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Enhancing STEM Education at Oregon State University – Year 1

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Dr. Kathleen Quardokus Fisher is a post doctoral 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.

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I am a third year doctoral student studying organizational change and science 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).

Enhancing STEM Education at Oregon State University – Year 1

Overview

Development and implementation of innovative instructional practices are currently underway in courses in many STEM programs at Oregon State University. Not surprisingly, they tend to be largely siloed within a discipline, target different, specific elements, and are at varying stages of implementation. However, Oregon State University is witnessing elements of transdisciplinary collaboration emerging. The ESTEME@OSU Program presents an opportunity 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 (especially in years 1 and 2) early 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 things, the CoPs facilitate evolving relationships amongst members with varying expertise and teaching experience. Our approach is based on the premise that in the inclusion 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.

This poster presentation reports on Year 1 of this project.

Action Plan for 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.

<u>*Intra-departmental*</u>:

The *current state* within each of the units is shown schematically on the left side of Figure 1. While specific activity in each unit is different, the activity largely resides 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 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.

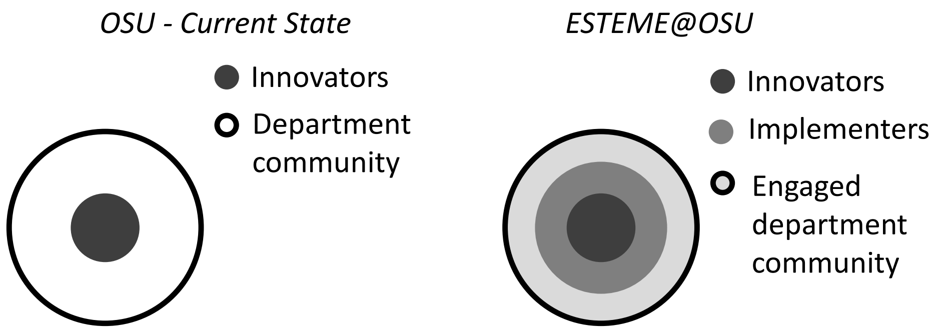

Figure 1. Schematic of increased disciplinary unit participation through *scaling*.

<u>*Inter-departmental:*</u>
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 builds on a current 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 will be 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 development) and receive support from other units' expertise.

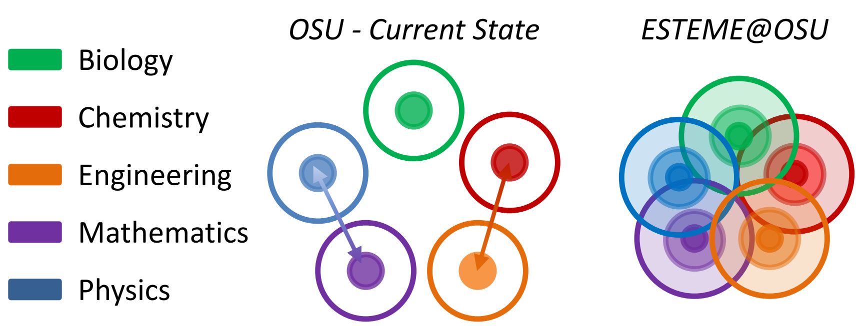

Figure 2. Increased interdisciplinary participation through *cross-pollination*.

Theoretical Foundation

Ultimately underlying our project's theory of action are models of organizational learning[1-3] and cognitive cultural models[4-7] based on research out of cognitive and social psychology that illuminates how individuals (*agents*) perceive, respond, and contribute to organizational and cultural knowledge. We recognize faculty members, even at major research universities, as agents with *critical agency*,[8] active in participation and capable of leading STEM education transformation by capitalizing on and challenging organizational norms to facilitate and secure meaningful change.[9,10] We intend to foster co-establishment of new routines towards STEM education improvement that build on and attend to the social resources within the institution[11] by uniting those possessing pertinent pedagogical and content knowledge and skills and those with typical administrative power via a distributed leadership model.[12] Our intent is to foster a continuously growing "choir" that can enact and sustain change through their work at various organizational levels and structures via *emergent* change strategies to create *reflective educators* with *shared visions/identity* regarding STEM education improvement.[13] We assume faculty, like all individuals, construct and hold cognitive "schemas" of knowledge, based on construction via experience, accessible in and impacting social situations. Our project is meant to facilitate changes to individual faculty/instructors' knowledge, attitudes, and behaviors towards improved pedagogical practices as well as the organizational distribution of cognitive schema and practices.[14]

Goals

The goals of the project include implementation, organizational change and student outcomes research, and sustainability:

Implementation:

1. Implement and institutionalize the use of the **EBIPs** (i) *interactive engagement with frequent formative feedback* (in lecture) and (ii) *formal cooperative learning* (in studio workshops) in first and second year STEM classes in the disciplines of biology, chemistry, mathematics, engineering, and physics.
2. Implement and institutionalize sustainable intra- and inter-departmental educator communities of practice (**CoPs**) to refine and propagate the use of EBIPs and to develop a venue of rich discussion, reflection, and learning about educational practice.

