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A Virtual Community of Practice to Introduce Evidence-based Pedagogy in Chemical, Materials, and Biological Engineering Courses

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Dr. Stephanie Farrell is Professor of Chemical Engineering at Rowan University (USA) and Fulbright Scholar in Engineering Education at Dublin Institute of Technology (Ireland). She obtained her PhD in Chemical Engineering from New Jersey Institute of Technology in 1996. Prior to joining the faculty at Rowan in 1998, she was an Assistant Professor of Chemical Engineering and Adjunct Professor of Biomedical Engineering at Louisiana Tech University until 1998. Dr. Farrell has contributed to engineering education through her work in experiential learning, focusing on areas of pharmaceutical, biomedical and food engineering. She has been honored by the American Society of Engineering Education with several teaching awards such as the 2004 National Outstanding Teaching Medal and the 2005 Quinn Award for experiential learning. Stephanie has conducted workshops on a variety of topics including effective teaching, inductive teaching strategies and the use of experiments and demonstrations to enhance learning.

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Stephen Krause is professor in the Materials Science Program in the Fulton School of Engineering at Arizona State University. He teaches in the areas of introductory materials engineering, polymers and composites, and capstone design. His research interests include evaluating conceptual knowledge, misconceptions and technologies to promote conceptual change. He has co-developed a Materials Concept Inventory and a Chemistry Concept Inventory for assessing conceptual knowledge and change for introductory materials science and chemistry classes. He is currently conducting research on NSF projects in two areas. One is studying how strategies of engagement and feedback with support from internet tools and resources affect conceptual change and associated impact on students' attitude, achievement, and persistence. The other is on the factors that promote persistence and success in retention of undergraduate students in engineering. He was a coauthor for best paper award in the Journal of Engineering Education in 2013.

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Brittany Nelson-Cheeseman is an Assistant Professor in the School of Engineering at the University of St. Thomas in St. Paul, MN. She received her B.S. in Materials Science and Engineering from the University of Wisconsin - Madison, and her M.S. and Ph.D. in Materials Science and Engineering with a Designated Emphasis in Nanoscale Science and Technology from the University of California - Berkeley. She was also a post-doctoral researcher at Argonne National Lab in the Materials Science Division, working in the Center for Nanoscale Materials.

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Cheryl A. Bodnar, PhD, CTDP is an Assistant Professor (Teaching Track) in the Department of Chemical and Petroleum Engineering at the University of Pittsburgh. She also is certified as a Training and Development Professional (CTDP) from the Canadian Society for Training and Development (CSTD). Dr. Bodnar's research interests relate to the incorporation of active learning techniques in undergraduate classes (problem based learning, games and simulations, etc.) as well as integration of innovation and entrepreneurship into the Chemical and Petroleum Engineering curriculum. In addition, she is actively engaged in the development of a variety of informal science education approaches with the goal of exciting and teaching K-12 students about regenerative medicine and its potential.

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ABSTRACT

This paper describes a model for a virtual community of practice (VCP) to support faculty efforts to adopt research-based instructional strategies in Chemical, Materials and Biological Engineering courses. The VCP was built on published recommendations for successful faculty development programs. The VCP program began with a 10 week virtual training period for five pairs of VCP leaders, during which they acquired the skills and knowledge needed to lead the faculty VCP. The faculty VCPs focused on one of five technical disciplines and were led by a pair of leaders having expertise in a specific technical focus area as well as in engineering pedagogy. Workshops were held using Internet conferencing software: the first 8 weekly workshops provided training in research-based pedagogy, and the second 8 biweekly workshops supported faculty efforts to implement chosen strategies in their courses. The participants were full-time faculty members with a range of teaching experience and pedagogical expertise, ranging from novice to expert. Improvement was measured via pre/post survey in the areas of familiarity and use of research-based pedagogy, as well as in perceived student motivation.

The second part of the paper focuses on the translation of faculty participant experiences from the VCP into the classroom as they implemented a variety of instructional methods in their courses. We describe their approaches and preliminary results using different instructional methods such as flipping the classroom, using game-based pedagogy, promoting positive interdependence in cooperative-learning teams, peer instruction, small group discussion, Process Oriented Guided Inquiry Learning (POGIL), and using Bloom's Taxonomy to structure a course.

INTRODUCTION

There is an abundance of research from cognitive sciences and related fields demonstrating the effectiveness of teaching approaches that engage students in the learning environment. Research on instructional practice and learning in engineering has led to a variety of teaching strategies that effectively increase student motivation and enhance learning outcomes. These strategies are accessible to educators through a variety of mechanisms such as journals and conferences, workshops, and webinars. Studies have shown that most faculty and department heads are aware of a variety of educational innovations and research-based instructional strategies, [1, 2, 3, 4] yet most engineering faculty continue to rely on traditional methods of delivery in their courses.

Over a decade ago, Felder et al.[5] explained that the gap between the current state of knowledge and the practice results are due to the perception and reality that good teaching is not valued in terms of career advancement. The authors made a compelling case for the need to create a positive campus climate for good teaching. Further research has shown that many faculty who attempt to implement research-based instructional practices (RBIS) stop using them when they encounter challenges or barriers.[2] These include lack of class time, lack of instructor time, lack of rewards or recognition, and fear of student resistance.[2, 6, 7] Ongoing mentoring and support can help address these well-understood challenges. [2, 4, 8, 9, 10]

The ASEE Virtual Communities of Practice (VCP) project[11] was launched to support faculty design and implement research-based instructional strategies (RBIS) in their engineering courses. The VCP project was a collaborative effort between the National Science Foundation (NSF) and the American Society of Engineering Education (ASEE). The overarching goal of the VCP project was to develop interactive and collaborative communities of instructors who share common goals related to the implementation of RBIS in engineering courses. The virtual aspect of the project aims to overcome the barriers of cost, scale and physical location that are inherent with local (face-to-face) communities.

