Collaborative Research: Center for Mobile Hands-on STEM

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Dr. Bonnie Ferri is a Professor and the Associate Chair for Undergraduate Affairs in the School of Electrical and Computer Engineering at Georgia Tech. She performs research in the area of active learning, embedded computing, and hands-on education. She received the IEEE Education Society Harriet B. Rigas Award.

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Al Ferri received his BS degree in Mechanical Engineering from Lehigh University in 1981 and his PhD degree in Mechanical and Aerospace Engineering from Princeton University in 1985. Since 1985, he has been a faculty member in the School of Mechanical Engineering at Georgia Tech, where he now serves as the Associate Chair for Undergraduate Studies. His research areas are in the fields of dynamics, controls, vibrations, and acoustics. He is also active in course and curriculum development. He is a Fellow of the ASME.

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Dr. Deborah Walter is an Associate Professor of Electrical and Computer Engineering at Rose-Hulman Institute of Technology. She teaches courses in circuits, electromagnetics, and medical imaging. Before joining academia in 2006, she was at the Computed Tomography Laboratory at GE's Global Research Center for 8 years. She worked on several technology development projects in the area of X-ray CT for medical and industrial imaging. She is a named inventor on 9 patents. She has been active in the recruitment and retention of women and minorities in engineering and currently PI for an NSF-STEM grant to improve diversity at Rose-Hulman.

Dr. Kathleen Meehan, Virginia Tech

Kathleen Meehan earned her B.S. in electrical engineering from Manhattan College and her M.S. and Ph.D. from the University of Illinois under the supervision of Prof. Nick Holonyak, Jr. She worked as a member of technical staff at Lytel, Inc., following graduation. At Polaroid, she was appointed a Senior Research Group Leader, responsible for the design of laser diodes and arrays. After leaving Polaroid, she was employed at Biocontrol Technology. She moved into academia full-time in 1997 and worked at the University of Denver, West Virginia University, and Virginia Tech. She is currently the director of the University of Glasgow-University of Electronic Science and Technology of China Electronics and Electrical Engineering programme. While at Virginia Tech, she collaborated with Dr. Robert W. Hendricks, with assistance of a number of undergraduate students, to develop an instructional platform known as Lab-in-a-Box, which is used in a number of courses within the Virginia Tech B.S.E.E. program. She continues to be actively involved in the development of mobile hands-on pedagogy as well as research on other topics in STEM education, the synthesis and characterization of nanoscale optical materials, and fermentation processes.

Abstract

Remarkable progress has been made in the development and implementation of hands-on learning in STEM education. The mantra of *See One, Do One, Teach One* overly simplifies the idea but does provide a helpful structure to understand how many engineering educators are attempting to change the learning experience of our students. Until recently, this effort has been faced with a major limitation. We can easily incorporate traditional paper and pencil and numerical analysis, synthesis, and simulation in our classrooms. However, the remaining key aspect of doing the job of an engineer – experimentation – has only been included through the use of expensive and limited-access lab facilities. Small, low-cost Mobile Hands-On STEM (MHOS) learning platforms (e.g., mobile personal instrumentation and control devices like *myDAQ, Analog Discovery* and *ADALM1000*) provide almost unlimited opportunities to solve this remaining problem in engineering courses. Pedagogy based on these tools has been implemented and studied in several institutions in the US and in other countries, impacting thousands of students each year. In all cases in which hands-on learning has been studied, the pedagogy has been successfully implemented. This has occurred even in traditionally theory-only courses, resulting in more engaged students and instructors. Although the initial assessments of this new approach to STEM education argue for broad application, the definitive case for its adoption has yet to be documented so that all STEM educators can fully appreciate its merit.

Goals

The Center for Mobile Hands-On STEM is pursuing activities that gather strong evidence of the effectiveness of Mobile Hands-On STEM (MHOS) pedagogy on student learning and develop an effective and pro-active dissemination strategy for the entire STEM educational community. To achieve these goals, we have recently focused on:

- Creating and implementing new standardized assessment tools that measure student learning, especially through the development of new experimentally focused concept inventories, as well as measure ease of adoption by instructors.
- Identifying implementation barriers for wide-spread adoption and how these might be overcome by applying the business start-up methodology of the NSF I-Corps program, working with faculty who have recently received funding to implement the mobile pedagogy, and holding focus groups among different constituencies.
- Delivering a set of workshops for faculty and administrators on effective use of Mobile Hands-On Learning. The first was held at the 2012 ASEE Conference in San Antonio, the second at Georgia Tech in conjunction with the 2013 ASEE conference and there were two workshops the following year, one at ASEE and one at the American Control Conference. Other workshops were offered jointly with other projects, like the HBCU ECP project (see below).

