

A Virtual Instructor Service-Oriented Architecture for Teaching Robotics in Mixed Reality

Jayfus T. Doswell, Ph.D.
The Juxtopia Group, Baltimore, Maryland
doswellj@hotmail.com

Pauline H. Mosley, D.P.S.
Pace University, Technology Systems, Pleasantville, New York
pmosley@pace.edu

Abstract- One of the biggest challenges faced by most computer science educators is assessing whether a student comprehends programming and robotic design concepts. In this paper, we introduce the benefits of exploring new technologies for learning in the form of LEGO robotics and obtaining problem solving skills. Students use the LEGO (Mindstorms for Schools) Team Challenge kit #9790 in conjunction with a programming environment called ROBOLAB. Finally, we propose a Virtual Instructor as a mixed reality based instructional system that addresses these learning challenges and reduces the learning curve for robotics as well as enhances robotic instruction.

Index Terms- LEGOs, robotics, service learning, virtual instructor, virtual reality,

I. INTRODUCTION

Using robotics as an educational tool is growing in popularity. Students in computer science, engineering, psychology and other disciplines are beginning to have an interest in this field. To reinforce the material, it is necessary to complement classroom lectures with hands-on laboratory exercises. However, providing robot hardware to a large group of students may be cost prohibitive not to mention time intensive because of the time needed to learn programming and design techniques. In spite of these hurdles, using robotics is proving to be well worth the investment.

Robotics provides students with the opportunity to test the results of abstract design concepts through concrete, hands-on robotic manipulation [5]. Using robotics requires a conceptual shift away from learning from technology toward learning with the technology that is consistent with the "Mindtools" approach to problem-solving advocated by Jonassen [6]. In this learning environment, students often discover they need to learn new knowledge and continuously revise existing knowledge before they can begin solving problems.

One of the biggest challenges faced by most computer science educators is assessing whether a student comprehends programming and robotic design concepts.

Even though learners may have all the material from which to learn, they may still need guidance on how to use the material to crystallize ambiguous concepts and for out-of-classroom practice.

In this paper, we introduce the benefits of exploring new technologies for learning in the form of LEGO robotics and obtaining problem solving skills. Students use the LEGO (Mindstorms for Schools) Team Challenge kit #9790 in conjunction with a programming environment called ROBOLAB. We describe various LEGO robot construction tasks undertaken by any undergraduate student at Pace University in Pleasantville, New York. We then demonstrate the end products of their work-autonomous robots solving problems. Finally, we propose a pedagogical model Virtual Instructor that addresses these constituents and could thereby reduce the learning curve as well as enhance the robotic curriculum.

II. SERVICE LEARNING AND RELATED WORK

The first university to institutionalize service-learning is thought to be the University of Cincinnati (Varlotta, 1996). Since then many institutions have embraced the notion of linking college students to the community via service learning. According to Professor Jill Dardig she attempted to find a model for her course but was unable to locate anything similar, so she developed the course Urban Connections: Columbus Behinds the Scenes (Dardig, 2004). Professor Dardig seized the opportunity to help students explore in her course, the important links among academic disciplines and to take a more holistic and integrated view of their studies and the world. Mahendra Gujarathi and Ralph McQuade have established intellectual and pedagogical legitimacy for integrating service-learning in their Intermediate Accounting course (Gujarathi and McQuade, 2002). These professors of Bentley College revised their Accounting course to include a service-learning component in which students could offer professional assistance in: bank reconciliation, general ledger,

accounts receivable, accounts payable, etc. to local agencies. Likewise, Mark Stemen created a service learning component for his course, Nature and Society (Stemen, 2003). Regardless of the subject, more and more educators are seeing the value of service learning and redesigning their courses to include this vital component.

Although studies clearly indicate that alternative pedagogies (not lecture) are of great benefit to students, Siegfried, Saunders, Stinar, and Zhang (1996) report that an overwhelming majority of instructors still rely solely on the lecture mode of information transmission. A reexamination of the classroom paradigm is further motivated through the work of Phillips (1984). This research validated that we remember 10% of what we hear, 15% of what we see, 20% of what we hear and see, and 60% of what we do, 80% of what we do with active reflection, and 90% of what we teach. Well planned service-learning projects can take advantage of hearing, seeing, doing, and reflection activities. This paper presents a course that we have developed that reinforces robotic assembly principles through practice, i.e., teaching and that may be enhanced with a virtual instructor intervention. It is our hope that virtual instructors will apply principles from Phillips' research to assist robotic students retain conceptual and psychomotor (i.e., hand-on) knowledge.

