Enhancing STEM Education at Oregon State University – Year 2

Dr. Milo Koretsky, Oregon State University

Milo Koretsky is a Professor of Chemical Engineering at Oregon State University. He received his B.S. and M.S. degrees from UC San Diego and his Ph.D. from UC Berkeley, all in Chemical Engineering. He currently has research activity in areas related engineering education and is interested in integrating technology into effective educational practices and in promoting the use of higher-level cognitive skills in engineering problem solving. His research interests particularly focus on what prevents students from being able to integrate and extend the knowledge developed in specific courses in the core curriculum to the more complex, authentic problems and projects they face as professionals. Dr. Koretsky is one of the founding members of the Center for Lifelong STEM Education Research at OSU.

Dr. Jana Bouwma-Gearhart, Oregon State University

Jana L. Bouwma-Gearhart is an associate professor of STEM education at Oregon State University. Her research widely concerns improving education at research universities. Her earlier research explored enhancements to faculty motivation to improve undergraduate education. Her more recent research concerns organizational change towards postsecondary STEM education improvement at research universities, including the interactions of levers (people, organizations, policy, initiatives) of change and documenting the good, hard work required across disciplinary boundaries to achieve meaningful change in STEM education.

Dr. Shane A. Brown P.E., Oregon State University

Shane Brown is an associate professor in the School of Civil and Environmental Engineering at Oregon State University. His research interests include conceptual change and situated cognition. He received the NSF CAREER award in 2010 and is working on a study to characterize practicing engineers' understandings of core engineering concepts.

Prof. Thomas Dick, Oregon State University

Thomas Dick is a professor of mathematics at Oregon State University. He serves as the Coordinator of Collegiate Mathematics Education, as Faculty Director of the OSU Math Learning Center, and as the OSU Math Excel (Treisman Emerging Scholars) program. His main mathematics education research interests are in the use of technology to enhance teaching and learning of mathematics. He was recognized in 2009 with the Pacific Northwest Section of the Mathematical Association of America Distinguished Teaching Award. He most recently served on an Equity Task Force for the Association of Mathematics Teacher Educators.

Dr. Susie J Brubaker-Cole, Oregon State University

Dr. Susie Brubaker-Cole is vice provost for student affairs at Oregon State University. Prior to this appointment, she served for six years as OSU's associate provost for academic success and eight years as Stanford's associate vice provost for undergraduate education. She earned her bachelors' degrees in French and Comparative History of Ideas from University of Washington, and master's and doctoral degrees from Yale in French literature. She is interested in student perceptions of innovative pedagogies and course designs, and the impact of co-curricular engagement on student success.

Ann Sitomer, Oregon State University

Ann earned a PhD in mathematics education from Portland State University in 2014. Her dissertation examined informal ways of reasoning about ratio, rate and proportion that adult returning students bring to an arithmetic review class and how these ways of thinking interacted with the curriculum. Other research interests include teachers' professional noticing of learners' mathematical thinking and organizational change. Ann works on both the implementation and research sides of the ESTEME@OSU project.

Dr. Kathleen Quardokus Fisher, Oregon State University

Dr. Kathleen Quardokus Fisher is a postdoctoral scholar at Oregon State University. She is currently participating in a project that supports the use of evidence-based instructional practices in undergraduate STEM courses through developing communities of practice. Her research interests focus on understanding how organizational change occurs in higher education with respect to teaching and learning in STEM courses.

Ms. Christina Smith, Oregon State University

Christina Smith is a graduate student in the School of Chemical, Biological, and Environmental Engineering at Oregon State University. She received her B.S. from the University of Utah in chemical engineering and is pursuing her Ph.D. also in chemical engineering with an emphasis on engineering education. Her research focuses on how the beliefs of graduate students around teaching and learning interact with and influence the environments in which they are asked to teach.

