uCollaborator: Framework for STEM Project Collaboration Among Geographically-Dispersed Student/Faculty Teams

Stephen M. Fiore
University of Central Florida

Walter E. Rodriguez
Florida Gulf Coast University

Deborah S. Carstens
Florida Institute of Technology

Abstract

This paper presents a framework for facilitating communication among STEM (Science, Technology Engineering and Math) project teams that are geographically dispersed in synchronous or asynchronous online courses. The framework has been developed to: (a) improve how engineering and technology students and faculty work with collocated and geographically-dispersed teams; and (b) to connect the physical and virtual worlds. The research addresses the distributed network for: (1) conducting research in STEM-team collaboration; (2) creating an open team collaboration infrastructure; and (3) evaluating design prototypes for transferring technologies to commercial developers, application service providers, licensees or manufacturers. As a proof-of-concept and framework assessment, teams of students and faculty developed various design prototypes using "paper" modeling, geometric modeling and visual simulation methodologies

I. Introduction

This research explores a new framework for delivering online courses that connect the physical and virtual worlds both synchronously and asynchronously. As part of this effort, the authors have developed a simulated prototype system, labeled uCollaborator, to integrate the best practices from the science of teamwork with the latest in visual simulation and sensor-based technologies. The uCollaborator framework and simulated prototype platform (Figure 1) was developed to improve distributed teamwork (i.e., teamwork occurring when project-team members are geographically dispersed and often interacting at different times). The objective is to enhance STEM (Science, Technology, Engineering, and Math) collaboration and project team performance via the integration of visual simulation, networked sensors, distributed data acquisition, and voice recognition technologies (http://www.fgcu.edu/wrodriguez/uCE/).

II. Industry Need and Outcome

Distributed teamwork continues to impact global competitiveness as collaboration across time and space becomes increasingly frequent in the workplace (Fiore, Salas, Cuevas, & Bowers, 2003). Yet, there have not been any computer-aided design (CAD)/computer-aided manufacturing (CAM), or other engineering design graphics technologies that have been fully developed or integrated for design collaboration— that is, collaboration linking both geographically distributed designers and data, information and graphic information (i.e., images, pictures, graphs, diagrams, videos). While there is a plethora of groupware products on the market, coordinating design-work in an efficient

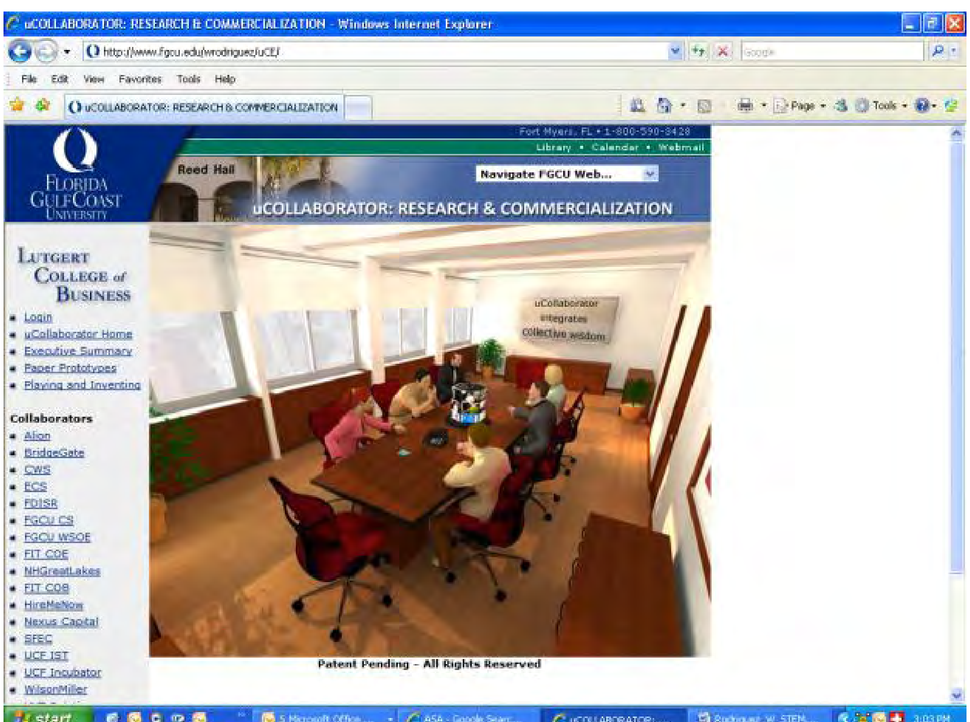

Figure 1. uCollaborator Simulated Prototype.