III. CASE STUDY

The objective was to conduct a pilot study of students' problem-solving approaches to building and programming LEGO robots. Students self-selected themselves into collaborative teams of three or four. The students were asked to record their problem-solving approaches in a reflective logbook during the building and programming of their group's robot. Video was used extensively to capture various stages of robot construction. Qualitative methodologies were implemented to obtain an understanding of the complexities associated with robotic technology. The objective was to further improve the human aspects of robotic utilization: ease of learning, ease of use, and the impact of robotic design construction.

This study was implemented in the spring of 2006 and the fall of 2006. There were 27 students enrolled in the spring semester and 28 students in the fall. This study seeks to generate an understanding of how robotic learning among 56 students takes place and the complexities associated with the learning process; the study chose this approach rather than testing a set of hypotheses. Thus, this study can be classified as interpretive rather than positivist in nature.

A. The Students

The participants for this study ranged from senior undergraduate students to first-year graduate students with varying majors. The goal was to obtain a representative cross-section of majors with varying levels

of LEGO experience and expertise from which meaningful data for the study could be derived. Students representing various training backgrounds, genders, ethnicities, and various cultures were sought to provide a variety of different perspectives regarding the use of robotics.

Table I gives a detailed breakdown of the students and their experience with LEGOs. Students representing various training backgrounds, genders, ethnicities, and various cultures provided a variety of different perspectives regarding the use of robotics. The classroom dynamic was further enriched by participation from students of varying majors and varying ranks.

TABLE I.
Student LEGO Experience (n=56)

None	Novice	Moderate	Expert
48%	27%	17%	8%

B. The Course

The course consisted of one instructional component: open laboratory. Students were instructed throughout the laboratory session on how to construct and program the robot. Students were placed into groups of 4 and each group was given a LEGO kit. Two members of the group were responsible for constructing the robot and other two members were responsible for programming the robot. Roles were rotated among the group members such that all parties had an opportunity to learn each phrase of robotic construction and assembly. This informal environment provided students with hands-on experience with building and programming robots. The course consisted of five laboratory exercises. Each of the exercises required two to three lab sessions to complete.

C. The Laboratory Exercises

The five lab exercises were designed to be fun while yet challenging the students to think as team and develop solutions. Lab No. 1 was designed to acquaint students with the 500+ pieces accompanying the kit. Students were instructed to build a building utilizing any 12 LEGO pieces. The team with the highest structure having undergone the wind, paper, and water tests would be declared winner. The wind test consisted of a small fan blowing air at full-speed on the structure. The paper test consisted of dropping little balls of paper onto the structure to simulate snow. The last test, the water test, was spraying the structure with water blasts from a bottle. Table II depicts all of labs covered in the course.

Lab number one took one session to complete, labs two, three, and four took two sessions to complete and lab five took three sessions to complete. Lab two was clearly the favorite lab of most students. They enjoyed designing their own robotic drag-cars and racing them. Lab four was the most difficult one for teams to complete.

TABLE II.
Student Lab Exercises

Lab	Title	Objectives
1	Skyscraper	<ul style="list-style-type: none"> To become familiarized with the LEGO pieces and their functionality. To learn the names of the assorted building elements. To investigate the various manners in which the elements can be combined.
2	Cars	<ul style="list-style-type: none"> Construct a chasis using plates, beams, and connectors.
3	Racing	<ul style="list-style-type: none"> To become familiarized with gears, gear ratios. To understand the relationship between gears and motors in regards to acceleration.
4	Sensors	<ul style="list-style-type: none"> To become acquainted with the light and touch sensors. To learn the advantages of sensors.
5	Talent Show	<ul style="list-style-type: none"> To design a problem and develop a solution using all the skill sets covered in class.

IV. QUALITATIVE RESULTS

The research involved a longitudinal quasi-experimental design to study how the combination of a facilitator and teaching strategy impacted students' comprehension of robotic design and programming. Longitudinal research provides important opportunities to investigate cognitive complexities associated with robotic concepts.

At the beginning of the study, a pretest questionnaire was distributed to all the students enrolled in Problem Solving Using LEGOS during the second week of the semester. The objective of this questionnaire was to collect measures such as background information, programming and robotic experience, and the subject's current experience with LEGOS.

Data was collected in the following fashion: students were required to complete a lab report for each lab exercise. These documents would aid in measuring the degree or depth at which each knowledge unit was taught. In addition, students were given a comprehensive exam after completing two laboratory exercises.

