AC 2010-2106: SPECIAL SESSION: INNOVATIVE PEDAGOGIES FOR TEACHING INTRODUCTORY MATERIALS COURSES

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Stephen Krause is a Professor in the School of Materials in the Fulton School of Engineering arrived at Arizona State University in 1981 after completing his research on polymer deformation at the University of Michigan. Courses he has developed and taught include; Bridging Engineering and Education, Materials Characterization, Polymers and Composites, and Materials Capstone Design,. Innovative learning tools and assessments he has developed include: Materials Mentor Fold Out Notes; Materials Lecture Work Notes; Materials Lecture Activities; a Materials Concepts Inventory; and a Chemistry Concept Inventory. His technical research is in nano-characterization of polymers and semiconductors. His educational research is in K-12 engineering outreach and in misconceptions and conceptual change in teaching and learning in engineering education. He is currently supported by NSF for a CCLI grant for development of Just in Time Teaching materials science modules and for IEECI grants to study the student learning trajectory and effectiveness of active learning processes in a broadly subscribed Introductory Materials Science course in engineering.

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Dr. Elliot P. Douglas is Associate Professor of Materials Science and Engineering at the University of Florida. His research activities are in the areas of active learning, problem solving, critical thinking, and use of qualitative methodologies in engineering education. Specifically, he has published and presented work on the use of guided inquiry as an active learning technique for engineering; how critical thinking is used in practice by students; and how different epistemological stances are enacted in engineering education research. He has been involved in faculty development activities since 1998, through the ExCEEd Teaching Workshops of the American Society of Civil Engineers, the Essential Teaching Seminars of the American Society of Mechanical Engineers, and the US National Science Foundation-sponsored SUCCEED Coalition. He is also active in the POGIL project; he has been invited to attend the last three POGIL National Meetings and serves on the Education Research Committee for the project. He has received several awards for his work, including the Presidential Early Career Award for Scientists and Engineers, the Ralph Teetor Education Award from the Society of Automotive Engineers, being named a University of Florida Distinguished Teaching Scholar, and being named the University of Florida Teacher of the Year for 2003-04. He is a member of the American Society for Engineering Education, the American Educational Research Association, and the American Chemical Society. He is a Past Chair of the Polymeric Materials: Science and Engineering Division of the American Chemical Society and is currently Editor-in-Chief of Polymer Reviews.

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Michael Prince is a professor in the Department of Chemical Engineering at Bucknell University, where he has been since receiving his Ph.D. from the University of California at Berkeley in 1989. He is the author of several education-related papers for engineering faculty and gives faculty development workshops on active learning. He is currently continuing the work of Project Catalyst, an NSF-funded initiative to help faculty re-envision their role in the learning process, and researching the use of inductive teaching methods to correct common student misconceptions in engineering. Address: Department of Chemical Engineering, Bucknell University, Lewisburg, PA 17837; telephone: 570-577-1781; e-mail: prince@bucknell.edu.

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Dr. Trevor S. Harding is Chair and Professor of Materials Engineering at California Polytechnic State University–San Luis Obispo where he teaches courses in service learning, introductory materials engineering, biomedical materials design, and tribology. Dr. Harding has published numerous manuscripts in the area of ethical development of engineering undergraduates through application of psycho-social models of moral expertise. He also conducts research in student motivation, service learning, and project-based learning. His technical research is focused on degradation of biomedical materials in vitro. He currently serves as Associate Editor of the online journal Advances in Engineering Education, is Chair of the ASEE Materials Division, and ERM Program Chair for the 2010 ASEE Annual Conference. Dr. Harding was invited to deliver a workshop on Ethics in the Engineering Curricula at the 2009 NSF Engineering Awardees Conference, and to participate in the NSF Project Based Service Learning summit. He recently received the 2008 President's Service Learning Award for innovations in the use of service learning at Cal Poly. In 2004 he was named a Templeton Research Fellow by the Center for Academic Integrity, Duke University. Dr. Harding received both the 1999 Apprentice Faculty Grant and 2000 New Faculty Fellow Award for his contributions to engineering education.

