PEDAGOGICAL PERSPECTIVES

Policy in Support of Pedagogy: Collaboration Among Scientists, Science Educators, and Engineers in Preparing Qualified K-8 STEM Teachers

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ABSTRACT

Teachers with knowledge of science and science teaching pedagogy are essential to teaching science in K-12 schools. We present collaborative efforts among science and science education faculty members that build a science teacher program with an overarching objective of training qualified science teachers. Our Foundational Level General Science program goes beyond increasing science content knowledge. Its design fosters a sustained collaboration for faculty in science and education to integrate inquiry-based pedagogy into curricula with the goal of recruiting and retaining STEM teachers. Our experience suggests that certain policies within the higher education infrastructure are necessary to sustain these efforts.

Introduction

Current calls for science education reform point to a need for efforts outside of teacher preparation programs and professional development to sustain more than adequate shifts in science teaching (National Board of Science of the National Science Foundation (2014), National Academy of Engineering (2009), National Research Council (2009). Modeling science and engineering practices, as delineated in the Next Generation Science Standards (NGSS, 2015) in undergraduate science courses and in added authorization education programs is an ideal arena for such shifts to take place. According to the National Academy of Engineering (NAE) and the National Research Council (NRC), teachers who have knowledge of science and science pedagogy are essential to the success of science in elementary and secondary schools. To this end, the NAE has proposed that K-12 engineering education promote "engineering habits of mind" (i.e. those that include systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations (NAE), 2009). In order to address these needs, it is imperative that science (including engineering) faculty members work alongside science education faculty members to prepare future science teachers (Otero, Finkelstein, McCray & Pollack, 2006). Here we discuss how we have implemented programs and infrastructure to meet this need. We accomplish this through an increased awareness of the importance of collaboration among faculty within colleges of science and education. Consequently, other institutionalized structures have resulted as an ongoing function of science and education faculty working together to emphasize the importance of university-wide attention to these matters. Since the advent of our Foundational Level General Science (FLGS) program, our Institute for STEM Education has flourished to provide a mechanism for various science, math and engineering related practices and research to thrive. Science education programs at our institution, such as a NASA Lift-Off grant (NSF DUE #0851713) and an Integrated Middle School Science (IMSS) partnership (NSF DUE #0962804), as well as corporate funding from Bayer USA and Chevron, have created financial leverage to combine resources in developing the Institute. Faculty members' involvement in these programs have brought institutional attention to the shifts in science pedagogy and practice that are needed to meet the growing demands of STEM education. Our Institute for STEM Education continues to foster and support faculty work in this area. The current manuscript describes the development, implementation and successes of the FLGS program at CSU, East Bay as well as discusses its effects on faculty's own pedagogy and is integrated with other University initiatives (See Appendix and Table 5 for additional rationale for the program design).

In this narrative, we will provide the rationale for a particular community of practice related to preparing STEM teachers, how this community has driven our shifts in pedagogy, summarize the methods we use to study the effectiveness of our program evolution along with some of the evidence collected, and implications for the need of supportive policy at the university to sustain and grow such practices.

Essential Community of Practice

Effectively training the next generation of science teachers requires the cooperative work of individuals with diverse disciplinary expertise and perspective. In that regard, the development of the FLGS program has led not only to the benefit of shifts in teaching preparation and awareness, but also sparked the formation of new and strengthened existing communities of practice (COPs)(Lave & Wenger, 1991; Wenger, McDermott & Snyder, 2002). By working in interdisciplinary teams, with consultation from engineers (from Bechtel, Broadcom Engineering, and other corporations) and engineering faculty members, we have been able to address crosscutting themes outlined by the NGSS (such as cause and effect, structure and function, energy and matter) and more explicitly apply engineering skills and habits of mind in our own teaching. Recruitment of junior faculty in more science disciplines with the same educational interests further builds the content depth of our COPs.

The FLGS courses are unique in their combination of audience (a mix of pre-service, in-service teachers and regular university students using the courses to fulfill General Education requirements), goals, content focus, and format. As such, their development requires both a unique approach and time above and beyond that of preparing for a standard science course. All courses were developed by an interdisciplinary team of faculty and vetted through quarterly workshops involving both faculty and practicing engineers. This process strengthened the STEM connections between the courses (and the accompanying Single Subjects Methods courses in teacher education), ensured that real-world connections and applications were emphasized, and helped develop curricula that emphasized the skills needed for 21st century engineering and science. This is an important component of the program and highlights the impact of the design on several levels: preparation of K-8 teachers to integrate science content more deeply and accurately into their classrooms, integration of engineering habits of mind and project based learning as a matter of classroom practice. An increased awareness of and changes to pedagogical practices among science and science education faculty that benefit K-8 teachers has resulted from this COP.

Subsequently, the early design of the FLGS program prepared for the Science and Engineering Practices outlined in the NGSS (Table1). All classes were modified to align with the new Science Framework (NRC, 2012) in which scientific and engineering practices, crosscutting concepts, and disciplinary core ideas were emphasized. As the Next Generation Science Standards (NGSS) move through the adoption process in California, the courses continue to be modified to accommodate any further state-specific modifications to the NGSS (assessments, course design, etc.).