and effective manner continues to be a major challenge for both public and private organizations. Currently collaboration is supported in piecemeal fashion by technologies such as groupware (i.e., electronic bulletin boards, chat systems, CAD, visualizations, document-sharing, virtual multiplayer gaming and video- and teleconferencing, among other technologies) designed to support communication and coordination activities among distributed coworkers. Additionally, none have leveraged the potential utility of visual simulation to externalize cognition (Fiore et al., 2010) and distributed or embedded sensor technologies for supporting real-time design collaboration. Thus, a ubiquitous collaboration system still remains to emerge, particularly one that effectively integrates visual tools and methods arising out of STEM, modeling and simulation, and the organizational and behavioral sciences.

The research challenge is to develop intuitive and visually-based technologies in an open infrastructure that would support high-performing STEM project teams who deploy their creativity, knowledge, organizational skills, and verbal and visual thinking to achieve results (Fiore, 2008). These verbal and visual communication challenges exist regardless of the team or industry, but they are particularly relevant to architecture, science, engineering, technology, mathematics, construction, maintenance, product/system/process design, manufacturing, and life-cycle management, among other fields.

III. Overview

The workplace (or STEM edu-space) of the future is rapidly evolving into distributed workgroups (or study groups) that overcome the barriers created by geographical distance and time. Unlike current verbal and visual communication systems, such as HP Halo or Cisco Telepresence, the uCollaborator simulated prototype system connects the virtual and physical worlds using visual simulation and distributed sensor technologies. The integration of the virtual world via simulation and the physical world via sensor technologies with collaboration tools provides a mechanism to add content, expertise, and virtual or replacement team members to support the dynamic solving of complex problems—anywhere and at any time. The uCollaborator framework and simulated prototype environment embeds the following characteristics and capabilities:

(1) Integration of visual simulation—This is a web-based feature that has been developed by the first author (Rodriguez, Opdenbosch, & Santamaria, 2006). In this new research (Rodriguez, Fiore, & Carstens, 2009), additional work has been undertaken to facilitate correlated interoperation and expansion of features on a variety of platforms, including mobile computing and telephony devices. Furthermore, the researchers are developing powerful visual data acquisition and database connectivity features.

(2) Distributed Network Sensors—These capabilities provide for embedded and networked sensors to improve team decision-making performance and help characterize and reduce the risks, uncertainty and variability that often arise when real-time data is not provided to a decision maker (i.e., dashboards displaying the data and information).

(3) Team Performance Improvement system—These process scaffolding capabilities provide portable visualization tools that help to externalize cognition (Fiore et al., 2010; Zhang, J., & Norman, D., 1994) to augment dynamic problem solving and decision making to improve performance. Specifically, these features integrate distributed sensors with team interaction scaffolds to support process and performance.

(4) Automated Voice Recognition and Digital Stylus (Këpuska, 2002).

(5) Usability Evaluation tools to ensure that readability, comprehension, and clarity of written and visual information are exchanged to enhance virtual team performance.

IV. Conception to Implementation

The new ubiquitous collaboration technologies will potentially transform the traditional workplace into an efficient and effective STEM project team-space. uCollaborator is the first simulated prototype system to address geographical and temporal fragmentation as well as data collection, data distribution, and data visualization via remote networked sensors, visual simulations, and voice recognition, among many other functions. As shown in Figure 1, while accessing and receiving real-time data embedded in the physical world, users (real or virtual) "see" all the team members as they chat synchronously (at the same time) or query each other asynchronously (at different times), working together towards a solution of a complex problem and arriving at a collective decision.