Innovative Pedagogies for Teaching Introductory Materials

Abstract **–** This panel discussion will focus on innovative pedagogies for teaching introductory materials courses. The first brief presentation gives an overview of the general characteristics of active learning embodied by the general approach of inductive teaching methods. This is then followed by presentation of the broadly used innovative pedagogies of Process Oriented Guided Inquiry Learning (POGIL) and Just-in-Time-Teaching (JiTT) and Inquiry Learning. The implementation of active learning tools in a setting with a diverse populations is then discussed. Finally, the impact on a department's students and faculty of implementing active methods, such as problem and project base learning, at a broad curricular level is considered. After the panel members make their brief presentations, this will be followed by breakout focus group discussions, group reports, and a wrap-up with open discussion.

Introduction

Engineers work across the globe on teams with major corporations. As such, students who are future engineers must develop skills sets for a changing technological environment where secure, lifetime jobs have become nonexistent in the new global economy. Effective pedagogies help facilitate lifelong learning because they develop self regulation which allows for ongoing revision of intellectual ideas and innovations. This panel session will present different approaches to engage students in learning of content as well as developing metacognitive skills for becoming autonomous, life long learners. The emphasis here is shifting the pedagogical paradigm from recall based teaching and learning to teaching and learning for development of a conceptual framework through reshaping classroom environment. The general research question addressed here is, "What types of pedagogy can more effectively graduate engineers who can succeed and lead in the modern day engineering environment?" The panel will introduce five research based innovate pedagogies. The breakout session will have group tables which will model various approaches and the reflect upon them to discover what barriers and opportunities are present for each of the various approaches.

Inductive Teaching Methods

Engineering and science are traditionally taught deductively. The instructor introduces a topic by lecturing on general principles, then uses the principles to derive mathematical models, shows illustrative applications of the models, gives students practice in similar derivations and applications in homework, and finally tests their ability to do the same sorts of things on exams. Little or no attention is initially paid to the question of *why* any of that is being done—what real world phenomena can the models explain, what practical problems can they be used to solve, and why the students should care about any of it. The only motivation to learn that students get—if they get any at all—is suggestions that the material will be important later in the curriculum or in their careers.

A well-established precept of educational psychology is that people are most strongly motivated to learn things they clearly perceive a need to know[1,2]. Simply telling students that they will need certain knowledge and skills some day is not a particularly effective motivator. A preferable alternative is *inductive teaching and learning*[3]. Instead of beginning with general principles and eventually getting to applications, the instruction begins with specifics—a set of observations or experimental data to interpret, a case study to analyze, or a complex real-world problem to solve. As the students attempt to analyze the data or scenario or solve the problem, they generate a need for facts, rules, procedures, and guiding principles, at which point they are either presented with the needed information or helped to discover it for themselves. Inductive teaching and learning is an umbrella term that encompasses a range of instructional methods, including inquiry learning, problem-based learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching. These methods have many features in common, besides the fact that they all qualify as inductive. They are all *learner centered* (aka *student-centered*), meaning that they impose more responsibility on students for their own learning than the traditional lecture-based deductive approach does. They are all supported by research findings that students learn by fitting new information into existing cognitive structures and are unlikely to learn if the information has few apparent connections to what they already know and believe. They can all be characterized as *constructivist* methods, building on the widely accepted principle that students construct their own versions of reality rather than simply absorbing versions presented by their teachers. The methods almost always involve students discussing questions and solving problems in class (*active learning*), with much of the work in and out of class being done by students working in groups (*collaborative* or *cooperative learning*).