A previous paper described the structure, goals, organization and technology of the VCP for Chemical, Materials, and Biological Engineering[12], but the previous paper did not include any detailed information on the instructional innovations developed and implemented by individual members of the community. This paper specifically focuses on the experiences of eight participants who transformed their courses through the implementation of a variety of RBIS. Faculty participants developed individual action plans to transform their course through RBIS using approaches such as game-based pedagogy, cooperative learning, peer instruction, small group discussion, case-based teaching, Process Oriented Guided Inquiry Learning (POGIL), and hierarchical learning objectives based on Bloom's Taxonomy. Each course transformation is described and results are presented in terms of student learning, student engagement, and student feedback.

VCP MODEL

The organization and structure of the community of practice was built on an existing knowledge base that recognizes that motivation should guide development efforts.[13, 14] Specifically, for this engineering and technical audience, the recommendations of Felder *et al.*[15] for successful faculty development programs were followed:

- Facilitators had expertise in both engineering and pedagogy
- Facilitators used engineering-related examples and demonstrations
- Facilitators identified and targeted the needs and interest of the participants
- Facilitators provided choices of different methods for implementation
- Facilitators modeled the recommended pedagogy during the workshops
- Participants had opportunities to practice the new content in a supported environment
- Participants were actively engaged throughout the training

This section presents a brief overview of the VCP model and the community participants. For more detail on the structure of the VCP, the reader is referred to the paper by Pimmel et al.[11]. The VCP used a two-tier structure that included a Leadership VCP and a Faculty VCP.

Leadership VCP

The leadership VCP comprised 6 weekly sessions which prepared five pairs of faculty leaders to facilitate their own VCPs in different subject areas. These sessions, led by Karl Smith and Cynthia Finelli, were conducted weekly and lasted approximately 1.5 hours; there were also two follow-up sessions after the faculty leaders began leading their own VCPs. The six sessions provided an introduction to the VCP and training in research-based practices of active learning, enhancing motivation, learning objectives and Bloom's Taxonomy, as well as student teams and cooperative learning. Final sessions focused on reflection, planning, and practice using the virtual technology. Throughout the sessions, the leaders modeled research-based instructional practice to the trainees.

Faculty VCP

The second tier was the Faculty VCP sessions, led by the two trained faculty facilitators and attended by faculty participants. This VCP was established for faculty teaching courses in chemical engineering, materials science and biological engineering and was led by Stephanie Farrell and Stephen Krause. Eight sessions during the fall semester focused on introducing research-based pedagogy to the faculty participants. By the end of the fall semester, the faculty participants developed and presented an action plan for implementing research-based pedagogy into their spring courses. The spring semester VCP sessions were conducted approximately every two weeks, with each session being held on two different days to accommodate the schedules of all the participants. The purpose of these sessions was to provide ongoing support to the participants as they implemented the enhanced pedagogy in their courses. The format of the spring semester VCP was a faculty-driven, open-ended discussion that focused on their successes and challenges in implementing their pedagogical enhancements.

Participants

Eighteen participants were chosen from applicants in the fields of chemical engineering, materials science, and biological engineering from large and small engineering schools across the United States. All participants were full-time faculty members; their experience ranged from never having taught a course before and having no exposure to pedagogical methods of engagement to 20 years of teaching experience with extensive use of active learning and teamwork. Most participants had some teaching experience but little support or modeling for implementing effective pedagogy in their classes. All participation was on a voluntary basis.

The VCP sessions were conducted using Adobe Connect Internet conferencing software. This software allows the use of screen sharing, breakout discussions, participant polling, session recording, and a variety of other features useful for maintaining an environment of engagement and interaction. A web-based portal was also created using the Open Atrium collaborative toolkit, and this was used to post resources and facilitate asynchronous group discussion between VCP sessions.

IMPACT

This section describes the evaluation and results of the Virtual Community of Practice for Chemical, Materials, and Biological Engineering Courses. This summarizes the results presented previously by Farrell and Krause.[12]

Evaluation

A pre/post VCP survey was used to evaluate three areas of impact: (1) participants' familiarity with research-based pedagogical strategies before and after the VCP; (2) participants' frequency of use of research-based pedagogical strategies before and after the VCP; and (3) student motivation with the implementation of the research-based pedagogy. The results for the 12 faculty participants who completed the entire VCP cycle were used in the analysis.

Results

The results of the pre/post survey on familiarity with pedagogy showed significant gains in familiarity with Bloom's Taxonomy, learning objectives, active learning, and cooperative learning, and student motivation. The participants' ratings of familiarity with pedagogical strategies before and after the VCP are shown in Figure 1.

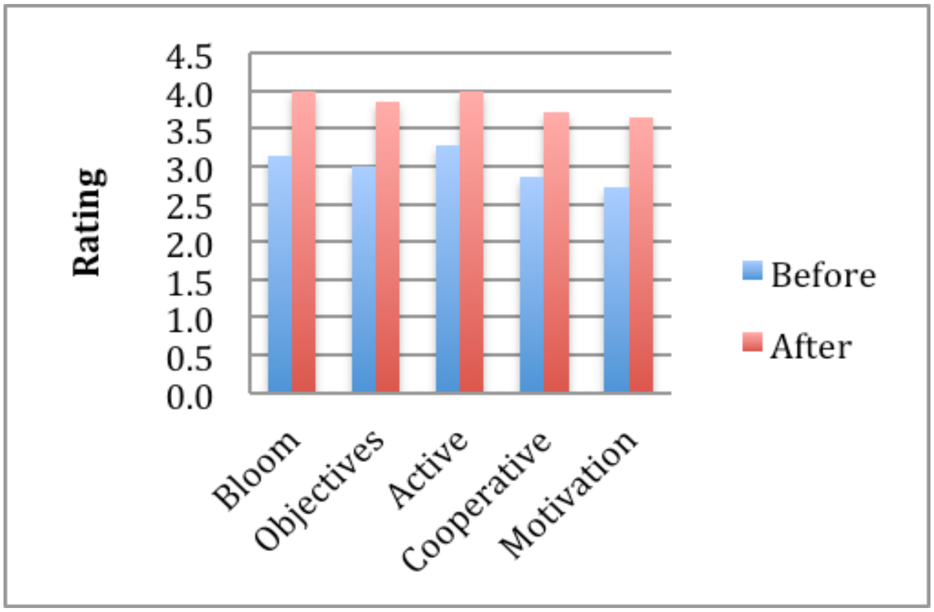

Figure 1. Faculty participants' familiarity with topics before and after the VCP. Familiarity was rated on a scale of 1 (unfamiliar) to 5 (very familiar).

