (e.g., color or infrared [IR] cameras) and control the slew of the sensor package. The performance of the platform, in the flight environment, is influenced by the student's choice of design. For example, electrical components with higher electrical draw will deplete available electrical power quickly and limit the ability of the UAS to perform a given task, while rapid changes in altitude will deplete fuel stores more quickly. The fidelity developed in the simulation is designed to demonstrate real-world applied consequences of design decisions to the student.

SUMMARY

Described within this paper is the design and development of a multiple-module, virtual aerial robotics laboratory for application to undergraduate and graduate level STEM courses. The modules include a component bench test environment, an integration and assembly environment, and a flight test and analysis environment. These modules can be considered as a toolbox to be used independently or in combination to address the range of capabilities of students and their project objectives. The laboratory is anticipated to enhance the learning environment and student experience through exploration, manipulation, design, application, and examination of individual component-level elements, integrated subsystems, and unique UAS configurations within virtual environments and modules. It is also expected to aid in satisfying accreditation requirements for pursuit of future programmatic accreditation. It provides the increased interactivity that can be utilized in the generation and development of future learning outcomes, activities, and goals, as well as provide the opportunity for the application of knowledge and skills within a structured learning environment.

ACKNOWLEDGEMENTS

The ARVL project team would like to express their gratitude towards all those involved in the funding and development of this project and the related ERAU Virtual Crash Lab, including Dr. John R. Watret (Interim President, ERAU), Dr. Brad Sims (Chancellor and Chief Academic Officer, ERAU-Worldwide), Dr. Katherine Moran (ERAU-Worldwide), Scott Burgess (ERAU-Worldwide), Jamie Sipe (ERAU-Worldwide), Becky Vazquez (ERAU), Brian Zipse (ERAU-Worldwide) and Michael Durant (Pinnacle Solutions). A sincere thank you is due to the ERAU-Worldwide SMEs who contributed to requirements analysis and development, including David Thirtyacre, Padraig Maloney, John Wilson, Dr. Robert Deters, Stefan Kleinke, Dr. Patti Clark, Dr. Bruce Conway, and Ted Thompson. Additionally, recognition is due to Ron Dionne, I/ITSEC Simulation subcommittee representative, for providing guidance and support as “birddog” for this paper.

REFERENCES

Abdulwahed, M., Nagy, Z.K. (2009). Applying Kolb's Experiential Learning Cycle for laboratory education. *Journal of Engineering Education, 98*(3), 283-294 Retrieved from https://dspace.lboro.ac.uk/2134/5412

Accreditation Board of Engineering and Technology. (n.d.). *Accreditation*. Retrieved from http://www.abet.org/accreditation/

Engineering Accreditation Commission. (2014). *Criteria for accrediting engineering programs*. Baltimore, MD: Accreditation Board for Engineering and Technology, Author. Retrieved from http://www.abet.org/wp-content/uploads/2015/05/E001-15-16-EAC-Criteria-03-10-15.pdf

Furse, C. (2011). Lecture-free engineering education. *IEEE Antennas and Propagation Magazine,, 53*(5), 176-179. doi: 10.1109/MAP.2011.6138460

Feisel, L.D., & Peterson, G.D. (2002). A colloquy on learning objectives for engineering education laboratories. *Proceedings of the 2002 American Society of Engineering Education Annual Conference and Exposition.*

Garner, I. (2000)., Problems and inconsistencies with Kolb’s learning styles. *Educational Psychology 20*(3), 341-348. doi: 10.1080/713663745

Hafner, K., (1983). Pointers on computer-based training. *ComputerWorld*, *17*(24), 63.

Hagg, S., & Palais, J. (2002). Engineering online: Assessing innovation in education. *Journal of Engineering Education,91*(3), 285-290. doi: 10.1002/j.2168-9830.2002.tb00705.x

Kullenberg, G. (2002). The Virtual University approach. *Ocean & Coastal Management, 45* (9-10), 709-718. doi:10.1016/S0964-5691(02)00095-9

Kapp, K.M. (2012). Games, gamification, and the quest for learner engagement. *TD Magazine*, 64-68. Retrieved from https://www.td.org/Publications/Magazines/TD/TD-Archive/2012/06/Games-Gamification-and-the-Quest-for-Learner-Engagement

Kapp, K.M. (2014). *The gamification of learning and instruction fieldbook: ideas into practice*. Hoboken, NJ: John Wiley & Sons.

Kolb, D.A. (1984). *Experiential Learning:Experience as a source of learning development*.. Englewood Cliffs, NJ: Prentice Hall. Retrieved from http://academic.regis.edu/ed205/kolb.pdf

Lagoudas, D.C., Whitcom, J.D., Miller, D.A., Lagoudas, M.Z., & Shryock, K..J. (2000). Continuum mechanics in a restructured undergraduate curriculum.*International Journal of Engineering Education*, *16*(4), 301-314. Retrieved from http://www.ijee.ie/articles/Vol16-4/IJEE1095.pdf

Muscat, M., & Mollicone, P. (2012). Using Kolb’s learning cycle to enhance the teaching and learning of mechanics of materials. *International Journal of Mechanical Engineering Education*, *40*(1), 66-78. Retrieved from http://ijj.sagepub.com/content/40/1/66.full.pdf

Stocia. M., Mircea, M., & Chiclic-Micu, B. (2013). Software development: Agile vs .traditional. *Informatica Economica, 17* (4), 64-76. Retrieved from http://www.revistaie.ase.ro/content/68/06%20-%20Stoica,%20Mircea,%20Ghilic.pdf

Tucker. C., & Moore, J. (2014). *Using Unity to implement a virtual crash site investigation laboratory in support of distance learning objectives* (Paper no. 14050). Paper presented at the Interservice/Industry, Training, Simulation and Education Conference, Orlando, FL.

Whittington, C.D., & Sclater, N. (1998). Building and testing a virtual university. *Computers & Education, 30*(1-2), 41-47. doi:10.1016/S0360-1315(97)00077-8