Process Oriented Guided Inquiry Learning (POGIL)

Active learning techniques are being used with increasing frequency as a means to engage students in their own learning. The use of active learning in the classroom spans a continuum, ranging from the occasional use of problems for students to solve, to the extensive use of discussions, problems, or other activities in a class. Guided inquiry falls at the extreme end of this continuum. In a traditional class, students acquire knowledge by coming to the classroom, listening to instructors' lectures, and taking notes. In a guided inquiry class, the instructor does not lecture. Rather students work in teams, typically of four students, to complete worksheets. The worksheets contain three components: 1) Data or information as background material; 2) Critical thinking questions, which are designed to lead the students to understanding the fundamental concepts represented by the data, and 3) Application exercises, which provide the students with practice in solving problems using the concepts they have derived. The instructor's role is to guide the students, walking around the room and probing them with questions to check their understanding. This approach replaces a traditional teacher-centered model with a new student-centered model. This approach has not been used within engineering, although elements of the approach exist within other approaches such as cooperative and collaborative learning and guided design.

The guided inquiry approach used in our work is modeled after work done in the chemistry curriculum, called Process Oriented Guided Inquiry Learning (POGIL)[4]. Several studies conducted on implementation within chemistry have shown the effectiveness of POGIL. Several common, and important, outcomes observed in all of these assessments of implementations are: more students successfully complete the courses; student mastery of content is at least as high as for traditional instructional methods; and students generally prefer the approach over traditional methods. However, whether these outcomes will also hold true when guided inquiry is implemented in engineering courses is unknown. Also, there have been no studies examining how student learning occurs within a guided inquiry classroom. We have begun to examine these issues in order to better understand how to use guided inquiry within engineering.

Just-in-Time-Teaching and Inquiry Learning

One innovative, recently-developed active learning method is called Just-in-Time-Teaching (JiTT)[5]. It was developed by a team of physics faculty for teaching introductory physics but has been used for other subjects in science[6,7,8]. The JiTT technique is a teaching and learning strategy which has a "feedback loop" that provides student responses of web-based, pre-class study question sets to the instructor who uses them to frame the day's classroom inquiry activities. Students then experience the day’s lesson as shaped by their own responses. The pre-class questions target specific content-related issues such as misconceptions, developing concepts, vocabulary, etc. The feedback also provides opportunities to address differences in skills and needs of diverse learners. The components of JiTT consist of The WarmUp concept questions, typical student response misconceptions, content for informational mini-lectures, follow-on classroom inquiry learning activities, closure, and *Puzzle* two-tiered question sets to be completed later on-line.

JiTT is a teaching, learning and monitoring strategy that can be exploited for benefits such as use as a tool to systematically study and monitor the progression of student learning and associated conceptual change over time. Pre-class web-based questions could be configured so responses would open a window on the *mental models* of students’ thinking and understanding. As such, this could reveal students’ prior knowledge, understanding, misconceptions, reasoning skills and model use at selected intervals as well as the path of sequential points of time across a semester. Another benefit of JiTT would be to promote desirable learning skills through appropriate shaping of pre-class questions. Such skills would include those described by *How People Learn*[9] for fostering a shift from "novice" to "expert" understanding such as developing metacognition to facilitate skills like concept organization and relationships and monitoring learning progress. Finally, and most significantly, JiTT would be used to promote student learning through conceptual change of the understanding of materials by engaging students in effective lessons for introductory MSE classes. Thus, JiTT can reveal prior knowledge, monitor student understanding, and enhance learning skills, and promote student learning of MSE content through conceptual change. There is great potential for of this strategy inside and outside of engineering education.

Implementing Innovative Active Learning Tools in a Diverse Setting

The educational outcomes for civil engineering require students to meet specific performance standards at the time of graduation. Courses involving these performance standards are taken several semesters prior to graduation; therefore the challenge is to encourage the students to maintain their proficiencies until their senior year and beyond. Maintaining those memories is an issue. Research in the field of memory demonstrates that how quickly and reliably students recall information depends on how long since they last used the information and how well they practiced it[10]. Standard departmental practice dictates passing a Senior Exam similar to the Fundamentals of Engineering exam, and completing a Senior Design project. Data from several years of administering pre-tests of pre-requisite material clearly indicate that student retention declines rapidly over time.