The following is a scenario to help explain the simulated prototype system: *It is the year 2015. Dr. Cynthia Wells, Project Manager for AEC International Inc, is working intensively at her Application Service Provider (ASP) proxy office in Kuala Lumpur where she will be meeting with a potential client for her engineering consulting firm. Suddenly, she receives a voicemail alert on her system notifying her that the stability sensors in Storage Silo 7 of her company's new power plant being built in Madrid, Spain, have indicated a problem. She accesses the data using her system and requests an up-to-date time-series graph from the sensors at that silo. Upon inspection she sees there has been increasing pressure at the base of this silo and that it could approach critical levels within days if not addressed immediately. She uses the system broadcast voice feature to send an urgent message with the graph to select members of her engineering team on-site and distributed throughout the world. Using her index finger, she annotates it with the system's markup feature to highlight the critical data and schedules a meeting in 30 minutes to diagnose and assess the problem. She next accesses her company's centralized Madrid database. Real-time sensor data is fed to her display screen indicating changes in stability across several of the silos. Additional visualization data from the on-site weather sensors provide readouts of moisture, temperature and precipitation in the immediate vicinity. Construction schedules and project tasking are additionally accessed. Her system notifies her when the remote team has virtually assembled and they prepare to discuss the situation. In addition to the graphics presenting the data, on-site cameras provide visual inspections of the site and her team's desktop system includes video display of her dispersed team members. This virtual team includes their Madrid site's construction manager, Julio Medem, along with their on-site safety inspector, Adei Santurtzi. Also included is her company's resident expert in structural engineering, Dr. Susan Hoover, currently in Tennessee where she has been contracted to oversee the TVA's annual dam inspection. Lastly, she invites her company's political consultant, Wilson Brookings, located in Washington, a member of the team brought on due to problems with Basque separatists operating in the city of Madrid in recent years.*

In Nashville, Dr. Hoover points to an anomalous data point in Silo 39's sensor J17, presented in tabular format to the team. The system's dynamic deictic gesture projection system indicates to her distributed teammates the table in question by highlighting that portion of the screen and overlaying the pointing icon in that section of the grid. As Dr. Hoover sweeps her hand across one of the rows of the table while explaining her concern about this data, the deictic gesture projection system similarly provides a graphical representation of this motion. During this discussion, Dr. Wells notes that her on-site project manager looks haggard even though the system tells her that it is only 10:00am in Madrid. She can tell by his lack of focus that he is clearly distracted by something. She uses the system private talk feature to ask him if there are any problems. On pressing this matter she finds that he has spent the morning dealing with a problem with the suppliers of their silo arches. He states that their credentials seemed questionable to him and, when he confronted them, they caused a disturbance. With this added information Dr. Wells goes back to the meeting mode and informs her team. Dr. Brookings uses the system to initiate an immediate web search of private and public databases related to Basque separatists' activity in the region. The Safety manager, Adei Santurtzi, was on-site instead of in her office, and has been participating using her system handheld foldable device. She uses the inventory search function for this project to access the main office database and determine the required arch load capacity for these silos and to determine whether these match what has been delivered. Upon noting a difference she goes back to meeting mode and interrupts Dr. Hoover to explain the difference and asks whether silo arches at this load capacity could cause this problem. After some discussion, the team decides that this is a distinct possibility. Dr. Brookings comes back and displays an article form Cinco Dias, the Madrid business paper, that states that some elements of the separatist movement have been increasing their construction-sites sabotage through indirect means. Dr. Wells requests a cross-check of this supplier to determine if there is any potential linkage to separatists and orders an immediate stop and inspection of all silos.