Approach

All of these general areas of activity represent works-in-progress. In the former we are investigating formulations of concepts and possible learning and assessment activities and collecting data on their effectiveness. We identify three objectives of Hands-On instruction, 1) to apply instrumentation to make measurements of physical quantities, 2) to identify limitations of models to predict of real-world behavior, and 3) to develop an experimental approach to characterize and explain the world. We have consulted with experts to develop a list of common misconceptions students display in laboratory instruction. A unique feature in testing Hands-On concepts is that laboratory skills are inextricably tied to analytical concepts and therefore both analytical and hands-on concepts have to be tested in order to distinguish the root cause of the misunderstanding. Based on these common misconceptions, test questions are being developed and data are being collected on their effectiveness to assess learning.

Feedback from faculty and students interested in MOHS pedagogy is being solicited. For the latter, we have had a group of our colleagues go through I-Corps training as part of a pilot program to expand the impact of educational research. Strong collaborative relationships have been developed with new groups who are aggressively implementing similar pedagogy throughout all of their engineering programs.

Finally, we will be hosting a series of online practitioners' workshops rather than the usual physical face-to-face workshop, because of the potential for wider and longer term impact. The workshops will engage leaders in various aspects of hands-on learning who will develop videos that address issues associated with adoption and sustainability, key areas within engineering curricula where students gain significantly by engaging in active learning, a review of the models of adoption, etc. An exemplar video is being created for use as a guide for those who will be asked to develop videos on specific topics and as the video associated with the first online workshop.

Outcomes

A large amount of content utilizing MHOS Pedagogy has been developed and is readily available online for interested students and faculty. All partner institutions have several fully developed circuits and electronics intensive courses covering most levels from 1st year intro/survey courses through required sophomore and junior courses, both inside and outside of electrical and computer engineering[1-12,14-19]. At Georgia Tech, the content has been used to build MOOCs that can be easily used by other institutions[13]. The activities and materials used were tested and are part of on campus courses where they enable a very effective blended learning experience for their students.

Materials have been shared with and implemented by many schools; primarily those who have participated in workshops and more significantly by those who have obtained related funding and/or who are using the approach to impact the recruitment and retention of minority students. One group consists of all 13 HBCUs with ECE programs and another is all engineering programs in Puerto Rico. There has also been impact on schools at all levels (K-16) through outreach and education programs at ERCs, an ASEE Virtual Community of Practice and participation in the pilot I-Corps-L program. Building this network has proven to be the most effective approach for dissemination.

Evolution of Pedagogy

A more mature version of MOHS Pedagogy has recently evolved based on collaboration with the HBCU Experimental Centric Pedagogy project[21,23]. By playing an active role in this project, it has been possible to better understand what ECP is and the core role it should play in engineering education. ECP is now a much a more concrete concept which makes it easier to assess progress. The guiding hypothesis is that engineering education works best in a learning environment in which experimentation plays a central role rather than existing on the periphery as is too often the case at too many engineering schools.To make this new pedagogy a reality, we have to better understand what toolset is necessary for both the students and instructors involved. This is the purpose of the experimentally focused concept inventory under development. In addition, we need to further develop and facilitate the network of practitioners, which we will be doing with online workshops to keep the barriers to participation low.

Impact

Evidence based studies have been and continue to be conducted at all collaborating sites to document use and effectiveness of personal instruments and subsequent impact on instructional practices and student learning. In addition to information addressed in nearly all of the references below, the following information is based on their use at RPI. During the Fall '14 and Spring '15 semesters students enrolled in four sections of Electronic Instrumentation, a course for students with majors other than electrical engineering. Data sources for the following information included pre-surveys (n=100), post-surveys (n=146), independent evaluator observations (n=13) of use (conducted to document fidelity of implementation) and on-going interviews with faculty, TAs and students. The students were undergraduates; 83% were in their third and fourth year of study. 23% were of ethnic minority; the male to female ratio was approximately 4:1; and 85% of students' primary language was English. The majority of students were mechanical or aeronautical engineering majors. Visual, sensing, sequential, and active learning approaches were the most prevalent self-reported learning styles; all groupings reported their styles were reinforced. This alignment of the learning style preferences with actual use of the personal instruments was further supported by evaluator reports (e.g. observations noted that students used the hardware to create signals (e.g., relevant for active learners), measure output on their computers (e.g., relevant for visual learners) while following a step-by-step process (e.g., relevant for sequential learners) laid out for them in the lab manuals.