The results of the pre/post survey showed noticeable gains in frequency of use of these tools and approaches in their course as shown in **Figure 2**.

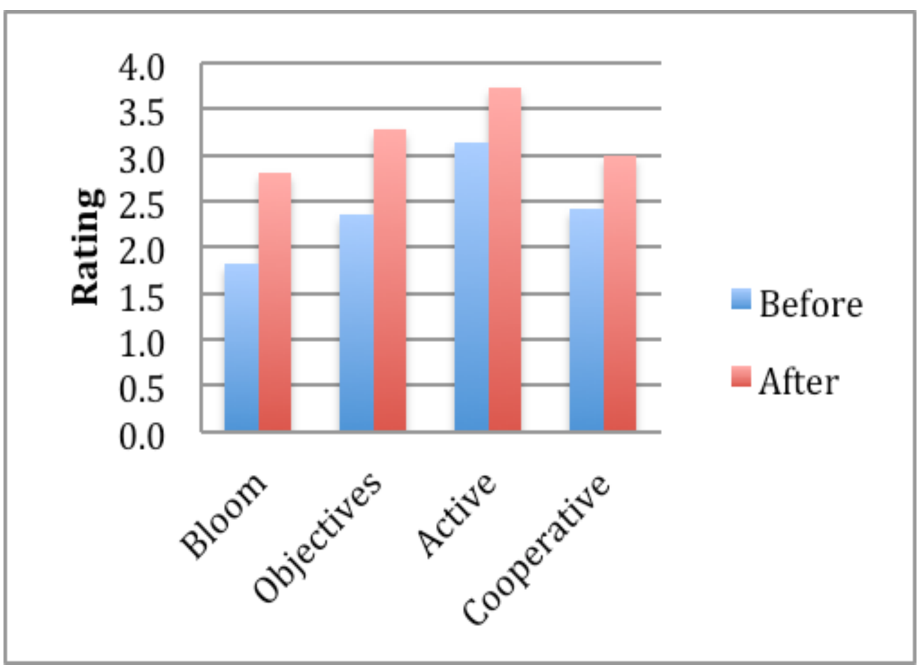

Figure 2. Faculty participants' frequency of use of pedagogical strategies before and after the VCP. Frequency of use was rated on a scale of 1 (never) to 5 (in all classes).

The results of faculty perception of student motivation were very positive. The survey asked faculty to describe student behavior in eleven areas that are closely associated with motivation. They were asked to describe student behavior prior to the implementation of enhanced pedagogy and after the end of the course in which the enhanced pedagogy was introduced. The normalized average gain was between 36.4% and 69.7% in ten of the 11 behaviors linked to student motivation:

- students coming to class on time
- students using critical thinking
- students seeming interested in the class
- students appearing motivated to perform well in the class
- students seeking help outside of class
- students being non-disruptive in class
- student participation in class
- students' ability to apply material learned in class
- student attendance
- students keeping up with reading.

The results were perplexing with regard to the perception of student performance on exams, which showed a negative change. One faculty member's response was eliminated because the individual informed us that exams were not used in the class this year. Some of the faculty have suggested that they gave more challenging exams because of their perception that students were achieving deeper learning. This question has not yet been explored with every member of the virtual community, but our informal analysis suggests that it may be difficult to compare exam performance between the control group and the intervention.

PARTICIPANTS' EXPERIENCES AND RESULTS

At the conclusion of the second semester of the VCP, each participant had implemented his or her course transformation using RBIS. From the conversations during the VCP sessions, the idea emerged for the participants to disseminate their RBIS experiences with the broader community at the ASEE Annual Conference. All participants who completed the VCP were invited to contribute to this paper. A special session has been organized in which the authors of this paper will share their research-based instructional strategies for chemical, materials, and biological engineering courses.

Redesign of "Error Analysis and Optimization Methods" (Nancy Ruzycki)

At the University of Florida, the Department of Materials Science and Engineering has been undergoing curriculum redesign using research based learning strategies, and data for informed decision making. For the 2013-14 year, EMA3800 – Error Analysis and Optimization Methods, a sophomore introductory course in the materials curriculum was selected for redesign. Previously, the course had been combined with a graduate class, and student feedback data indicated that this course should be separated from the graduate class, and the course content needed to be redesigned to better support undergraduate students in statistical analysis and experimental design.

The previous course design can be seen in Table 1. Student feedback indicated that undergraduate students felt that they did not have requisite background knowledge to successfully approach course content at the level it was presented. The class format was a mixture of live and video-taped lecture, and the textbook was *Measurement and Analysis for Engineering and Science*[16]. The graduate students had an additional research project in their grade structure, but for undergraduates their final grade was composed of 3 exams that constituted 54%, a final exam worth 26%, and homework worth 20%. All students (graduate and undergraduate) took the same exams.

Table 1: Spring 2013 EMA3800

Topic	Weeks
Introduction to measurements	1
Electronics and circuits	2
Measurement Systems and Data Acquisition	3
Statistical Analysis of Measurements	2
Uncertainty Analysis	2
Regression and Correlation	2
Design of Experiments	2

The new course was completely redesigned, and content was changed after consultation with multiple faculty members in the department about what information and skills should be developed in this course. Each learning outcome was paired with a student-produced work, so that all of the concepts and models taught had an application. All of the applications utilized engineering data collected within the department, and some of the data correlated to content they were learning in their other sophomore materials class (EMA 3011 – Fundamental Principles of Materials), as well as their Physics class and laboratory. Table 2 shows the content breakdown for the newly designed course. The texts for the class were changed *to An Introduction to Error Analysis*, John R Taylor, 2nd Edition, 1997, University Science Books, and *A First Course in Design and Analysis of Experiments*, Gary W. Oehlert, 1st Edition, 2000, W. H. Freeman.