Mr. john David ivanovitch, Oregon State university

I am a fourth year doctoral student studying organizational change and STEM education at the collegiate level. My education includes a BA in cell and molecular Biology and a MSc. in integrated biochemistry/microbiology. Prior to entering the Doctoral program at Oregon State University I worked for over a decade as a biomedical researcher, with projects ranging from biochemistry to molecular virology. My current education research interests include transdisciplinary integration of STEM, and teaching-related cultures at the micro-, meso- and macro levels (i.e., discipline, departmental, institutional).

Julie Risien, Center for Research on Lifelong STEM Learning

Julie is the Associate Director of the the Oregon State University Center for Research on Lifelong STEM Learning. In this role she focuses on investigating and enhancing the quality of research impacts, working to redefine undergraduate success, and working across campus to support transformation of undergraduate STEM education practices. Julie brings experience working with research organizations at OSU including Oregon Sea Grant and the Institute for Natural Resources. Prior to her work as research administrator Julie spent many years working for non-profit organizations and as a U.S. Peace Corps Volunteer on marine conservation issues including state and regional research planning and policy initiatives, citizen-science water quality monitoring and enforcement, marine habitat restoration, marine reserves establishment and monitoring, endangered species conservation and management, and community-based conservation programing in the Pacific Islands. Julie has a MSc. in Marine Resource Management from OSU. She serves as an advisor to the office of research development, and serves on the National Alliance for Broader Impacts steering committee.

Dr. Lori J. Kayes, Department of Integrative Biology, Oregon State University
Dr. Devon Quick, Oregon State University

Dr. Quick is an Instructor in the Integrative Biology Department at Oregon State University where she teaches life science students anatomy and physiology. Dr. Quick promotes student learning and success through incorporating evidence based instructional approaches into both the large lecture and laboratory courses, including active learning techniques that foster student interaction.

Enhancing STEM Education at Oregon State University – Year 2

ESTEME@OSU and the Theory of Change
In this paper, we update progress through the second year of the NSF WIDER funded ESTEME@OSU Project. The ESTEME@OSU Project is summarized below, and more detail can be found elsewhere.[1] ESTEME@OSU seeks to catalyze broad institutional change through scaling and cross-pollination of efforts utilizing two evidence-based instructional practices (EBIPs), ***interactive engagement with frequent formative feedback*** and ***formal cooperative learning***, in targeted classes in five STEM departments (integrative biology, chemistry, engineering, mathematics, and physics). Project EBIPs are based on an interactive lecture environment combined with a studio workshop-based cooperative recitation or laboratory environment; targeted outcomes are students' well-connected conceptual knowledge structures and abilities to non-linearly and iteratively solve problems utilizing conceptual understanding. The courses we have initially selected for implementation of EBIPs are calculus-based introductory courses. Normalizing effort across these courses ensures that there are opportunities for students to have multiple synergistic experiences early (i.e., in the first two years of college) in demanding STEM majors.

We use ***communities of practice*** *(*CoP) of educators as the primary mechanism for implementation and scaling of EBIPs. CoPs permit faculty and instructors to explicitly address and negotiate an *essential tension*: developing one's skill in instruction requires an educator to deepen her/his understanding and metacognition concerning what she/he is teaching (disciplinary content) and how she/he is teaching it (instructional strategies) in light of evidence concerning how people best learn. Rooted in conversations about these aspects of teaching practice, the CoPs facilitate evolving relationships amongst members with varying expertise and teaching experience. Our approach is based on the premise that in the presence of three interacting elements - (i) using community-agreed upon EBIPs; (ii) while working to increase scale, and (iii) learning about what other units are doing and how they are doing it through CoPs - we have components for emergent organizational change.

