ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #38333

Problem Based Learning as a Framework for a Research Experience for Teachers

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This paper shares the findings from the first year of a Research Experience for Teachers (RET) site, funded through the National Science Foundation's Division of Engineering Education and Centers (Award # 1953645), supporting community college science instructors from our region in a seven-week research experience focusing on cyber physical systems (CPS) used for energy production and management. We describe the motivation behind the recruitment for the RET, the goals of the research experience, and the problem-based learning method we used to design the RET for focusing on learning threshold concepts.

Motivation for the RET

Over the past four years, transfer students from regional community colleges make up 34.5% of new students in the College of Engineering and Computer Science (CECS) at the University of Tennessee at Chattanooga (UTC). This is not surprising because the state of Tennessee has focused much funding and attention to building a strong community college system that is essentially free to all Tennessee high school graduates who enroll right after graduation or independent Tennessee residents who have been out of school for a required number of years and have not earned a previous associate or bachelor's degree. We have found that these transfer students do not have as much knowledge or experience with emerging engineering fields and threshold concepts as their counterparts who attended the four year university for the first two years of college. Our RET, *Providing a Research Experience and Practicum in Cyber Physical Systems* (PREP-CPS), aims to build a learning community that includes UTC engineering and engineering education faculty, graduate and undergraduate engineering students, and community college faculty and their students. This learning community is designed to introduce community college faculty to emerging engineering technology and evidence-based ways of applying that technology in introductory science and math coursework. The learning community is also a place to exchange ideas about the learning needs of community college students and the professional learning experiences sought by community college faculty, as well as research collaborations between faculty and students at all institutions involved.

We recruited science, math, and engineering faculty from community colleges and small regional universities located within a two-hour radius from Chattanooga, Tennessee. We limited our recruitment to this radius so that participants could meet in person at least four days per week in the engineering research labs and for group activities at UTC. In-person meetings were preferred by all after the professional isolation that most participants had endured during 2020. The RET summer research session began in mid-June and ran seven weeks, ending in early August. The participants that applied and were accepted to the RET (3 women and two men in our first cohort) had the support of their deans and were a diverse group in gender, race or ethnicity, age, teaching experience, and STEM disciplines taught. All the participants had earned a Ph.D. in the STEM field in which they taught and were full-time faculty at their institution.

The objectives of the RET were to: (1) Increase participants' research skills and practical knowledge of CPS; (2) Increase participants self-efficacy in creating and implementing laboratory-based investigations and problem-solving opportunities using cutting-edge technology with students in the classroom; and (3) Help bridge the preparedness gap between what is exhibited by community college transfer students and what is expected by university engineering faculty.

Research focus

Cyber Physical Systems (CPS) are state of the art systems that integrate computational and physical capabilities and allow humans to interact with the systems using a variety of modalities [1] [2]. RET participants conducted research on CPS applied to engineering challenges in energy production and management, potentially leading to new knowledge, technology, and process optimization in biofuels production, geothermal systems, solar energy harvesting, and rocket propulsion systems. We chose energy production as a focus because of its importance to the region that is home to our university and the community colleges, whose students transfer to our university to complete their baccalaureate degrees in STEM. Participants gained skills in instrumentation and signals processing; data acquisition and instrument control; management of interconnected device networks; and web services. Each participant joined one of these on-going CPS research projects:

- Inline Quality Monitoring of an Algal Biodiesel Reactor Train
- Examination of Soil Humidity on Geothermal Heat Pump Efficiency
- Real Time Monitoring of a Full Spectrum Solar Energy Harvester
- Stage-wise Carbon Monitoring of a Biohydrogen Production System
- Small-scale Rocket Propulsion System Instrumentation and Control

To accomplish program objective (1), participants received a three-day introduction to Arduino – a simple, inexpensive, and open-source electronics platform. They were also given a microcontroller and accompanying hardware kit. They worked with a research mentor and participated in a five-week research experience on using cyber-physical systems for energy solutions. In addition to daily interactions with their faculty mentor's research team, participants also engaged in weekly literature review and roundtable discussions on research progress as well as a weekly seminar series featuring guest speakers related to CPS for energy production and management.