Physical and Logical Design: The uCollaborator simulated prototype system may be manufactured in different sizes and configurations. For instance, a basic conference room table-top unit may be visualized as a flattened cylindrical shape where the sides are standard LCD panels or foldable (collapsible) LCD segments (similar to iPhones connected in parallel side-by-side). In Figure 1, the uCollaborator processing unit is located in the middle with a protruding telescopic post holding a 360-degree camera projecting the image of team members (real-time image). For users in a different time zone, the simulated system provides asynchronous mode capabilities by storing prerecorded video or avatar simulations. Such avatars may be a way to help build cohesion for when work is asynchronous. At a rudimentary level, these avatars could simply embody the work that has taken place earlier in support of distributed cognition. For example, for team members collaborating asynchronously, one's actions can be instantiated in an avatar for when another team member begins work (e.g., interaction with the system tools can be recorded; one can make audio recordings of annotations to the work). At a more sophisticated level, an avatar might be endowed with personality traits of a team member. Currently, online personalities can be gleaned from behavior. For example, recent research by Nick Yee at the Palo Alto Research Center found that real-world traits are discernable from activities in virtual worlds (Yee, Ducheneaut, Nelson, & Likarish, 2011). From this, then, it may be feasible to create personality profiles for avatars of team members. These, then, could behave accordingly in the simulation. For example, from the interpersonal standpoint, the avatar could be endowed with the demeanor of the team member such that teammates who know each other could still have some sense of connection despite the asynchronous nature of their work. Users may be able to select the way video images and workspace visualization data are displayed on the LCD screens. For instance, teams at various sites may be selected to appear on rings (bands) of the display (so that anyone seating on opposite sides of the table will be able to see the participants at various locations.) This simulated tabletop unit may be located in the center of the conference table (at each locale) with business executives around the table or against a wall. The tabletop system has a handle for easy transportation, while the smaller portable devices look similar to laptops or interconnected (foldable) PDAs with a built in telescopic camera.

Architecture: The uCollaborator simulated prototype provides a ubiquitous (anytime, everywhere) environment realized through mobile and fixed technologies and scaffolded by group support software (groupware). The core of this integrated platform is a collaboration engine consisting of an architecture that supports both generic collaborative processes and with task-specific team processes instantiated through a sophisticated suite of advanced modular technologies. This uCollaborator simulated system drives dynamic and real-time collaborative problem-solving and decision-making by integrating sensor and human data from the physical world on location in the field with groupware that efficiently and effectively manages team interaction.

Concept	Components
Technology	Visual Simulation Sensors Mobile/Hand-held Automated Voice Recognition Usability Evaluation Tools
Process	Forming-Storming-Norming Decision Making and Problem Solving Communication and Coordination
Content	Data from Sensors Graphic/Visualizations on Simulation Text/Images supporting any of the processes above

Table 1: uCollaborator's Components

The authors are pursuing a systematic program of research and development in order to seamlessly integrate extant theory on team process and performance (Salas, Fiore, & Letsky, 2012) with developing technologies. Table 1 lists how we are conceptualizing our technology development plan and illustrates that, for distributed collaboration to succeed, what is required is recognition that technologies, processes, and content all need to be integrated.

While some of these technologies exist, they are either underutilized or used in a piecemeal fashion, and a significant amount of applied research and development needs to be done to fully integrate them with distributed collaboration technologies.

To recap, the uCollaborator characteristics and capabilities are:

(1) Integration of visual simulation, a web-based feature that has been developed by the first author with NSF funding and further implemented by partner companies, such as XYZ Solutions Inc. However, additional R&D will be undertaken to facilitate correlated interoperation and expansion of features on a variety of platforms, including mobile computing and telephony devices. Furthermore, we have already developed powerful data acquisition and database connectiv-

ity features that will be integrated with the uCollaborator.

(2) Distributed Supply Network capabilities, which may provide supply-chain management (SCM) collaboration tools and associated networked sensors to improve team decision-making performance and help characterize and reduce the risks, uncertainty and variability associated with the local, regional and global supply-chain of products and services.

(3) Team Performance Improvement, providing portable tools to support distributed team processes and feedback for improvement.

(4) Automated Speech Recognition.

(5) Usability Evaluation tools to ensure that readability, comprehension, and clarity of information is exchanged to enhance virtual team performance.