The ESTEME@OSU project seeks to catalyze organizational change with a targeted plan concerning five STEM disciplinary units. The plan operates at both *intra-departmental* and *inter-departmental* levels and builds on innovative educational activity already in place in each of the units. The *initial state* within each of the units at the start of the project is shown schematically on the left side of Figure 1. While specific activity in each inaugural unit was different, the activity largely resided within a core of central participants, who we term *innovators*. The project plan focuses on ***scaling*** processes for specific common, large-enrollment first- and second-year classes that already use

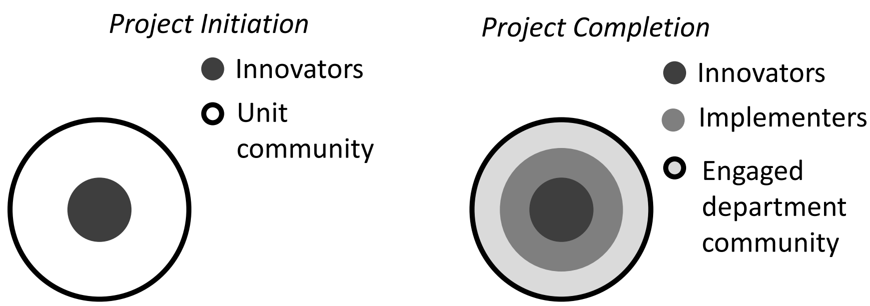

Figure 1. Schematic of increased disciplinary unit participation through *scaling*.

innovative classroom practices. The process of scaling includes increasing the number of sections, and thus students impacted, and will prompt participation by additional community members we term *implementers*. A model of the changed and engaged departmental community is shown on the right of Figure 1.

The plan for organizational change includes activity between units to promote ***cross-pollination***. A schematic of the current state and a model of the interacting disciplinary communities are shown in Figure 2. This plan was built upon an initial state where there are emerging elements of transdisciplinary collaboration such as those between physics and mathematics and between chemistry and engineering (shown by double arrows). During the process of scaling, each unit has been modifying their curriculum using shared EBIPs, with corresponding activity organized through interdepartmental communities of practice. This structure allows units to share areas in which they have experience (e.g., use of technology, GTA or LA development) and receive support from other units' expertise.

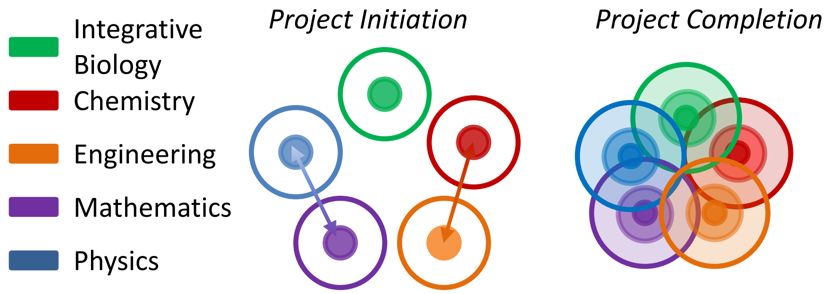

Figure 2. Increased interdisciplinary participation through *cross-pollination*.

Two EBIPs, *interactive engagement* and *formal cooperative learning*, are being utilized to intentionally cultivate development of well-connected knowledge structures and non-linear and iterative problem solving skills across courses in 5 disciplines.[1] They are based on a common architecture in all ESTEME@OSU classes: larger "lectures" punctuated by small section studio workshops (or laboratories). The relationship of EBIPs, environment, and learning goals is shown in Table 1.

Table 1. Relation of evidence-based instructional practice to learning goals

Evidence-based Practice	**Environment**	**Leaning Goal**
Interactive Engagement with frequent formative feedback	Lecture	Conceptual Understanding: Well-Connected Knowledge
Formal Cooperative Learning	Studio Workshop or Laboratory	Non-linear and Iterative Problem Solving

Implementation

Implementation in classes under the auspices of the project began Winter 2014. Table 2 lists the unit, number of courses, student enrollment, and the type of activities by EBIPs implementation over the course of the project. In sum, the project has touched approximately 27,000 enrolled students over two years.