Problem based learning as a conceptual framework for threshold concept acquisition

Engineering transfer students often arrive at UTC struggling with engineering 'threshold concepts' which delays conceptual understanding and student advancement in coursework. Threshold concepts are defined as concepts that are fundamental to ways of thinking and practicing in that discipline.[3]. A threshold concept represents a transformed way of understanding, or interpreting, or viewing a 'core concept' without which the learner cannot progress. [4]. A common example of a threshold concept in physics is Newton's 1st Law of Motion. Although many introductory level physics students can recite the definition of the law and use the corresponding mathematical equation that models the Law, most students do not have a mental model that aligns with the science, because how we usually experience motion is not consistent with the Newtonian view [5]. In order for students to truly understand the Newtonian view (that a body at constant speed and direction will keep moving unless changed by an external force), they must experience the concept in question in a way that aligns with the

Newtonian view but would not make sense if their mental model held on to the common but inaccurate idea that a body in motion at constant speed *requires* an external force. [5]

The notion of threshold concepts encourages the thinking of problems as entry points for tackling vital concepts within particular disciplines and is relevant for the integration of the constructivist-based strategy, Problem-Based (or Project-Based) Learning (PBL) [6]. Much has been written about the effectiveness of using problem or project based learning for deeper conceptual learning in college science coursework [7], [8]. Markham, Larmer, and Ravitz describe PBL as "a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic questions and carefully designed projects and tasks. [9]. The concepts of PBL can be thought of as either problem-based in nature (students work to solve an authentic problem) or project-based (students produce an artifact that demonstrates mastery of a concept). Although problem-based learning and project-based learning can look different, we will use the term PBL here to refer to either approach as both have a research basis to show that they are more effective for student learning than traditional lecture-based instruction. We want our community college faculty peers to have evidence-based ways that they can support their students in constructing deep and accurate threshold concepts, so we chose to frame the RET and the design of curricular materials using the PBL approach.

We used the research-informed model for PBL instruction as described by the organization PBLWorks (formerly the Buck Institute for Education) as "Gold Standard PBL" [10]. This approach to PBL combines the most effective PBL practices in seven design elements that should be addressed in a PBL unit: (1) a challenging problem or question, (2) sustained inquiry, (3) authenticity, (4) student voice and choice, (5) reflection, (6) critique and revision, and (7) a public product [10]. The template from PBLWorks (https://www.pblworks.org/) that our participants used can be found at https://my.pblworks.org/resource/document/project_design_overview_and_student_learning_guide. The participants specifically pointed out to our evaluator that they found this template to be helpful in undertaking the planning necessary for these new curricular units. The participants were looking at all of their curriculum to see how PBL could be integrated into their teaching.

RET program objectives and activities

Objectives of the RET included increasing participants' knowledge of cyber-physical systems, research skills, and efficacy in creating and implementing problem-based learning (PBL) instruction using advanced technology to support mastering threshold engineering concepts. During the first week of the RET summer session, participants were trained to program and use Arduino open source electronics as a microcontroller for hands-on lab activities related to their summer research experiences. Each participant worked on a CPS project in the laboratory of their research mentor and interacted daily with graduate research assistants over the seven weeks.

Because we asked participants to translate their research experiences into a curricular unit by creating a PBL unit for a community college course, we designed the RET to be a PBL experience for participants. The driving question was "What kinds of energy production and controls would we need to travel to Mars?" The entry event on the first day of the RET PBL was a luncheon featuring videos of the research groups' on-going projects and a guest speaker, aligned with the driving question. Weekly guest speakers and field trips involving alternative energy production, NASA projects on Mars, and innovative engineering design as well as a space mission experience at the Challenger STEM Learning Center on our campus continued to support the "Mission to Mars" PBL experience. A three-day bootcamp during the first week introduced the participants to the design elements, research, and rationale of PBL instruction. Weekly PBL workshops with a STEM education faculty member guided participants to create, peer critique, and revise a PBL unit of their choice that they would implement in a course during the academic year. The public products for the RET were a seminar presentation on their energy CPS research and PBL unit and a grant proposal for classroom materials to implement the PBL unit. The seminar was attended by university faculty and students, and the grant proposal was submitted to the RET leadership for peer review and funding approval.