Organizational Change:

3. Using surveys, interview protocols, observations of classroom teaching, observations of CoPs, and artifact content analysis, study changes that occur within the 5 participating STEM department communities and the institution. We will identify significant enablers and barriers to change, and the role of the interactions amongst individuals, organizations, and structures in catalyzing change. We will identify commonalities and discipline-specific aspects of change pathways.
4. Document and distribute findings regarding larger organizational/institutional change toward improved project innovation and postsecondary STEM education improvement efforts at Oregon State University writ large.
5. Document and distribute tools and frameworks most affording successful, time-dependent inquiry into organizational change concerning postsecondary education innovation to the larger education research field.

Assessment of Student Outcomes:

6. Develop and/or improve data collection instruments and processes regarding student growth concerning: conceptual learning via concept inventory and Concept Warehouse questions; student measures of interactive engagement and frequent formative assessment viewed through the Interactive, Constructive, Active, and Passive framework (ICAP);[15] student social network development related to participation in ICAP activities; and other student outcomes measures (such as content self-efficacy) based on faculty particular interest in students in their classrooms.
7. Utilize and facilitate individualized portions of above data collection processes with faculty regarding student growth to inform reflection and change to practice.
8. Develop ICAP and social network student instrument mentioned above utilizing established rigorous and robust survey development methodologies. The resulting instrument is intended to be useful at OSU and other STEM programs across the country.

9. Compare D, W, F grades and STEM retention rates in ESTEME targeted and non-ESTEME courses.
10. Institutionalize a valid and reliable Integrated-STEM survey instrument based on a subset of meaningful items from ICAP and other student outcome instruments.

Sustainability

11. By the end of the grant cycle: (i) transfer organization and delivery of the STEM-centered CoPs into the portfolio of the Center for Teaching and Learning; (ii) imbed the *Integrated-STEM* survey instrument into Office of Institutional Research data collection processes; (iii) provide instructors continued access to the *Material Tools* used in this project such as the Concept Warehouse.

ESTEME@OSU: Evidenced Based Instructional Practices

Framework

Traditional instructional practices commonly lead students to view knowledge as a set of separate, unrelated facts[16] and to view proficiency in problem solving as being able to proceed unencumbered directly from problem statement to solution.[17] This tendency is only exasperated in cases of large student enrollment early in the curriculum. Conversely, expertise across the STEM disciplines is characterized by a **well-connected, coherent knowledge structure** in which concepts are fluent, related, and interconnected.[18,19] Expert practitioners also undergo **non-linear and iterative problem solving processes** where they continually assess, adjust, and reflect on their solution path relative to their goal.[20-22] By non-linear and iterative problem solving, we mean what the NRC Discipline-Based Educational Research (DBER) committee describes as follows:

"*Representation and step-by-step solution are interactive processes, however, and both are important in most cases of problem solving. As noted, the solver's representation of the problem guides the process of generating a possible solution. The step-by-step solution process, in turn, may change the solver's representation of the problem, leading to corresponding changes in the solution method attempted. This iterative process of representation and step-by-step solution continues until the problem is solved or the solver abandons the goal.*"[23(p.81)]

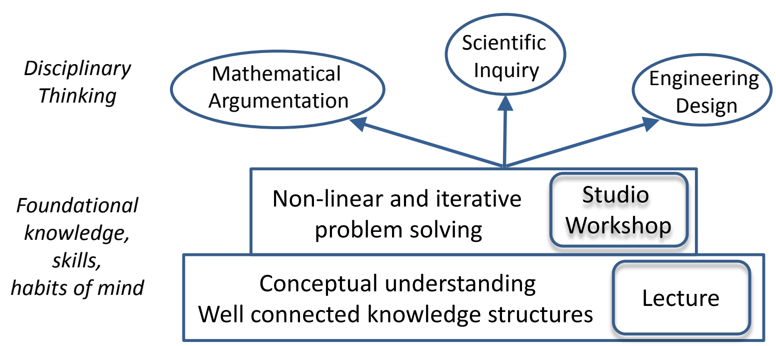

Figure 3. Foundation for disciplinary thinking

Figure 3 portrays our view that well-connected knowledge structures and non-linear and iterative problem solving are foundational skills to disciplinary thinking in any of the STEM departments participating in the ESTEME project, whether it is mathematical argumentation, scientific inquiry, or engineering design.[24-26] As such, these *habits of mind*[27] should be cultivated early in the undergraduate experience and reinforced through students' experience in courses across disciplines.