TABLE III
Frequency of the Predominant Themes From Respondents

Percentage of Times the Themes were Identified in the Responses	Percentage of Responses*
Becoming familiar with LEGO pieces	92%
Learning the mechanics for building a structurally sound chassis	94%
Obtaining hands-on experience and practice	83%
Learning the diagrammatic tools for programming and controlling the RCX via ROBOLAB	74%

*=Respondents report opinions on this experience, inclination, or belief

Lastly, a post-experiment test was distributed to the students at the end of the semester. The measures collected were the same as the pretest measurements to evaluate the differences before and after the study.

The results from this study identified four areas that make learning robotic concepts and programming difficult. They are:

1. *Becoming familiar with various pieces of LEGO robotic kits.*
2. *Learning the mechanics for building a structurally sound chassis.*
3. *Obtaining hands-on experience and practice.*
4. *Learning the diagrammatic tools for programming and controlling the RCX via ROBOLAB*

V. PROPOSED MODEL: VIRTUAL INSTRUCTOR MIXED-REALITY ENVIRONMENT

Researchers investigated how intelligent virtual instructors within mixed-reality environments facilitate guided pedagogical approaches for teaching robotic concepts and for applying science, technology, engineering, and math (STEM) skills for learning hands-on robotic skills.

The term *mixed-reality environments* defines various types of real-to-virtual human computer interfaces defined in Milgram's mixed-reality continuum as illustrated in Figure 1 [9]. In *augmented reality*, digital objects are added to the real environment. In *augmented virtuality*, real objects are added to virtual ones. In *virtual environments* (or virtual reality), the surrounding environment is completely digital.



Figure 1. Milgram's reality-virtuality continuum.

A. Virtual Instructor Subsystem

Virtual instructors are intelligent pedagogical agents with the option of being displayed as embodied characters or conversational interfaces [3] that use the best instructional method for tailoring instruction to the best way a human learns. Hence, the virtual instructor provides a personalized human learning experience by applying empirically evaluated and tested instructional techniques (i.e., pedagogy, andragogy) that may be exemplified by an embodied (e.g., 3D-animated character or robot) or non embodied form. In order to serve as an effective learning intervention, the virtual instructor must combine the knowledge of "master" instructors that possess expertise in specific academic/knowledge domains, understand how humans learn, and effectively

deliver instruction based on their location or the environmental context at which the learning takes place (e.g., *outdoors, museum, classroom, etc.*) [6].

In our research, we investigated how virtual instructors apply empirically tested pedagogical techniques of scaffolding. Scaffolding is an instructional technique formulated by Lev Vygotsky's socio-cultural theory in which a teacher breaks a complex task into smaller component tasks, models the task, and create links to students' existing knowledge. Scaffolding supports students in their learning until they are ready to pursue a task independently [1]. Thus, by using scaffolding pedagogy, the virtual instructor automatically provides gradually decreasing guidance ("crutch") until the student is ready to independently learn and apply previous learning to address new challenges. The virtual instructor guides students in a combination of virtual reality and augmented reality based training simulations providing a multi-modal learning environment to support the visual, auditory, kinesthetic, and tactile learner understand complex and ambiguous robotic conceptual and construction tasks (i.e., psychomotor tasks).

B. Virtual Instructor in VR

During robotic conceptual learning, a student may interact with a virtual instructor, which has a pedagogical purpose to provide effective instruction to increase conceptual learning and increase robotic construction accuracy and assembly task repeatability. The virtual instructor uses its mixed reality delivery method to teach fundamental components used to build mobile robots. The components in virtual reality environments are computer simulated three-dimensional (3D) models and animations that include, but are not limited to gears, gear combinations, motors, sensors, and sensor rotation. In the virtual reality environment, the virtual instructor applies the pedagogical technique of scaffolding to step a new learner through the process of robotic component assembly and gradually decreases the instruction as it assesses that learning progress is being made.

C. Virtual Instructor in AR

To create the bridge between applying concepts learned in the virtual reality environment to hands-on exercises in the real world, we applied preliminary research on how wearable mobile augmented reality (AR) systems may provide both decision support and hands-on assembly assistance [3][4]. To enhance learning performance and robotic assembly accuracy, students could wear AR based lab goggles equipped with speech recognition, object recognition, and instructional services.