Consistent with our guiding principle of emergent change,[2] implementation approaches differ among the five units, building on prior innovations and structures in place. These activities are distributed between interactive engagement with frequent formative feedback in lecture (POGIL,

Table 2. Implementation activity in ESTEME@OSU grant

Term	Unit	Number of Courses	Enrollment Number	Activity
Winter 2014	Integrative Biology	2	1628	Clickers; Inquiry-based laboratories
	Chemistry	3	743	Pre-post assessment by topic
	Engineering	1	161	Concept Warehouse; Cooperative learning studio
Spring 2014	Integrative Biology	3	1997	POGIL; Clickers; Inquiry-based laboratories; Pedagogically-trained LAs
	Chemistry	5	2005	Pre-post assessment by topic; Inquiry-based laboratories
	Engineering	1	233	Cooperative learning studio
	Physics	1	200	Clickers; SCALE-UP studio
Fall 2014	Integrative Biology	5	2140	POGIL; Clickers; Inquiry-based laboratories; Pedagogically-trained LAs
	Chemistry	5	2628	Pre-post assessment by topic
	Engineering	4	1389	Concept Warehouse; Cooperative learning studio; Reflection
	Mathematics	1	70	Clickers; Treisman Excel Studio
	Physics	1	398	Clickers; SCALE-UP studio
Winter 2015	Integrative Biology	4	1933	POGIL; Clickers; Inquiry-based laboratories; Pedagogically-trained LAs
	Chemistry	3	450	Pre-post assessment by topic; Flipped class
	Engineering	2	420	Concept Warehouse; Cooperative learning studio; Reflection
	Mathematics	1	70	Clickers; Treisman Excel Studio
	Physics	2	799	Clickers; SCALE-UP studio, Flipped class
Spring 2015	Integrative Biology	5	2207	POGIL; Clickers; Inquiry-based laboratories; Pedagogically-trained LAs
	Chemistry	5	1967	Pre-post assessment by topic; Flipped class
	Engineering	1	213	Concept Warehouse; Cooperative learning studio; Reflection
	Mathematics	1	70	Clickers; Treisman Excel Studio
	Physics	2	702	Clickers; SCALE-UP studio, Flipped class
Fall 2015	Integrative Biology	5	2699	POGIL; Clickers; Inquiry-based laboratories; Pedagogically-trained LAs
	Chemistry	4	1106	Pre-post assessment by topic; Flipped class
	Engineering	6	1383	Concept Warehouse; Cooperative learning studio
	Mathematics	1	78	Clickers; Treisman Excel Studio
	Physics	2	958	Clickers; SCALE-UP studio, Flipped class, Pedagogically-trained LAs

CLICKERS, CONCEPT WAREHOUSE, REFLECTION, FLIPPED CLASSROOM) and cooperative learning in studios or laboratories (INQUIRY-BASED LABORATORIES, COOPERATIVE LEARNING STUDIO, TREISMAN'S EXCEL STUDIO, SCALE-UP STUDIO). In addition, Chemistry's approach is to begin by developing a technology-based assessment process to comprehensively assess their entire lower division suite of courses (PRE-POST ASSESSMENT BY TOPIC). The activities are described in more detail below:

POGIL. Process Oriented Guided Inquiry Learning (POGIL)[3] in large lecture classes is one approach to include the EBIP of interactive engagement with frequent formative feedback. The feedback provided to teams is in-person from trained undergraduate learning assistants (LAs).

CLICKERS. Using audience response systems or clickers,[4] students answer questions to demonstrate understanding or factual knowledge of lecture content. Clickers are often used in conjunction Peer Instruction pedagogy.[5]

CONCEPT WAREHOUSE. Using the Concept Warehouse,[6] students work individually and in teams to complete concept-based activities in lecture. The instructor has immediate access to the teams' work and the tool has data analytics built in.