Two EBIPs, *interactive engagement* and *formal cooperative learning*, are being utilized to intentionally cultivate these habits of mind across courses in 5 disciplines. 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

Interactive engagement with frequent formative feedback:
The NRC Discipline-Based Educational Research (DBER) committee "*characterizes the strength of the evidence on making lectures more interactive as positively impacting learning as strong*." [23(p.122)] In a paper commissioned by the NRC for the Evidence on Promising Practices STEM Education Workshop,[28] James Fairweather writes "*The largest gain in learning productivity in STEM will come from convincing the large majority of STEM faculty that currently teaches by lecturing to use any form of active or collaborative instruction.*" A recent metaanalysis showed that classes with active learning outperformed classes taught solely by traditional lecture by 0.47 standard deviations and that students in traditional lecture are 1.5 times more likely to fail.[29] In the ESTEME classes, we base this practice on what Chi[15] calls *interactive activities* that both are cognitively active (e.g., students responding to conceptual questions with clickers or through the Concept Warehouse) and require socially collaborative discourse [e.g., using peer instruction[30,31]]. The connectedness of concepts is promoted by having students reason through concept based questions making connections to the lecture topics while talking to one another. Critical in these environments is for instructors to explain and model norms of social interactions and evidentiary reasoning processes.[32] The approach is consistent with the DBER committee's recommendation to pose "*formative assessment questions at higher cognitive levels and socially mediated conditions for learning such as allowing students to discuss their responses in groups before the correct answer is revealed.*" [23 (p.124)]

Formal Cooperative Learning
The studio workshops are intended to reiterate and build on the conceptual foundations of the previous interactive lecture and engage students in small group activities (mostly three-person teams) that allow students to experience non-linear and iterative problem solving. We use the mechanism of *formal cooperative learning,*[33] as based on social interdependence theory. Cooperative learning incorporates the following five principles:[34] (i) *Positive interdependence* (i.e., shared goal, rewards, resources, functional roles in group); (ii) *Face-to-face promotive interaction* (i.e., shared decisions about materials, monitoring and outcomes; reflection on the process), (iii) *Individual accountability* (i.e., responsibility for own and group's learning); (iv) *Teamwork skills* (i.e., decision-making, trust, communication, conflict-management); and (v) *Group processing* (i.e., reflection on goal-achievement, fostering group working relations). Formal cooperative learning differs from collaborative learning in its additional emphasis on structured individual accountability.[35] In a meta-analysis of 158 studies, Johnson et al.[36] present evidence that cooperative learning methods are likely to produce positive achievement results.

Johnson & Johnson state, "*Findings from the research on social interdependence have an external validity and a generalizability rarely found in the social sciences*."[37(p.371)] These studies show strong positive effect sizes on student achievement, interpersonal relations, and psychological health.

Implementation

Implementation in classes under the auspices of the project began Winter 2014. The units involved, number of courses, enrollment numbers, and activities are shown in Table 2. Some of the specific innovations are described next.

Table 2. Implementation activity in Year 1

Term	Unit	Number of Courses	Enrollment Number	Activity
Winter 2014	Integrative Biology	2	1628	Clickers in lecture and Inquiry-based laboratories
	Chemistry	3	743	Pre-post assessment by topic
	Engineering	1	161	Concept Warehouse in lecture and cooperative learning in studio
Spring 2014	Integrative Biology	3	1997	POGIL and clickers in lecture, use of 24 trained Learning Assistants (LAs) in lecture, Inquiry-based laboratories
	Chemistry	5	2005	Pre-post assessment by topic and inquiry-based laboratories
	Engineering	1	233	Cooperative learning in studio
	Physics	1	200	Clickers in lecture and SCALE-UP studio
Fall 2014	Integrative Biology	5	2140	POGIL and clickers in lecture, use of 22 trained LAs in lecture, Inquiry-based laboratories
	Chemistry	5	2628	Pre-post assessment by topic
	Engineering	4	1389	Concept Warehouse in lecture and cooperative learning in studio, introduction of teaming strategies and reflection activities
	Mathematics	1	70	Clickers in lecture and Treisman Excel Studio Workshop
	Physics	1	398	Clickers in lecture and SCALE-UP studio