It should be noted that none of these features are available in current collaboration software systems. The uCollaborator simulated system is based on theories of externalized cognition (Fiore et al., 2010), such that it supports visualizing quantitative and qualitative data (via integrated dashboards), information, and tacit knowledge; radio frequency identification techniques; sensors and network communications; and adaptive (sense-and-response) systems, among other technologies.

Student Involvement: uCollaborator is based on an NSF-sponsored R&D efforts that involved hundreds of students, particularly in the testing and evolutionary construction of working prototypes of the Construction Visualizer system (Rodriguez et al., 2006). The system later evolved into the 3D nViewer system that XYZ Solutions Inc markets. Succinctly, Visual Simulation is a web-based uCollaborator feature that has been fully developed with NSF funding and commercialized. New research is being undertaken to facilitate correlated interoperation and expansion of features on a variety of platforms, including mobile computing and telephony devices. A client server architecture is envisioned as a research (and possibly production) platform to investigate and optimize several visualization questions principally brought about due to multiple users employing heterogeneous hardware and software platforms.

Research and Development Tasks: To solidly ground the uCollaborator R&D efforts, we differentiate between tools that support the collaborative process and those that support training and development. uCollaborator is designed to support a range of these functions, each of which is critical to effective teamwork. First, from the standpoint of supporting the collaborative process, uCollaborator's visual simulation capabilities and sensor integration methodology provide a truly unique capability—that is, an important virtual context and real-time data to support complex problem solving experienced by distributed teams. These technologies support our performance scaffolding research task—that is, the component that will provide portable tools to augment dynamic problem solving and decision making. Specifically, these are foundational elements of our team performance improvement functionality; by incorporating real-time data from both distributed sensor systems and team members dispersed throughout the globe, with group support software, this element of the uCollaborator will result in significant gains in team performance. Second, from the standpoint of training and development, uCollaborator is designed such that team training and development can be supported via inclusion of a distributed briefing-debriefing system and a team development capability. Finally, our research tasks encompass technology development hurdles through inclusion of usability evaluation and automated voice recognition—issues that must be addressed for the uCollaborator to function effectively. Ultimately, our goal with the uCollaborator is to connect the real and virtual worlds in service of enhancing team process and performance. We next discuss the research thrusts we have developed to help us realize our goals.

Integrating Visual Simulation Functionality: In this task we are developing additional visual simulation techniques to augment the capabilities developed under a previous NSF-funded project. The new capabilities apply to a broad range of operational environments. These include not only normal complex collaborative tasks (e.g., construction), but also situations with limited visibility, such as mining, nuclear power plants, and underwater recovery operations, where on-site visualization tools can substantially aid collaborative problem solving and decision making.

Challenge: In many operational environments a variety of task factors can lead to a loss of visibility associated with the task (e.g., in underwater construction, depth, combined with enormous pressures and low temperatures, makes the site a place where only tele-operated construction equipment and robots can operate). Furthermore, limited feedback from sensors placed on robots and related on-site technologies makes operational processes such as construction very expensive and time-consuming. Many conventional technologies such as GPS, laser tracking, and radio waves have limited range or simply don't work for physical reasons. As a result, the sensors currently used provide limited information. The cameras available today can only provide an image of the immediate vicinity even under good visibility conditions. To complicate things even further, the data collected by all these sensors and cameras are often scattered across many systems, making perception and analysis very difficult. All these factors adversely impact decision making. Fortunately, poor perception conditions can be improved through visualization, visual data consolidation and management techniques.

Approach: We have already developed a uCollaborator visual simulation capability (3D viewer) to improve the perception and understanding of scenes where near real-time data is available. Algorithms, heuristics and software development lessons learned from implementing these complex systems will be applied to the new uCollaborator development efforts (Rodriguez et al., 2006). This initial development of the system is now web-enabled for dispersed team collaboration and marketed by XYZ Solutions Inc.