Table 2: Spring 2014 EMA 3800

Topic	Student Product	Weeks
Why do we care about error analysis? Uncertainty in measurement. Propagation of uncertainty. Statistical analysis of uncertainty, Normal Distribution. Getting started with MatLAB or SciLab.	Statistics Concept Inventory Homework Taylor (individual) Student in class activities on measurement and error analysis (group) MATLAB programs on error analysis (group and individual) In class formative assessments	2
Rejection of Data Weighted averages Least Squares Fitting Covariance and correlation Poisson Distribution Chi-Squared Test for Distribution	Homework Taylor (individual) Student in-class activities using experimental data (group) MATLAB programs (group and individual) In class formative assessments In class Summative Assessment (EXAM)	3
Decision Analysis Bayesian Analysis	Student in class activities using experimental data (group) In class formative assessments Student decision making projects	1

Topic	Student Product	Weeks
Design and Analysis of Experiments Randomization and design Completely randomized design Contrasts Multiple comparisons Checking assumptions Power and Sample size Data Cleaning Tests of significance How your research questions determines statistical analysis (what test to use when)	Homework Oehlert (individual) Student in class activities using Oehlert text, and experimental data for data cleaning (group) MatLAB data cleaning exercise. In Class Summative Assessment (EXAM)	3
Student projects in error analysis and experimental design related to a specific departmental focus area.	Student Analysis of Experimental Design Group Analysis of experimental design and data Student and group experimental design proposal/peer review Student research presentations Paper on student research project (group) Concept inventory (post) In class final Summative Assessment EXAM	3

Additionally, grading was restructured with the final grade composed of student products worth 70%, student formative assessments 10%, in-class activities 10%, and summative assessments 10%.

The class was focused on student centered activities, and model building. Specific support from the Virtual Community of Practice was for classroom activities including; "Think, Pair, Share", In-class paired problem solving/solution demonstration, "whiteboarding", and "Students as Experts". The research supporting the developed classroom activities include the work of Richard Felder's Cooperative Learning [17], David Hestenes' Modeling Instruction in Physics[18], and *How People Learn* by John Bransford.[19]

The support of the Virtual Community of Practice (VCP) served a vital purpose as a sounding board and vetting tool, as well as a peer learning resource. Having weekly meetings where one could listen to what others were doing, sharing problems and solutions, and asking for feedback were important for supporting changes to the curriculum. In particular, the VCP helped this author to refine in-class activities and manage students during this time (once students warmed up to the activities, it was difficult to get them back to focus on the wrap-up parts).

Student feedback to the course structure was elicited, and changes were incorporated based on their feedback. Students wanted at least one group problem solving, one whiteboard exercise per lesson, and wanted extended peer "Students as Experts" for problem solution demonstrations.

On a scale of 1-5 students rated the Instructor a 4.9 overall (college mean 4.14). The ratings had a 96% response rate, and students rated "stimulation of interest in the material" as 4.85. In their ratings, students supplied many good ideas to improve the class for the next year, including new ways to organize the material, such as incorporating programming, and homework sets. A typical comment on the course is "I expected this course to be boring because it is based on statistical analysis, but in fact it was my favorite class this semester. I feel that I learned a lot from both in-class activities and the two text books we used and that I can now comfortably approach experimental design and preliminary analysis of data", and "This course has high relevance to any engineering major and the skills I learned here will definitely be beneficial to my career. I liked the Taylor book we used and thought we went at an appropriate speed despite finishing the book in just half a semester. I also like the assignment of a data analysis project where we get the chance to manipulate real data using the tools we have learned this semester."

The pre-post concept inventory used was based on Taylor's text, and did not cover all concepts learned in the course. Students showed an average post score of 80% with a gain of 30%. This would not be unexpected given few students in the course had any significant statistics background prior to taking the course.

In Spring of 2014, the Instructor won a Faculty Award from the Department, and in Fall 2014 was name an Anderson Faculty Fellow, an award based on sophomore student nominations for excellence in teaching. The course, with changes suggested by student feedback will be taught again Spring 2015.

Hierarchical Learning Objectives in "Physical Materials I and II" (Amber Genau)

Creating explicit learning objectives can help both students and teachers focus on the particular skills and abilities that students should take away from a course. The best learning objectives are student centered and break complex tasks into specific, actionable items [20]. Bloom's taxonomy, a hierarchical description of cognitive ability [21], equates particular verbs with different levels of ability, and provides a useful framework for creating measurable learning objectives (MLOs). An updated version of Bloom's taxonomy lists six ability levels, from lowest to highest, as *remember, understand, apply, analyze, evaluate, and create* [22]. Verbs associated with the first level include *list, define*, and *recite*, while the third level includes verbs such as *calculate, illustrate*, and *organize*.

Each year, this instructor teaches Physical Materials I and II (MSE 281 and 381), both required courses for materials engineering majors at the University of Alabama, Birmingham. Watching several cohorts of students move through these sequential classes, it was unsurprising to discover that students who did not master the basic concepts struggled with more advanced applications. However, it was surprising to discover that the students themselves were not aware of this as a problem. A student might come to office hours asking for help with a design problem, but would be unable to discuss the problem because they didn't know definitions of important terms in the problem.

To address this issue, this instructor has implemented hierarchical MLOs as exam review for both classes. Each subtopic is presented as a multilevel bulleted list, as in the example from MSE 381 below. Level 1 objectives (black circles) are basic tasks corresponding to Bloom's lowest *understanding* level, and represent the minimum level of knowledge required to pass the course. Level 2 (white circles) correspond to Bloom's *apply* or *analysis* levels (2 and 3), and roughly correspond with a "B" in the course. Level 3 (black squares) are the most complicated tasks corresponding to Bloom's levels 4-6 and an "A" level of understanding for the course. This scheme is clearly explained to students when they are given the review sheets, emphasizing that understanding a topic is not black and white, but incremental, and that it is difficult to tackle higher-level objectives without first understanding the basics.

- Define heterogeneous nucleation.
- Define contact angle (aka, wetting angle).
    - Calculate the wetting angle based on relative interfacial energies.
- Define the shape factor.
    - Plot the shape factor as a function of wetting angle.
        - List and explain the factors which influence the minimum undercooling necessary for heterogeneous nucleation to occur.