POGIL. Integrative Biology: One activity in Integrative Biology has focused on using Process Oriented Guided Inquiry Learning (POGIL)[38] in large lecture classes as the approach to include the EBIP of interactive engagement with frequent formative feedback. This approach was piloted in Human Physiology (Z333) to 563 students in Spring term 2014. In POGIL, student teams work on specific activities throughout the lecture hall. The feedback provided to teams is in-person from trained undergraduate learning assistants (LAs). For this class, 25 LAs were involved. Integrated biology led development of a new LA training program so the LAs could provide effective feedback. The success of the LA program has led to initiation of LA programs in both Physics and Engineering, demonstrating cross-pollination among disciplinary units.

CONCEPT WAREHOUSE. Engineering: The School of Chemical and Biological Environmental Engineering (CBEE) is building on the use of the Concept Warehouse[39] for interactive engagement and frequent formative feedback and the recently developed studio model for formal cooperative learning.[40] Using the Concept Warehouse, 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.

TREISMAN'S EXCEL MODEL. Mathematics: Activity in Math has focused on integrating Treisman's Emerging Scholars model (called Excel at OSU) to form studio workshops in calculus (MTH 251), targeting underrepresented populations.[41] This approach was piloted in Fall 2014 with approximately 70 students and will continue throughout the series. In this course, the instructor has also woven interactive engagement into the course lecture time (using clickers) and used the calculus concept inventory in the section as summative feedback for the instructors.

SCALE-UP STUDIO. Physics: Major activities in Physics have focused on expansion of the SCALE-UP course sections building on the model of Beichner and colleagues.[42] In Year 1, Physics has increased the delivery of studio sessions from 200 students to 400 students. The sections use interactive engagement and frequent formative feedback.

Research

Research questions that are being addressed by early data analysis focus on describing the current practices and norms related to teaching and learning. These descriptive analyses will help the project team identify and address changes throughout the course of the ESTEME@OSU project, as well as identify correlations between context and processes of change. Research questions include:

1. What cultural threads (e.g., social networks, belief systems, practices and routines) are present in departmental units and interacting with teaching improvement activities?
2. What are the synergies and the nature of synergies (both formal and informal) between ESTEME@OSU and other STEM change initiatives?
3. What are the institutional and departmental contexts underlying current models for Graduate Teaching Assistants (GTA) learning about teaching?
4. What are faculty perceptions of and classroom practices of particular EBIPs? How are these perceptions and practices related to departmental and disciplinary positioning?
5. What are student perceptions of EBIPS in classroom environments? How does these perceptions relate to social network development in the classroom?
6. How does the process of faculty-selected student outcome selection and implementation relate to faculty change in teaching practice?

Discussion

Our initial experiences point to two critical elements of the ESTEME project in terms of meeting its goals: empowered actors and essential project tensions.

Empowered Actors:
Towards a Year 1 audit of project activities, we conducted informal conversations with unit leads from all the departments and one additional instructor each from Math, Biology, Physics, and Engineering. The goal was to verify activity in the departments and offer an open ended opportunity to share successes and challenges associated with the ESTEME@OSU project. All departments reported that the project has added momentum to existing efforts towards change in instructional practices. Faculty participants felt that the scale and interdisciplinary nature of ESTEME@OSU has added legitimacy to their work and empowered new faculty and faculty previously isolated in their endeavors toward change to join the community of instructors working to improve undergraduate STEM experiences and learning outcomes. The project team plans to further boost departmental activities by strategically involving administrative leadership. Leadership can add additional legitimacy to the work of instructors using EBIPs by placing their work in context of transformational change at OSU and in higher education nationally.

Essential Project Tension
The project team regularly reflects on the challenges and importance of high tensions associated with the project as we perturb the system to facilitate emergent change. The presence of tensions, while challenging to manage, aligns with the cultural historical activity theory (CHAT) framework.[43] One example of tension occurred at an inter-disciplinary CoP meeting hosted by the project. At this meeting, a member from one department identified her efforts to develop LAs into reflective practitioners through professional development as an essential feature of her approach. However, a member from another department disagreed. He suggested that it was a better use of time to only hire LAs who demonstrated "innate" teaching ability, rather than attempt to improve their teaching through professional development. The tension was interpreted to be based upon the two participants' differing beliefs about the likelihood of professional development leading to teaching improvement. This tension led to a constructive discussion among all CoP members about the complexity of the practice of teaching and the challenges to improving this practice.   It is the perception of the team that tension is a positive indicator of change. The team regularly engages with participating departments and instructors to build the social capital necessary to manage tension.

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