Integrating Networked Sensors Feedback: Central to uCollaborator's effectiveness is its ability to push and pull information from various networked sensors. The objective is to use and develop sensor technologies as identified by their function and connectivity: (a) sensors that are directly connected to handheld uCollaborator devices, such as cameras or an array of microphones, as well as sensors specialized for specific use of the device (e.g., cardiac pulse monitoring sensor); or (b) sensors connected to the network accessible by uCollaborator, such as accelerometers, pressure sensors, gyroscopes, piezoelectric sensors, geophones, microphones, or cameras). The sensors connected to the uCollaborator serve the purposes of: (a) controlling the device itself and (b) sharing its data with other users connected to the network. Note that a sensor may have dual use—for example, an array of microphones that can be used to control the device (e.g., "uCollaborator, call Cynthia!") as well as share the data with the users (e.g., voice transmission over the network).

Challenge and Approach: Integration of a large variety of sensors producing distinctive data measurements can be achieved within existing web-based technologies. Namely, XML in conjunction with XSL is specifically designed to bridge the gap of heterogonous data representation. XML is a general-purpose markup language. It is used to facilitate the sharing of structured data across different information systems (i.e, the Internet). It allows definition of custom tags. XSL is a language for creating style sheets.

Societal and Economic Impact: Gathering real-time data in this fashion will facilitate sense-and-response decision making and reduce risk and uncertainty in the supply chain of products and services, particularly in the construction, healthcare, and retailing fields, among others.

Integrating Team Performance Scaffolding: When manufactured, the uCollaborator's process scaffolding capabilities will provide portable tools to augment dynamic problem solving and decision making. By incorporating real-time data from both distributed sensor systems and team members dispersed throughout the globe with groupware, this element of the uCollaborator will result in significant gains in effectiveness across industries as diverse as surgery, software design and construction.

Challenge: The translation of best practices from the training sciences to team-based organizations has been slow despite data showing how process and performance can be improved. The challenge is to capture relevant contextual information that is often outside the electronically mediated data stream while also instantiating visualizations of both data from sensors and teams who are dispersed.

Approach: The backdrop against which the uCollaborator engine is developed is the notion of team competencies—factors that foster effective interaction behaviors and performance (Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995; Salas & Fiore, 2004). Our research team is pursuing innovative mobile and fixed location uCollaborator technologies based upon the aforementioned framework. We are focusing on creating systems that are able to utilize real-time data from team members who are not co-located and from sensors in the field to support distributed interaction as collaboration unfolds dynamically. First, through the development of simulation-based visualization and groupware, the uCollaborator will provide a powerful range of collaboration tools usable in more conventional business locations. Second, through the use of hand-held and mobile devices, our technologies will support collaboration with distributed members who may not have access to high-end simulations. Mobile device capabilities are continuously being enhanced, as today these devices already have features enabling users to instant message and webcam. In terms of data integration, mobile devices are being prototyped to support multiple speech-enabled applications and graphics/text such as multimodal input and output in a mobile handheld device (Schuricht et al., 2009).

Representative generic team and task factors that would be supported include conflict resolution, collaborative problem solving, communication, performance management, and planning and task coordination. For example, a mobile component of our system would scaffold planning processes via support of information management to align team interdependencies (e.g., real-time data targeting team leaders). A fixed component of our system would use simulations to scaffold collaborative problem solving—that is, simulations to help team members identify critical problem cues and effectively represent such data in service of eliciting appropriate team member participation. Creating and implementing such a system provides a unique opportunity through which to support a tremendous variety of complex collaborative tasks—impacting a number of industries and leading to significant economic development and increased productivity.