REFLECTION. The Muddiest Point and Most Surprised reflection activities[7] provide information and communication to the instructor about the attitudes, understanding, and learning approaches of the students that allows an instructor to directly and immediately address the specific difficulties and concerns that arise. Additionally, the activities encourage students to reflect and be metacognitive about their own learning.

FLIPPED CLASSROOM. In the flipped classroom,[8] students watch videos, read the text, and engage in other resources that present the core content and then use class time to interact in groups on activities where they make meaning and construct understanding.

INQUIRY-BASED LABORATORIES. Laboratory activities are not limited to learning specific scientific techniques and methods but rather the laboratory is designed to enable students to use the methods and procedures of science to investigate phenomena, solve problems, and pursue inquiry and interests.[9]

COOPERATIVE LEARNING, TREISMAN'S EXCEL, and SCALE-UP STUDIO. In studios, students actively apply concepts and problem-solving procedures to content that was just presented in lecture or will be presented in the next lecture as they work in teams.[10] Studios are based on cooperative learning and social interdependence theory.[11,12] Learning in studio is supported by graduate teaching assistants and instructors who interact with students in a facilitative rather than directive manner. The Treisman's Excel approach uses Treisman's Emerging Scholars model (called Excel at OSU) to form studio workshops in mathematics targeting underrepresented populations.[13] The SCALE-UP studio sections uses the classroom architecture developed by Beichner and colleagues[14] which can accommodate larger enrollments (72 students) than the others (24-30 students).

PRE-POST ASSESSMENT BY TOPIC. Chemistry's approach to ESTEME@OSU is to begin by developing a technology-based assessment process to comprehensively assess their entire lower division suite of courses. They have developed and revised a set of pre/post items as an assessment tool for the department. Students access the items using the Concept Warehouse. The survey tool allows Chemistry to compare on campus versus online courses and regular sequence courses versus trailer sections that start the quarter after the primary sequence begins and have smaller class sizes.

Communities of Practice, Scaling and Cross-Pollination

In this section we present two examples of initiatives developed by the ESTEME@OSU Program to support our strategy of scaling and cross-pollination through Communities of Practice (CoP): the Action Research Fellows Program and the Learning Assistants Program. For a more detailed description of the strategy and examples of other CoPs, see reference 1.

Action Research Fellows Program

In Fall 2015, we initiated an interdisciplinary CoP with the ESTEME@OSU Action Research Fellows Program. The purpose of the program is to support instructors already using EBIPS in lower division science, mathematics or engineering courses to take the next step in educational innovation through action research; that is, asking and answering questions about practice and collecting evidence in their own classroom to inform practice. Twelve faculty are participating in the initial cohort through nine unique projects

Fellows are supported in four ways: 1) participation in an interdisciplinary community of instructors with similar goals to apply what research tells us about learning in the classroom (four to six times over the academic year); 2) partnership with a member of the ESTEME@OSU research team with expertise in education research and classroom practice to support research design, data collection and analysis; 3) a brief consultation with a member of the ESTEME@OSU Advisory Board and 4) modest financial support. Action Research Fellows will present their findings at a "Faculty, Food, and Fun" gathering, which is an interdisciplinary CoP that occurs once a term, the Spring of 2016, and at disciplinary professional society meetings.

Learning Assistant Program

We present the Learning Assistants (LA) Program as an example of one of the ways EBIPs are propagating according to our theory of change, as represented by Figures 1 and 2. The LA program is modeled after a national program,[15] and develops pedagogically-trained undergraduate students to support ESTEME@OSU EBIPs. The program's goals include: (i) improving undergraduate student learning in STEM courses; (ii) supporting curricular reform efforts; (iii) providing high performing students an opportunity to learn about science teaching and to develop their scientific content knowledge and interpersonal skills, and (iv) providing experiential learning opportunities for OSU students.

The LA program contains three integral pieces: training, practice and content knowledge.