Multiple types of personal instrument use, including different formats and support for different instructional styles, were noted; however, the most frequent was student-centered, collaborative use during lab time accompanied with autonomous use. Overall, 93% of the students reported working collaboratively with at least one of their classmates, and 73% reported at least some independent use. External observations confirmed and expanded on students' reported use reporting that the structure of the course required students to work in groups of two for lab experiments and groups of four to complete lab projects but that as part of this "shared" use, students each used the mobile hardware to complete different tasks or to check each other's work. Approximately one third of the students also reported working on experimental activities outside the required classroom/lab setting. When queried further, about this "outside use" it was typically reported as used with a partner and independently to reinforce learning by experimenting with different variables.

80% of the students found the personal instrumentation to be a valuable tool for the course, indicating that it was effective both as a learning tool and in developing their confidence within the content area. Students' positive perceptions related to its usefulness in promoting experiential learning to practice course concepts (72%), increasing knowledge (71%), reflecting real practice (57%), and in improving confidence levels (57%). 72% of the students reported that it facilitated a collaborative working environment with their fellow students. Approximately half the students wanted more use and more time for that use within the classroom/lab setting when it was assigned.

When queried as to specific outcomes, students re-emphasized that personal instrument use assisted them in the learning circuits content including practical applications (62%), helped in completing lab assignments with confidence (58%), the development of specific skills (67%), and aided them in thinking about problems in a visual way (60%). Specific gains were noted in developing skills in problem solving; this included enhanced problem solving capabilities within the content area (48%), developing different ways of solving problems and applying knowledge to new areas (44%). This was supported by increased perceptions of their knowledge of the content (49%), attitudes of self-direction and self-responsibility (45%), and greater interest in the content area (37%). Over one-third of these non-majors also had begun to transfer their problem solving knowledge in this are to other domains. Independent evaluator observations supported student and faculty responses, noting the presence of student discussion and use of trial and error to solve problems based on measured data.

Specific benefits of use, as noted by faculty, TAs and students, included application of learned knowledge grounded in a real world setting, support for visualization that helped with retention and transfer, and active experimentation that allowed for deeper understanding and better problem solving. As an example, students noted the use of personal instruments helped facilitate their knowledge acquisition and "pull back" through memory of visual representation provided by their measurements; this then helped them "move" theory into practice and provided a valuable hands-on experience that could be applied to the real world (*"allowed me to build and test actual circuits," "graphically showed circuits, made it easier to understand,"* and "*provided real world examples of how circuits work"*). Students also noted that they could "*take the lab home,*" noting that it collapsed larger more expensive equipment into their back-pack.

Suggestions for future use included increased initial instruction for use of the hardware that would meet the needs of both sequential and global learners, more follow-up instructor demonstration that focused, not on theory, but on use in the real world and provided examples of transferring knowledge, and more use in class/lab and assignments that would foster generalization of theory to the real world. *("Provide more demonstrations and how it can be used in a non-class setting"*).

Broader Impacts

Impacts are of two general types. The first is the development of content and a collaboration network that facilitates the spread of the pedagogy. Included are

- Developing/facilitating a community of practitioners.
- Making content available to others through workshops, MOOCs, freely available online materials, etc.
- Having a positive impact on businesses working in this space. Project participants serve as advisors in the development of and act as early testers of new hardware and software.
- Participation in and support of other communities working on related projects has helped them achieve their goals. This has been the most effective dissemination.
- The usual participation in conferences, publication of book chapters, giving seminars at other universities, commentary for ECE leadership[20-23], also has helped to spread the word, if less effectively than collaborations.

The second, and more important impact of this work has been in the focus on facilitating the adoption of the pedagogy at minority serving institutions and spreading the word throughout the world. In addition to the HBCU and Hispanic serving schools mentioned above, there has been a very effective effort to engage essentially all of the engineering schools in Sub-Saharan Africa. Several meetings and workshops in countries like Ethiopia, Ghana, Cameroon, Nigeria ... have been organized with the most recent involving most, if not all, engineering deans. There has been good industrial support for this effort (mostly from Analog Devices) to make it possible to provide hardware to schools there.

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