Figure 2 provides a schematic view of goggles along with its embedded sensors. Researchers designed intelligent AR based goggles using on-board sensors including cameras, microphones, speakers, and several inertial sensors. The camera sensors provide the virtual instructor with a visual display of the robotic components that need to be assembled. The microphone sensors provide the virtual instructor with a method to collect

human speech (speech input). The speaker sensors provide a method for the virtual instructor to speak instructions to the student. Together, the microphone and speaker sensors facilitate real-time interaction between the human and virtual instructor using advanced speech recognition and speech synthesis. Inertial sensor supports the collection of head movements, orientation, and distance to assist with AR based tracking and registration, which are two of the most challenging areas in augmented reality research.

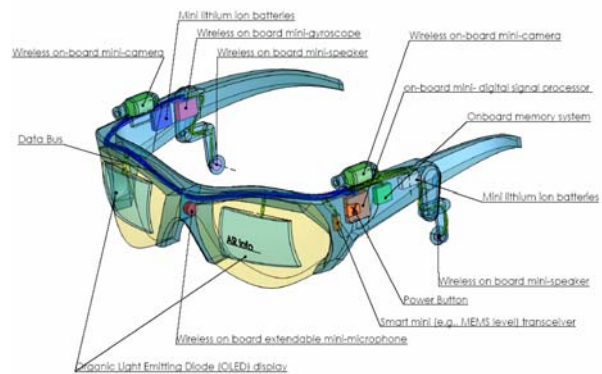


Figure 2. Mobile augmented reality head mounted display.

While wearing these intelligent AR goggles, students could be provided guidance from the virtual instructor on the step-by-step process to assemble gears, motors, and sensors during robotic construction tasks as defined by the LEGO exercises. To assist the student, the AR goggles could serve as an intelligent human computer interface by annotating robotic components with graphical guides to illustrate the connectivity and rotation paths for assembly. Because robotic assembly requires two hands, the goggles could provide a hands-free computer interface by supporting speech interactivity with the virtual instructor guide.

VI. VIRTUAL INSTRUCTOR ARCHITECTURE

For an effective virtual instructor delivery system through mixed reality environments, an extensible, interoperable, modular, and scalable software/system architecture model is required. Research was conducted to design such architecture, the Context Aware-Agent Supported Augmented Reality System (CAARS). The CAARS architecture was originally developed for virtual instructor guidance through augmented reality but has been recently extended to support virtual reality instructional mediums.

As indicated in Figure 3, the CAARS architecture is designed as service oriented architecture (SOA) made up of several subsystems that provide visual display, conversational interaction, and training services. The CAARS-SOA also applies principles from product oriented architecture approach that defines kernel (i.e., required) and optional components that may be selected