Anecdotal evidence favors the MLOs as a review tool, compared to the straight list of topics provided previously, with favorable verbal feedback from students. In the future, the instructor plans to build assignments and exam questions to more closely reflect the connection between the MLO hierarchy and grading, purposely including level 1, 2, and 3 questions. Although this instructor was somewhat familiar with both learning objectives and Bloom's taxonomy before participating in the VCP, she had not directly used either one in previous classes. The VCP program provided both structure and accountability, forcing her to create time in her schedule for incorporating pedagogical research into her classroom practice.

A Flipped Classroom Approach to "Introduction to Materials Science and Engineering" (Brittany Nelson-Cheeseman)

During the VCP experience, Professor Brittany Nelson-Cheeseman was a second year tenure-track faculty member at a private teaching college. She focused her VCP experience on changing a required upper-level "Introduction to Materials Science and Engineering" course for Mechanical Engineering majors. The format of the course before the change was primarily lecture slides with a few clicker questions, demos, and short videos throughout lecture. While the students had given the instructor good evaluation scores in the past, the instructor was frustrated that most students did not appear to master the course material at the depth she desired. She felt that most students did not keep up with the reading, crammed for exams, and did not master underlying mechanisms and conceptual linkages. The instructor hypothesized that this was due to the large amount of material to be covered and the lack of time for in-depth interaction with the course material. In short, she felt too much time was spent in lecture with the instructor *introducing* students to course material instead of the students actually *applying* the course material.

The Fall 2014 VCP discussions allowed the instructor to learn about key aspects of learning theory and evidence-based pedagogy in a structured, accessible environment. This foundation was critical for (1) increased understanding of terms used in the literature (e.g. Bloom's Taxonomy) and (2) more productive participation in a number of faculty development opportunities on campus, including workshops and in-person learning communities. The in-person Faculty Learning Community (FLC) she participated in during Spring 2014 read the book, <u>Effective Instruction for STEM Disciplines: From Learning Theory to College Teaching</u>[23]. This introduced the instructor to The Testing Effect and its connection to long-term memory, which is now a foundational concept in her teaching philosophy.

In Spring 2014, the instructor altered her course towards a flipped learning environment in order to spend more in-class time applying concepts. She introduced pre-lecture reading and quizzes, and filled class time primarily with clicker questions, including some demos and videos. The main challenge encountered was that pre-lecture quizzes did not adequately motivate students to read the material and, thus, class time was still spent introducing students to material through contrived clicker questions. Student learning improved only marginally.

The lack of student motivation was overcome in Fall 2014 by restructuring the learning readiness activities. At the beginning of each class period, students took a short individual quiz and then a team IF-AT (Immediate Feedback Assessment Technique)[24, 25] quiz. While this took up class time (7-10 min total), it motivated students to prepare for class, fostered collaborative/team-based learning, and allowed students to practice knowledge recall and discuss comprehension (lowest levels of Bloom's Taxonomy). This freed up the majority of class time for clarifying misconceptions and focusing on higher levels of learning (e.g. application, analysis, and evaluation). Student learning dramatically increased as evidenced by an average learning gain of 0.53 from pre- and post- concept inventory tests and a 10% increase in average final exam performance (70% (F13 & S14); 80% (F14)). The instructor also perceived that students had increased fluency with vocabulary, more robust concept linkages, and increased retention from previous exams to the final. From a year earlier, the median post-test Concept Inventory score went from 15/30 (50%, F13) to 21/30 (70%, F14).

The Spring 2014 VCP discussions allowed the group to share informal, anecdotal techniques and results quickly and easily. The turnaround time and effort was much less than communicating through the published literature, creating a more straightforward way to both gather and disseminate information. In part, due to the success of this VCP, the instructor in now leading an on-campus FLC of 15 faculty members on "Flipping the Classroom" during the 2014-15 academic year.

Game-Based Pedagogy in "Introduction to Chemical Product Design" (Cheryl Bodnar)

One active learning methodology that can be employed within engineering is game-based learning. Game-based learning has been used in education in a variety of different formats ranging from simple classroom-based games to commercially designed digital games[26]. The benefit of using games for teaching is that they can provide students with a designated goal, scaffolding to help them achieve this goal and then provide immediate feedback on their performance[27]. Unfortunately, there is still not a lot of literature documenting the impact of applying games on student learning outcomes within an engineering education environment.

Through her participation in the Chemical, Materials and Biological Engineering Virtual Community of Practice (ChE VCP), Dr. Bodnar sought to determine the impact of utilization of game-based learning on student perceptions of the classroom environment and student learning outcomes within a sophomore level Introduction to Chemical Product Design class. Dr. Bodnar was interested in performing this study as she has seen the benefits of using games in other courses that she has taught, but had never performed any assessment to determine the actual impact of their application on student learning. As part of this study, two sections of the Introduction to Chemical Product Design class were offered. The first section was run with active learning methodologies such as clicker questions, think-pair-share, case studies and group discussions while the second section utilized the same strategy but had additional game-based learning components. These components included live classroom games and the use of a game-based portal for student homework.

Assessment of the benefit of game-based learning was performed through the use of the College and University Classroom Environment Inventory (CUCEI) and a selection of questions from the National Survey of Student Engagement (NSSE) alongside analysis of student performance on clicker questions throughout and during a review session at the end of the course. Results from the CUCEI survey indicated that students in the game-based class rated the classroom environment higher across all seven dimensions with statistical significance being achieved on the personalization dimension although this was no longer significant after accounting for multiple comparisons[28]. Analysis of student performance on clicker questions throughout the course demonstrated that students in the game-based learning class performed as well if not better than students in the other class section. Review of the results from the summative assessment performed on the last day of class revealed similar trends. In addition, it was found that students in the game-based section had statistically significant better performance on certain course learning outcomes such as market analysis and brainstorming. These preliminary results indicate that game-based learning may be helpful in promoting students' retention of class content [29]. For this reason, future implementations of this class will be offered utilizing the game-based learning pedagogy.