Findings

Preliminary findings indicated the RET effectively met the first two stated objectives. In comparing focus group responses from June to those from August, participants reported that they increased their efficacy in PBL planning and knowledge about their research topics overall. Specifically, they successfully adopted an effective template to design PBL instruction and felt able to garner support for the PBL approach at their institution. They were able to connect their research experience in CPS for energy production and management with threshold concepts that they teach, which gave them updated perspectives for teaching. Finally, the participants saw opportunities for working with their summer mentors on new research ideas in biology, chemistry, and physics.

Each participant designed a gold standard PBL unit using the project planning template mentioned earlier. Table 1 describes the seven 'Gold Standard PBL' design elements that each participant was asked to plan for in their PBL unit. We have visited three of the faculty participants classrooms this academic year to support their PBL unit implementation and to serve as outside experts and critical friends. The students in all three of the courses were extremely engaged and excited to be learning in the context of an authentic task.

Most participants listed a positive recommendation from their college's dean for the reasons why they chose to apply and attend the PREP-CPS RET. Support from administrators for examining teaching skills, creating new research-teaching connections, and taking the time for professional learning experiences reinforces the expectation that faculty view their role as a teacher as integral to the college community [11]. In addition, the participants expressed a great desire to stay connected with faculty research mentors at UTC and with each other. They plan to ask each other for support in teaching as well as research collaborations.

Future work

We hope to recruit a larger cohort for our second summer and be able to safely meet in person, following CDC guidelines for the COVID-19 pandemic. According to focus group responses, one way that we can better support participants would be to describe in more detail the possible research projects that participants could join as they are crafting their application for the RET. We will continue to attempt to recruit a diverse community college faculty cohort and will welcome return participants to act as peer mentors for new recruits. We hope to establish a professional learning community within each community college and between the colleges and UTC. We will begin to track the progress of students who transfer to UTC from the participating colleges and the courses taught by our RET participants. We are especially interested in threshold conceptual knowledge of the students who have participated in PBL units that transfer to UTC to earn their bachelor's degree.

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Table 1. RET Participants' Gold Standard Design Elements

Participant	Question or Problem	Sustained Inquiry	Authentic role for students	Student Voice & Choice	Reflection	Critique and Revision	Public Product
Alice (Biology)	Creating Wine for a Wedding Party? How does it compared to commercially made wine?	11 weeks	Winemakers	Type of wine; marketing campaign	Journals and focus groups	Wine critique Marketing plan popularity Alcohol content	Wine product and marketing campaign for newlyweds
Celia (Chemistry)	How does complexity of biomass affect rate of biogas production?	6 weeks	Biogas production plant team	Design and implement their own experiment	Whole class discussion and reflection writing every 2 weeks	Weekly progress reports to a discussion board for peer review	Research Poster presentation at UTC Research Dialogues conference.
Sabrina (Astronomy)	Colonizing Mars: How can we make a home for humans?	9 weeks	NASA Mars Exploration team member	Choice of aspect of Mars colonization:	Whole class discussion of ideas.	Paper critiques from peers 3 weeks before due date	White Paper to NASA Mars Exploration Program
Seth (Physics)	Design a solar tracking device	9 months	Solar Energy Engineer	Engineering Club activity	Work journal; meetings with local solar experts	Focus Group	Solar Tracking Device product. Presentation to local solar design experts.
Zhen (Physics)	Why is electrical system malfunctioning?	4 months	Astronomy Observatory technician	Customized circuit Optional project for students	Work journal Class discussions including a fishbowl discussion for troubleshooting	Design, test, and debug system with peers	Working electrical system product. Present at UG research conference