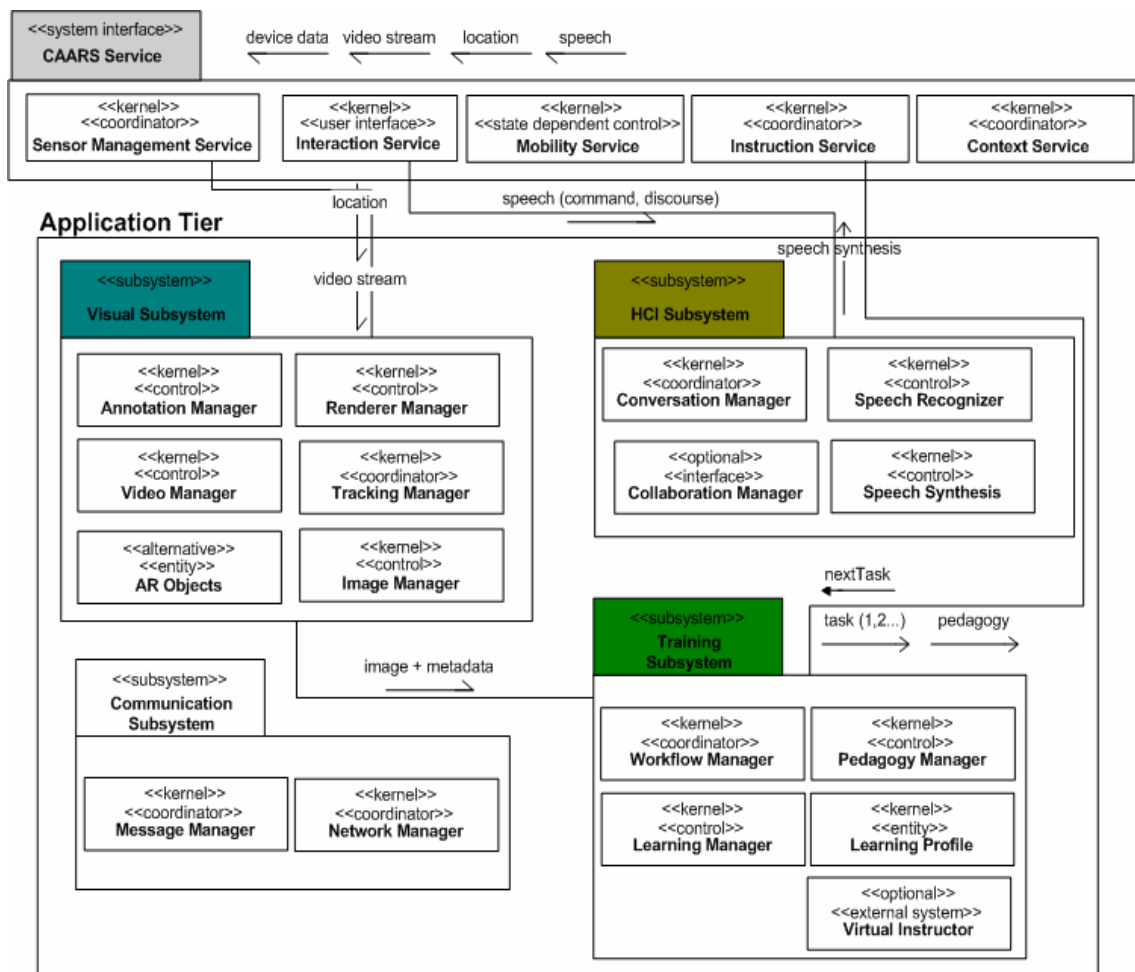


Figure 3. CAARS High Level Architecture

for a target virtual instructor mixed reality (VI-MR) system. This allows an “a-la-carte” type of component selection based on the requirements of a target VI-MR system. These <<kernel>> and <<optional>> notations are illustrated at the top of each component within each subsystem as illustrated in Figure 3. The CAARS-SOA describes a software architecture that defines the use of loosely coupled software services to support the requirements of robotic instruction and the underlying software components that orchestrate to provide virtual instructor services through mixed reality. The CAARS service layer includes an application programming interfaces (API) that encapsulate lower level objects allowing for improved software algorithms (e.g., instructional algorithms, speech recognition, object recognition, etc.) to be continually implemented to further enhance CAARS. The visual subsystem delivers AR based services (i.e., object recognition, tracking, registration; and digital annotation) and VR based services (e.g., 3D graphic rendering). The human computer interface (HCI) subsystem controls speech recognition and speech synthesis services that enable hands free and more natural interaction between the student and robotic training system. It also is designed to process and understand gesture communication. The

Conversation Manager is a coordinator software component within the visual subsystem that manages various types of conversation modalities currently available with voice. The *Collaboration Manager* is an <<optional>> component that, if selected for a target VI-MR system provides the capability of facilitating communicating between two or more students interacting with virtual reality or augmented reality. The Training subsystem utilizes a combination of underlying software agents and pedagogical models (e.g., scaffolding) to guide a learner understand concepts and perform step-by-step procedures for completing tasks. To facilitate this functionality, the training subsystem contains software agents that intelligently control the administration of training scenarios in both virtual and augmented reality methods [2].

As illustrated in Figure 3, the CAARS SOA is designed to be decoupled and accept data types from various types of virtual reality an augmented reality supported devices including: device data, video stream/image data, user/object location, and speech. Once received, an input manager identifies the data type, attaches meta data, and then routes the data to the appropriate aforementioned subsystem for processing. With this CAARS SOA design, continuous research may

be conducted to investigate the what algorithms, components, agents, and events are required to provide the best user interface to, consequently, facilitate the most effective instruction for individual students, particularly with robotic instruction.

VII. SUMMARY AND FUTURE DIRECTIONS

The research findings suggest many directions for future research. First and foremost, additional field studies will be needed to validate, refine, and extend the findings of this study. Finally, the model will be rigorously classroom-tested for aspects of its effectiveness. These tests would verify the validity of the model's superiority over more traditional or other computer based instructional models.

In summary, this study explored the learning acquisition of robotic concepts among Pace University undergraduate students using a qualitative field-study approach. The evidence gathered suggests that in acquiring problem-solving skills students often discover they need to learning new knowledge and continuously revise existing knowledge before they can begin solving problems. We feel that learning in a mixed-reality training environment will lessen the learning curve and decrease cognitive complexities associated with this paradigm.