The ChE VCP was very helpful during this study. It provided a network of talented and invested professionals that were willing to listen to the challenges that were being faced and provided constructive feedback on how the study could be improved, as well as perspective on the results being gathered. It also provided a framework for developing new tools and instruments that could be used to further the studies performed. This VCP participant believes that the support and guidance provided by the ChE VCP was a significant contributor to the success of this study.

Flipped Classroom Approach to Systems Physiology and Design (Joseph De-Chung Shih)

The instructor's participation in the ASEE VCP has changed his teaching philosophy, most notably in BIOE103: Systems Physiology, a lecture course for juniors and seniors. The 2013 version of the course was co-taught by two instructors, who did so in a traditional lecture format with 75 minute lectures, bi-weekly problem sets, midterm and final exams. The senior instructor had taught the course as well in 2012, and overall they found that some students performed poorly and student ratings of this class were significantly lower than the Stanford School of Engineering mean in both 2012 and 2013 (Table 3).

In order to address these problems, the junior instructor participated in the Virtual Community of Practice in fall 2013, where he was introduced to flipped classrooms and other active learning techniques. The instructors decided to do a pilot flipped class of BIOE103 in spring 2014. Prior to class there were assigned readings of basic human physiology students were expected to familiarize themselves with. During a 75-minute class, about 45 minutes were spent outlining the newest medical knowledge of diseases and treatments in an organ system, introducing whole class surveys and "think-pair-share" exercises of complex pathophysiology questions every 15 minutes to break up lectures and encourage student participation. At the end of class the instructors presented medical case studies simulating what medical residents encounter during their rounds. Students were randomly assigned to small groups for a particular case study, giving students the opportunity to work together for the remainder of the class time. Simulating the limited time doctors have to come up with diagnosis and treatments, students had 36 to 48 hours after introduction of the medical case study to submit as a group their differential diagnosis and potential tests or treatments online. Student answers were graded based on the logic of their responses and were provided with next day feedback on the quality of their answers online. Participating in the VCP provided an online community to bounce ideas off of and helped refine the case study model and other participatory methods in real-time. These real-world tasks with rapid feedback and increased in-class student participation proved to be popular and resulted in significantly improved student ratings of the course (Table 3) while exam grades compared to previous years of the course improved for the midterm and remained similar for the final exam (Figure 3). Since the final exam is cumulative, this could indicate that students are learning the material more quickly, as demonstrated in their improved midterm grades, but are still limited by the amount of material in the class such that, by the final exam, students are saturated in how much they can learn in a period of time.

Table 3. Mean course evaluation scores by year compared with all courses in the Stanford University School of Engineering. 5 = Excellent, 4 = Very good, 3 = Good, 2 = Fair, 1 = Poor.

Year	2012	2013	2014
BIOE103	3.18	3.24	4.23
School of Engineering mean	4.28	4.28	4.32

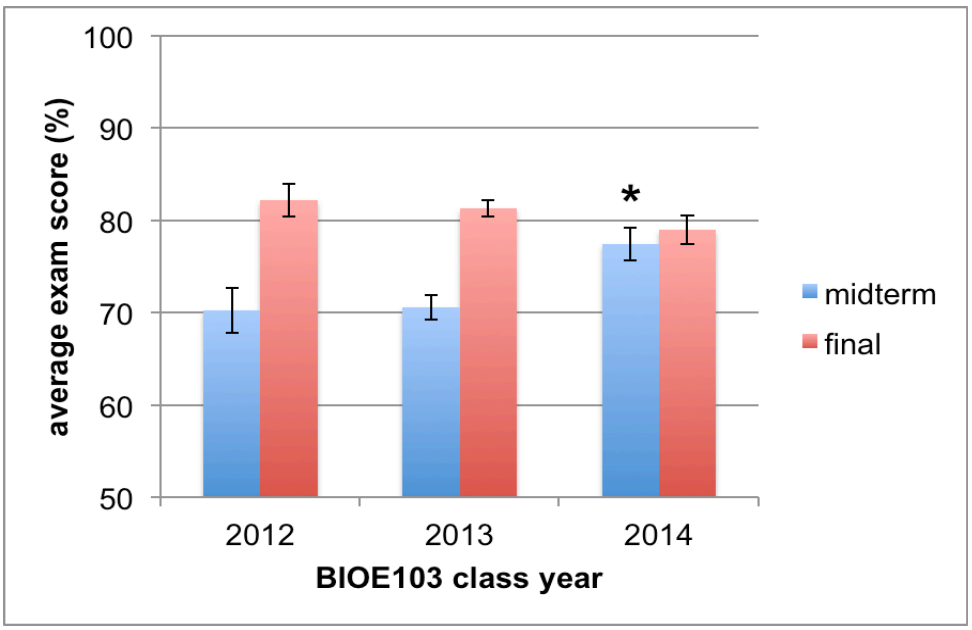

Figure 3. Average midterm and final exam scores for each BIOE103 class, 2012 – 2014. Error bars indicate standard error of the mean. N = 20 for 2012, N = 30 for 2013, and N = 26 for 2014. * P < 0.02 for 2014 midterm scores compared to 2012 and 2013 midterms.

Overall the instructors feel like the course is on the right track after a few years of low course evaluations; students are more excited about taking BIOE103 than ever before. After some initial skepticism, the senior instructor has also bought into the VCP suggestions as well once the positive student evaluations and feedback came in. For the 2015 iteration of BIOE103, there is a plan in place to flip the class more, introduce in-class case studies and limit lecture time to introducing students to the newest in medical therapeutics. The instructors are very excited to further improve the course going forward and are looking to take this course online in the future.

Peer Instruction in Heat and Mass Transfer (Daniel Lepek)

In an effort to improve student learning and engagement, the pedagogical approach used to teach the *Heat and Mass Transfer* course at The Cooper Union was changed to be focused around "Peer Instruction" during the Spring 2014 semester. "Peer Instruction" is an active-learning technique that has scientifically been shown to improve student learning [30]. Originally, the course structure was going to be changed by implementing the Process Oriented Guided Inquiry Learning (POGIL) approach, however conversations with another VCP participant, Professor Steve Yalisove from the University of Michigan, inspired this VCP participant to teach using peer instruction.