Societal Impact: uCollaborator is being designed such that it is usable in a variety of industries, thus having a significant and broad impact. The societal impact here rests on the fact that problems in coordination and communication continually create not only financial losses, but also losses in lives. For example, not only can the uCollaborator be used to help redress design problems before they occur in areas such as construction, supply-chain management, or software development, but our concept also holds great promise in enabling synchronization of complex efforts involving multiple teams. With regard to financial losses, as noted in a recent industry white paper, "the cost of poor quality—not doing it right the first time—in the software industry today is an estimated $100 billion. Seventy five percent (75%) of software projects undertaken are never completed (Benoit, 2000). More importantly, with regard to losses in life, many emergency response teams typically operate in the context of dynamic and time-sensitive tasks where their ability to rapidly exchange information in real time ultimately drives life or death outcomes. The context of interacting in a multiple team setting is made even more challenging by virtue of the fact that success requires the rapid transfer of information both within the team, and also across the boundaries of other teams with whom teams may or may not have any prior experience working (Zaccaro, Marks, & DeChurch, 2011). Systematic R&D in the uCollaborator-based technology would significantly impact coordination of teams by digitizing and rapidly transmitting information regarding the status of each team, transferring newly acquired information to other units, and enabling teams to perform distinct aspects of their tasks while properly supporting the efforts of other team members or other teams in the system.

Although current industries separately serve collaboration, they have yet to do so from a scientific and technical base arising from team theory (Salas & Fiore, 2004 ; Salas et al., 2012). Therefore, the potential is great for a powerful impact on both productivity and emergent industries.

V. Student Projects

From the beginning, the authors decided to engage both management and engineering students in the design of the uCollaborator simulated system. Figure 2 illustrates some of the

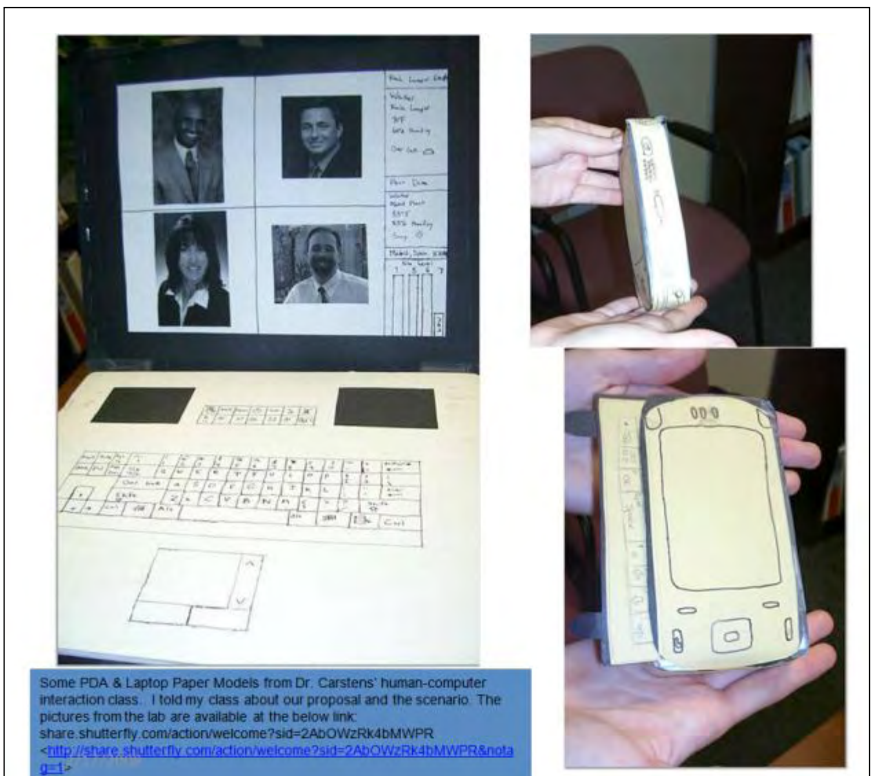

Figure 2. Sample Prototypes Created by Students

initial paper models developed by the students. Please note that some are very similar to laptops and PDAs but with a twist (e.g., slide-able tray and speech recognition features).