In the future, researchers plan to advance the virtual instructor guided mixed-reality learning intervention with the capability of tailoring instruction to student's learning profile that is automatically updated based on virtual instructor scaffolding results. Additionally, researchers plan to conduct longitudinal studies to measure student's learning performance of applied STEM skills while learning both robotic concepts and assembly exercises. Lastly, researchers plan to incorporate a monitoring function to monitor the progress of learning for both individualized and collaborative learning during classroom exercises.

REFERENCES

- [1] Baker-Sennet, J. & Hamison, G., Teaching and Learning in the zone of proximal development. In J. Andrews (Ed). Teaching students with diverse needs. Nelson, Toronto: Nelson Canada, 1996, pp. 206-219.
- [2] Blake, B. and Doswell, J. "Context-Aware Augmented Reality System (CAARS)". SALT New Learning Technologies Conference. February 2006.
- [3] Dardig, J., "Urban connections: A course linking college students to the community", *College Teaching*, 2004, 52(1), 25-30.
- [4] Doswell, J. , "It's Virtually Pedagogical: Pedagogical Agents in Mixed Reality Learning Environments", 32 International Conference on Computer Graphics and Interactive Technologies (SIGGRAPH) Conference 2005, Education Forum, Los Angeles, California.
- [5] Doswell, J., Blake, B., Green, J., Mallory, O., Griffin, C. "Augmented Reality Learning Games: 3D Virtual Instructors in Augmented Reality Environments", IC3D 2006 Symposium on Interactive Computer Graphics and Games. EA Redwood City campus, March 2006.
- [6] Druin, A., Hendler, J., Robots for kids: Exploring new technologies for learning, San Diego, CA: Academic Press, 2000.
- [7] Gujarathi, M. R. and McQuade, R. J., Service-learning in business schools: A case study in an intermediate accounting course. *Journal of Education for Business*, 2002, pp. 144-150.
- [8] Jonassen, D.H., Computers as Mindtools for schools: engaging critical things (2nd ed.). Upper Saddle River, NJ: Prentice Hall, 2000.
- [9] Milgram, P., F. Kishino, "A Taxonomy of Mixed Reality Visual Displays." *IEICE Transactions on Information Systems*, 1994, E77-D (12): 1321-1329.
- [10] Pace University Project Pericles (n.d.). Retrieved November 14, 2006, from http://appserv.pace.edu/execute/page.cfm?doc_id=16610
- [11] Phillips, G. (1984). *Growing Hope*. Minneapolis, MN: National Youth Leadership Council.
- [12] Siegfried, J. J., Saunders, P., Stinar, E., and Zhang, H. (1996). Teaching tools: How is introductory economics taught in America? *Economic Inquiry* 43 (January), 182-192.
- [13] Stemen, M. (2003). Keeping the academics in service learning projects, or teaching environmental history to tree planters. *The History Teacher* 37 (1), 73-78.
- [14] Varlotta, L.E. (Fall 1996). Service-learning: A catalyst for constructing democratic progressive communities. *Michigan Journal of Community Service-Learning* 3, 22-30.

Jayfus T. Doswell is board chair of The Juxtapia Group, Inc., a non profit organization that conducts interactive learning technology research for improving the learning proficiency of underserved and disadvantaged populations. Dr. Doswell is also co-director of the IEEE virtual instructor pilot research group (VIPRG) www.viprg.org, a 30 member international research group for developing a standard for building virtual instructors for various interactive learning environments. Dr. Doswell secured a Ph.D. in Information Technology from George Mason University and has spent six years researching, designing, and developing virtual instructors and what he defines as a "pedagogical embodied conversational agents"(PECA). He continues to collaborate with the researchers from the VIPRG towards developing an international virtual instructor standard. Dr. Doswell is also president/CEO of Juxtapia, LLC, a biomedical and information technology company that develops products and services to improves human learning and health performance

Pauline Mosley is an associate professor in the Technology Systems Department at Pace University. Among the courses she has taught since joining the technology systems faculty in 2001 are problem solving using LEGOs, web design for non-profit organizations, and introduction to computers. She has written articles on robotics, web design, and service learning. She is the recipient of the Award for Teaching Excellence from Who's Who Among America's Teachers. She holds a D.P.S. from Pace University where she studied cognitive factors that are likely to impact object technology adoption or implementation.