Prior to implementing this change, the course was taught by lecturing with slides, homework, exams, and computer projects. By implementing peer instruction, this instructor removed the lecturing portion of the course[31]. The main course content was delivered to the students in the form of an electronic textbook that could be annotated. To accomplish this, the course textbook, *A Heat Transfer Textbook*, was converted to annotated PDF files using the software package nb.mit.edu. This allowed students to annotate and comment on the textbook directly. In order to ensure that students read and annotate the textbook, approximately three well-though-out annotations were required for each reading assignment.

Inside the classroom, the students were required to form groups and conceptual questions were posed to them using the student response software, Learning Catalytics.[32] Instead of exams, the instructor gave short quizzes, which were used to evaluate the students' conceptual understanding of the course content. In addition, the homework assignments were now graded for effort and student reflections, instead of actual correct answers. The computer projects remained the same.

From the personal observations of the instructor, this pedagogical change significantly increased student engagement. Students became more actively involved in the classroom since they were allowed to interact with their fellow students. Compared to previous classes, the questions posed by the students seemed to be more advanced in nature. In addition, by using an electronic textbook, the instructor was able to monitor how often the students actually read the textbook. While the instructor observed an increase in engagement, a rigorous assessment would be required to conclude that student learning was significantly enhanced. The students who were taught using this approach were able to successfully complete assignments that were required for previous classes. Thus, although the classroom structure was changed to no lectures, students were able to perform just as well as previous classes taught using lecture.

The VCP was instrumental in transforming this instructor's classroom and approach in engineering pedagogy. Not only was his classroom structure changed, but the instructor was introduced to the body of knowledge on active learning and peer instruction in engineering education. Following this course, the VCP participant implemented the same instruction approach in his *Fluid Mechanics* course during the Fall 2014 semester. Similar results were found in this course, though difficulties using an electronic textbook limited the annotation part of the course. While there is significant work to restructure a course using these techniques, this instructor believes that it is worthwhile doing this, especially to obtain higher levels of student engagement and learning.

Small Group Discussions in Materials for Energy Storage (Lindsay Corneal)

At Grand Valley State University, the VCP topics discussed were applied to a "Materials for Energy Storage" course. This course is a combined undergraduate and graduate level class. One particular aspect of the VCP topics that was applied to this course was to have a graduate student grouped with undergraduate students to facilitate small group discussions.

The students receiving graduate credit for the course were required to complete an additional assignment composed of a literature review and paper on a specific course topic. Rather than presenting the information to the class as a whole, the graduate students were arranged into small groups with the undergraduate students and the graduate student presented the information that they had gathered. This was intended to build the confidence of the graduate students and provide additional exposure of the topics to the undergraduate students in addition to the exposure that they obtain from the lecture on the topic.

Observations of the activities showed productive discussions taking place. Feedback from the students indicated that they felt more confident in their understanding of the topic after the small group presentation and discussion. This improved confidence was experienced by both the undergraduate and graduate students.

Enhancing Interdependence Via Role-Taking in Group Project (Shannon Ciston)

CBE 185, Technical Communications is a junior-level required course for all chemical engineering undergraduate students at the University of California, Berkeley. The course is offered in sections of about 30 students each, and takes an active learning, workshop style approach to developing written, spoken, and interpersonal communication skills for the chemical engineering workplace. As much as possible, the instructor uses multiple-draft assignments with a high degree of authenticity, such as cover letters for entry-level chemical engineering jobs, and videos to explain a chemistry concept to a real audience of seventh graders, and a real student call for proposals.

The major team project for CBE 185 is a ten-page proposal for the US Environmental Protection Agency's P3 (people, prosperity, planet) Sustainability research and design student competition (http://www.epa.gov/p3/). Students are also required to give a 12- minute oral presentation on the proposal, and sometimes are required to create an item for a generalist audience, such as an infographic or a blog post on the topic area. Student teams rally around their proposal topic area and develop through multiple drafts and deliverables throughout the semester. This assignment is demanding for engineering students, who are still developing skills in creative problem solving and persuasive argumentation.

The course project invokes concepts from Professor Karl Smith's model of effective teams, which are elaborated in his book, Teamwork and Project Management.[33] Featuring illustrative examples, accessible language, and reviews of teamwork research, this book has been the instructor's foundation for instructing engineering students in how to function effectively in teams. Professor Smith describes the five characteristics of effective teams:

1. Promotive Interaction: Members do real work, usually face to face
2. Positive Interdependence: Members focus on a common goal, with complementary contributions

3. Individual and Group Accountability: Everyone takes responsibility for their own work and the overall work of the team
4. Teamwork Skills: Each member practices effective communication, decision making, problem solving, conflict management, leadership
5. Group Processing: Team periodically reflects on how well the team is working

In CBE 185, the instructor tries to create opportunities for students to engage with and learn about the process of teamwork by providing opportunities to develop each of these five characteristics of effective teams. The aspects of this course project unchanged by the VCP experience are described in a related post in the University of California, Berkeley Teaching Blog.[34] Approaches include: smart team formation using CATME Team Maker, assigning a challenging and multidimensional project, spending class time to coach team skills and group processing. The experience of participating in the Virtual Community built upon the instructor's prior exposure to the Smith model of teaming by providing additional materials and examples of ways to create team projects. In particular, the experience provided an opportunity to reflect on positive interdependence and to consider formal role assignments to support students in their efforts to contribute meaningfully to a group project. The materials presented several examples of complementary roles, with a focus on giving each member a chance to be a master, or take ownership of some concepts or content for a group project. These materials and the discussions with other Virtual Community members provided some inspiration to integrate role assignments as a method for developing positive interdependence.

Concepts of effective teamwork developed in the VCP experience were applied to the P3 proposal project in an effort to increase positive interdependence via role-taking. Specifically, students were required to choose from among several roles for the project, and were asked to reflect on their experience with role-taking at the end of the project.

Within one week of being assigned to a team with similar schedules and complementary skills, students were given class time to discuss several aspects of project planning as guided by a team worksheet, including topic area, aspects of audience and purpose analysis, and team roles as defined by the instructor:

Brainstormer: Lead brainstorming sessions, Suggests directions and solutions for project, Reads background information to generate new possibilities.