- First time LAs take a pedagogy course in which they discuss learning theory, teaching strategies, and students' conceptions.
- LAs practice what they learn in the pedagogy course as they teach in the classroom.
- Working with their lead faculty member, LAs select a research topic related to how students learn in the course in which they facilitate.

The program has grown through innovators in Integrative Biology. Growth is shown in Table 3. We can see that the use of LAs has grown steadily in the unit as illustrated by Figure 1, and now has reached 10 courses in Integrative Biology. In addition, as suggested by Figure 2, the LA program has been taken up by Physics starting in Fall 2015 and will be used in Engineering starting in Spring 2016.

To support this growth, the ESTEME@OSU Program is supporting professional development opportunities. In Summer 2015, we delivered a workshop for 14 educators interested in professional development in their units for the facilitation of cooperative learning (August 6). The goals of the workshop were to: (i) Develop and articulate a shared problem of practice around professional development with respect to the facilitation of cooperative learning in studio workshops, inquiry-based laboratories, and lectures; (ii) Discuss the value of interdisciplinary collaboration to address this problem of practice; (iii) Co-design interventions to address the agreed upon problem of practice for the 2015-2016 academic year. This group has continued collaboration in 2015-2016. In part, this has led to OSU hosting a regional workshop for learning assistants in Spring 2016.

Table 3. Growth of the Learning Assistants program initiated in Integrative Biology

Unit	Course	Total LAs used to date	Unique LAs trained	UG Students impacted	Terms Implemented
Integrative Biology	Human Anatomy & Physiology (Z 333)	23	23	530	1
	Advanced Human Anatomy & Physiology (BI 331, 332, 333)	22	15	230	3
	Introductory Human Anatomy & Physiology (BI 231, 232, 233)	35	8	1100	3
	Vertebrate Biology (Z 371)	1	1	200	2
	Paleobiology (Z 427)	1	1	23	1
	Principles of Biology (BI 213)	10	10	450	1
Physics	General Physics (PH201, 202)	10	10	600	2
Engineering	Process Data Analysis (CBEE 213)	7	7	225	1

Research

Our research activity is directed by a Design-Based Implementation Research (DBIR) Framework.[16,17] The research questions were first focused on the initial state of practices and norms in the units with respect to teaching and learning. In addition, the research focuses on questions whose answers will allow feedback into the implementation of EBIPs in the classroom and support of the Communities of Practice.

We have developed a model[18] relating the (a) implementation activities, (b) structure of higher education and associated theoretical frameworks, and (c) data sources to guide the continuing activities of the research group in DBIR. The model was constructed on both *a priori* (pre-award) notions of organizational functioning and change, as well as evolving notions informed by the identifications of obstacles and opportunities to study change in these complicated units. It has been used to guide the continuing research activities (planning, data collection, analysis, and writing). At its core, the model is a careful and deliberate meld of various theoretical frameworks informing problem framing and methodology, such as organizational learning, cultural models, and an understanding of aspects of our project as complex adaptive systems. Borrowed from various disciplines, these frameworks implicate diverse ontological, epistemological, and methodological assumptions and foci, encouraging us to explore learning and change from more of a systems perspective in considering various levels (micro-, meso-, and macro-), entities, and processes impacting and impacted by the organization. We explore a wide range of pertinent phenomena, including individual and collective knowledge schemas, sensemaking, routines and practices regarding pedagogy and pedagogical innovations; the movement of knowledge; and felt and realized contextual affordances for innovation, including physical resources and reward structures.

In addition, since graduate teaching assistants (GTAs) are taking a significant role in the facilitation of cooperative learning, we are seeking to understand the organizational structures designed and being designed to support GTA teaching development, as well as the activities in which GTAs participate that support inquiry into the facilitation of cooperative learning. We also seek to understand how GTAs epistemological perspectives evolve as they participate in teaching professional development and gain experience facilitating cooperative learning.

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