Integrating Automated Speech Recognition: The uCollaborator simulated system comes with a friendly and intuitive interface via Automatic Speech Recognition that enables it to convert a speech audio signal into its textual transcription. While many tasks are better solved with visual, pointing interfaces or keyboards, speech has the potential to be a better interface for a number of tasks where full natural language communication is useful, and the recognition performance of the Speech Recognition (SR) system is sufficient to perform the tasks accurately (Këpuska, 2002). This includes hands-busy or eyes-busy applications, for times when the user has objects to manipulate or equipment/ devices to control, as envisioned usages of the uCollaborator. Some motivations for building these systems are to improve human-computer interaction through spoken language interfaces, to solve difficult problems such as speech-to-speech translation, and to build intelligent systems that can process spoken language as proficiently as humans. Speech as a computer interface has numerous benefits over traditional interfaces like a GUI with mouse and keyboard: speech is natural and intuitive for humans, requires no special training, improves multitasking by leaving the hands and eyes free, and is often faster and more efficient to transmit than using conventional input methods.

VI. Conclusions

Developing and adapting visual simulation and networked sensors for collaboration brings important research into the practical reach of real teams in real organizations. Yet core technologies in these areas are fragmented. The uCollaborator framework and simulated system provides a proof-of-concept integrating existing and new core technologies to produce a suite of tools supporting collaboration. This technology will support growth in existing industries as well as attract industries whose products support visually-based collaboration. Most importantly, there is significant economic impact associated with the implementation of uCollaborator by end users. The impact of improving the effectiveness and efficiency of users such as project teams, product designers, and rapid response teams will be the primary indicator of its market value. The uCollaborator simulated platform is directly aimed at mobilizing a motivated and capable team to undertake skilled, innovative, and technologically complex projects with significant potential for productive economic impact (e.g., scientific teamwork; see Börner et al., 2010). By enhancing the growth of existing companies and incubating new ventures, our research team is supporting the creation of thousands of new high-wage technology and service-oriented jobs in the propitious collaboration software niche. Ultimately, uCollaborator devices and systems will be licensed to companies in the US that would target specific markets (healthcare, supply-chain/wholesale distribution, first responders, sports teams, corporate business, small businesses, and many others). Through integrated marketing strategies (i.e., advertizing, communications, public relations and marketing), businesses will learn about the benefits and applications of uCollaborator and how it can be exploited to create real business value. In addition, UCE will facilitate the creation of uCollaborator's Application Service Provider (ASP) depots to serve small businesses, government agencies and the community.

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Stephen M. Fiore, Ph.D., is faculty with the University of Central Florida's Cognitive Sciences Program in the Department of Philosophy and Director of the Cognitive Sciences Laboratory at UCF's Institute for Simulation and Training. He earned his Ph.D. (2000) in Cognitive Psychology from the University of Pittsburgh's Learning Research and Development Center. He maintains a multidisciplinary research interest that incorporates aspects of cognitive, computational, and organizational sciences in the investigation of learning and performance in individuals and teams. He is Editor of the journal Cognitive Technology, co-Editor of recent scientific volumes on Macrocognition (2008), Team Cognition (2004 ; 2012), and Distributed Learning (2007), as well as recent journal special issues on human learning and performance

Walter Rodriguez is Professor and Director of the Institute for Technological Innovation at Florida Gulf Coast University. He obtained his Ph.D. in Engineering Project Management from University of Florida in 1982. He founded and chaired the Engineering Computer Graphics Program at Georgia Tech (1985–1993) and was awarded the Harvard Foundation Medal (1994) and a Postdoctoral Fellowship (Information Technology) at the Massachusetts Institute of Technology (1996), while holder of the Louis Berger Endowed Chair at Tufts University. Professor Rodriguez has published over 120 research articles and has obtained multiple National Science Foundation and NASA research grants in systems development and collaborative technologies.

Deborah Carstens, Ph.D., PMP, is the Director for the Activity Based Total Accountability (ABTA) Institute and an Associate Professor of Management Information Systems at the Florida Institute of Technology. She obtained a Ph.D. in Industrial Engineering from the University of Central Florida (UCF) in 2000. She also holds an MBA from Florida Tech and a B.S. in Business Administration, also from UCF. She is certified as a Project Management Professional (PMP). Previously, she worked for NASA Kennedy Space Center (1992–2003) in the field of project management and human factors research. Her research is in human error analysis resulting in the optimization of systems, safety, processes, and human performance, and has yielded over twenty-five publications.

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