A researched technique for memory improvement is Preview, Question, Read, Self-Recitation and Test or "PQRST"[11]. This technique pertains to our strategies. Our department has adopted two strategies to combat loss of retention. The first strategy involves requiring students to pass an end-of-year exam that includes all completed subjects. Students failing the exam are required to enroll in a one credit review class. If they do not pass this class, they must transfer to a non-engineering major. End-of- year exams cover: mathematics, chemistry, ethics, computer programming, engineering economics, and eight engineering science subject areas. The second strategy involves maintaining student proficiencies in written, graphic and oral communication skills which are not included in the end-of-year exam. The department has developed standards to which the students must adhere in all classes throughout their tenure. Work not meeting the communication standards is returned for correction. The communication standards are distributed to each student in the form of a department handbook, and the standards take effect as soon as the student completes the associated course.

Going Beyond Content to Significant Learning

Against a backdrop of compelling societal needs, graduates in science and engineering now must master their disciplines *and* demonstrate a sophisticated level of cognitive, affective and social development. This has led a number of national and international commissions on science and engineering to urge educators to re-think the way in which STEM disciplines are taught[12]. We have chosen to "repackage" a traditional undergraduate materials engineering curriculum in a form designed to promote the development of higher-order cognitive skills like self-directed learning and design. Classic metallurgy experiments have been converted to project-based learning experiences where students are put in the role of "designers" of problem solutions and faculty play the role of coaches. These include: designing, prototyping and marketing of a cast metal object; systems designing, building and testing of a fiber optic spectrometer; product improvement of a prosthetic device; evaluation of oxidation process for production; design and evaluation of a heat treatment process for roller bearings; and materials characterization of an everyday product. Projects were designed to leverage known relationships within the educational psychology literature that enable deeper learning. Evaluation of 36 juniors in a project-based learning course (i.e., the test cohort) against a quasi-control group in traditional engineering courses showed that the test cohort scored significantly higher on two motivation scales shown to be critical components in self-directed learning ($p<0.001$). The test cohort also reported a significantly higher use of peers as learning resources than the quasi-control group. Their motivation scores also correlate highly with self-reported comfort with several aspects of design, implying that their motivation contributes significantly to students' ability to effectively engage in the design process. In this paper, we present examples of the materials engineering projects that were designed and implemented, and the design features that enable them to promote the development of sophisticated cognitive functioning.

Though we are in a state of continuous improvement, the results of our reform have thus far been overwhelmingly positive. We have collected statistical evidence of a significant increase in students' comfort with self-directed learning, a shift from extrinsic to intrinsic forms of motivation, a stronger sense of identity both within the discipline and the department, an increase in moral reasoning ability, and greater self-efficacy in design and learning. Anecdotally, students seem more engaged in their learning, and we have noted a steady improvement in students' preparation year-to-year for autonomous self-directed work. We attribute these gains to an emphasis on a safe, caring environment; positive interactions among students and between students and instructors in the classroom; learning experiences embedded within a meaningful context; providing time and space for students' to reflect on their learning; and faculty who are committed to their own professional development in teaching and educational psychology.

Despite these gains, we continue to face several challenges including higher workloads for students and faculty, identifying the appropriate level of autonomy for students based on class level and personal preparation, and providing sufficient resources for projects. However, our greatest challenge has been finding a balance between the traditional content-oriented goals of engineering (e.g. foundational knowledge, application, and integration) and the more student-oriented goals we have introduced (e.g. self-realization, identity and values formation, and self-directed learning). Introducing project-based and service learning has meant that there is less time available for instruction in content and application. Our faculty members regularly discuss this issue, but we suspect it will be an ever-present tension as we strive to bring the highest quality education possible to our students.

Conclusion

The panel session will have presented panelists and audience participants opportunities to explore and experience the characteristics and strategies of the innovative pedagogies. Discussions will have been held in a team building environment to consider the issues and opportunities with implementation of the different pedagogies in their own classrooms. At the end of the session there will be networking and a sign up for a mailing list of participants to create the potential for continuing discussions.

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