Examiner: Examines new ideas for merit, vets ideas with entire group. Contributes background information and detailed data.

Coordinator: Sets meeting times that work for the group, Sends a reminder before meetings, Compiles multiple components of written report.

Audience Specialist: Adjusts tone of materials to match target audience, Does background research by interviewing typical members of the target audience.

Design Specialist: Makes design choices for documents and images, Checks that all non-original images have citations, Coordinates multiple components of visual elements for cohesion.

As part of the final course student evaluations, students were invited to reflect on the impact of the role-taking on their learning experience with the following questions:

> "Please comment on how the adoption of specific roles in your team proposal project impacted your team's effectiveness. Did you keep the roles you assigned? Did it help you to develop interdependence with each member contributing in important ways to the group goals?"

Thirty-one out of 42 students responded to this prompt. Only six of the respondents indicated that their teams retained the roles chosen at the project outset and that this was helpful for their teaming process. However, an additional seven respondents indicated that the initial process of discussing roles and responsibilities gave them some basis on how they would distribute the work among their team, even though roles shifted during the course of the project. Sixteen respondents reported that their groups elected to take different types of roles, or distribute work based on skills and interests in a way that was not connected to the roles suggested. Two students reported difficulties within their team on distribution of responsibility.

Based on these responses, the instructor is reflecting on the quality and effectiveness of the suggested role assignments, considering revision of these roles, and considering integrating exercises as part of the mid-project group processing time that connect more strongly with these role identities.

Reflecting on the VCP experience holistically, this instructor especially appreciated the chance to develop community among other faculty members from across the country. Discussions with these faculty members were inspiring, exciting, and interesting, and helped to develop relationships that continue to grow with like-minded colleagues. Exposure to the types of learning methods, diverse courses, and even the virtual community technology has helped this instructor to grow.

Process Oriented Guided Inquiry Learning (POGIL) (Richard Eitel)

At Stevens Institute of Technology, Professor Richard Eitel teaches a large introductory course in materials science and engineering. The course is required of all students enrolled in the School of Engineering & Science during their junior year (>550 students/year). Depending on semester, enrollment varies from 50 to 180 students per section. With the background and support of the VCP the traditional stand and deliver lecture format has been replaced by an active classroom model. The goal was to increase student engagement, lecture persistence, and interest in the topic. The lecture format has been replaced by an active classroom using the POGIL (Process Oriented Guided Inquiry Learning) method, employing model activities from a recently published textbook[35].

The specific POGIL approach used in the current course employed several specific instructional/assessment strategies. Prior to each classroom session, students are assigned a topical reading from a traditional introductory textbook[36]. This reading is paired with an online quiz focusing on terminology which must be completed prior to the classroom session. Each classroom session begins with a brief topical introduction, followed by a team based POGIL activity. For the team based activity, students are asked to self-select a group of 3-4 students with whom to complete the activity. During the activity, the instructor and up to three peer instructional assistants float between groups to help steer discussions and stimulate inquiry. Near the end of each timed activity, a web-based BYOD polling platform is employed to deliver one or more "Concept Checks." These are conceptual or quantitative problems to provide formative assessment to the students and feedback to the instructor. Depending on the outcome of the "Concept Checks" further team based discussion or a mini lecture may be used to address specific areas of misunderstanding.

Additional out of class practice on each topic is then gained through follow up homework assignments focused on engineering problem solving and application of the knowledge gained in-class.

The effectiveness of the instructional approach was evaluated using student self-assessments. Specifically, students were asked to assess their experience and the learning environment in this course to their other coursework implementing a primarily lecture format. On the basis of these student self-assessments, implementation of the POGIL approach resulted in significant gains in nearly all assessed areas over traditional lecture based coursework. Specific gains report included: attention, critical thinking, interest in the topic, motivation, exam performance, participation, and keeping up with reading. The VCP experience was instrumental throughout the redevelopment of this course, providing both constructive feedback and specific implementation strategies relevant to creating an active learning environment in a large enrolment course. Specifically contributions of the VCP included the use of exit tickets and in-class teaching assistants (to engage/support students during group work). In addition, assessment/survey tools shared by the VCP leaders have been used extensively to fine tune the course structure and content, as well as providing scientifically grounded quantitative assessment of the efficacy of the proposed approach. Detailed results and analysis gained from these assessments will be presented separately.[37]

SUMMARY AND CONCLUSIONS

This model of a virtual community of practice for engineering pedagogy proved to be cost effective and time-efficient for the faculty participants. The VCP provided support for the development and implementation of RBIS in engineering courses. According to the pre-VCP and post-VCP surveys completed by the VCP participants, familiarity with and use of research-based pedagogy increased significantly during the VCP. Pre-post VCP survey results also show that the VCP participants' perception of student motivation, based on behavioral indicators closely associated with motivation, also increased after the research-based pedagogy was implemented.

VCP participants also observed positive results through their own course assessment, teacher evaluations, and in some cases through research designs comparing the new course to the previous course. Most of the participants reported enhanced student learning in their revised courses, pointing to evidence from pre/post tests and exam scores. Several faculty also noted increased student engagement, an improved classroom environment (from survey data), and better course and teacher evaluations. Some faculty repeated their revised course in the fall 2014 semester, and these faculty reported even more improvement the second time they taught the revised course.

The faculty also commented on the role of the VCP in supporting their implementation of evidence-based instruction in their classes. They found the VCP to be an efficient way to share knowledge about research-based pedagogy. One faculty member commented that the VCP provided structure and accountability that forced her to make time to integrate effective teaching strategies into her course. Another VCP participant appreciated the opportunity to share challenges with a supportive community, get feedback on a research design and obtain different perspectives on her results. One faculty member found the experience to be so valuable that she started a Faculty Learning Community at her own university.

In summary, the Virtual Community of Practice was a successful model for shifting faculty practice toward student-centered learning in ways that strongly benefitted participating faculty and their students. Their stories will be described personally in a Special Session at the 2015 ASEE Conference.

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