For example, science content area courses have been modified such that the homework had fewer quantitative problems and more assignments requiring teachers to describe real-world examples of phenomena or teaching strategies for the current topics (i.e. SEP #8, Table 1). The lab handouts were re-written so that the purpose of the lab, from the point of the view of the teacher, is transparent and focused on science practices and writing prompts that can be translated to their classroom (i.e. SEP #3, Table 1). Faculty members across the four major disciplines (chemistry, biology, earth science and physics) continue to work together to design course experiences to reflect common pedagogical approaches. As a result of the core science faculty being involved in the NSF IMSS project, teaching strategies that integrate argumentation from evidence is present (use of Claims, Evidence Reasoning

Table 1
Science and Engineering Practices (SEPs) (NGSS)

	Practice
1	Asking questions (for science) and defining problems (for engineering)
2	Developing and using models
3	Planning and carrying out investigations
4	Analyzing and interpreting data
5	Using mathematics and computational thinking
6	Constructing explanations (for science) and designing solutions (for engineering)
7	Engaging in argument from evidence
8	Obtaining, evaluating, and communicating information

(CER), MacNeill and Kracjik (2012). Since this is a consistent theme as a science practice and in both Common Core State Standards in English Language Arts (CCSS-ELA) and in mathematics (CCSS-M), CER is used in almost all written assignments in the sciences as well as in the science education courses. Further, students are required in homework assignments and in their final projects (in science courses and in education courses) to include explicit examples of how science and engineering principles, cross-cutting concepts and disciplinary core ideas are taught and reinforced through readings, assessments, media resources, and hands-on activities. Engaging in discourse with guest engineers and science faculty members during the initial meeting of the education courses also helped to frame the teachers' ideas about project-based learning and engineering habits of mind. These class periods not only unpack learning theory and best practices in the classroom but dissected hands-on activities for redesign to incorporate the elements of science, technology, engineering, and math. The major assignments in the education classes consist of redesigning current lessons to reflect authentic assessment of student content knowledge and skill acquisition. The ability of the school teachers in the program to make more connections to inquiry and project design appeared to be lasting, meaningful and more readily applied to their classroom teaching practices.

The process of making explicit to STEM teachers certain inquiry, science and engineering practices has driven not only a shift in our collective pedagogical approaches, but also in curriculum design. For instance, four upper division, undergraduate online courses and four corresponding in-person laboratory courses in chemistry, physics, biology, and earth science have been developed specifically for the FLGS program. These science courses are delivered along with teaching methods (Single Subjects Methods) courses that integrate the NGSS Science and Engineering practices. The science methods courses model specific examples of how engineering practices could be connected to the content in the four science content areas to boost application of inquiry practices among the teacher participants. An inquiry continuum rubric informed by research funded by a National Science Foundation project (Brandon, Taum, Young, Pottenger, & Speitel, 2008) informs curriculum design to allow for discussions about investigation and specific elements of inquiry (e.g., engaging the student in posing questions, encouraging the learner to design an experiment, developing the skills of supporting claims with evidence and practicing the skills of effectively communicating ideas). These elements of inquiry were likened to the habits of mind practiced by engineers in their own work. The use of these practices have driven course design and faculty pedagogical changes.

Sustaining the Need for FLGS: Methods for Evaluation of Success

Significant shifts in program curricular structure and support have resulted from a common awareness and active involvement in statewide implementation of science teaching practices and their impact on science education among faculty members involved. Without the leverage of various science projects on campus, now housed in the Institute for STEM Education, the momentum of the initial faculty vision would have waned when grant supports ended. Through our mixed methodology of data acquisition, we have gathered information from the following sources to support our rationale to sustain the FLGS and related programs: open-ended reflections from faculty and FLGS program participants, CSET scores from participants, focus groups with engineers, course syllabi (to summarize types of pedagogy and assessments), and grant funded programmatic reports.

In order to sustain this necessary program, science faculty members and science education faculty members, the deans of their respective colleges, the university provost and the Institute for STEM Education, continually work together to devise courses, curricula and experiences that address the calls to train effective science teachers. Here, we describe the necessary infrastructure needed to sustain such a program supported with data gathered in a mixed methods approach (Creswell, 2014). The effectiveness and impact of the FLGS program has been evaluated in several ways: pass rates on the CSET General Science exams, pre-post assessments in each of the content area courses, exit surveys for teaching candidates, and faculty reflections on pedagogical shifts.

First, the FLGS program has been highly effective at CSET preparation. For example, participants completing the FLGS program in 2011-2012 demonstrated 100% pass rates on their first attempts on single subject General Science CSET exams (subsets I and II). The state average passing rate for the same CSET is 82.4% (Taylor, 2014). Additionally, teachers reported that the content courses helped them to pass additional, more specialized CSET exams that allow them to teach high school level sciences.

Next, content assessments are given at the beginning of each science class and then as part of the final exams. Course instructors either design their own assessments or elect to use previously validated concept inventories. The goal of these instruments is, as in any class, to assess both content knowledge gained and the ability to apply that knowledge to problems. Test questions are designed to cover grades 6-8 science content standards and CSET expectations. Eventually, these assessments will reflect those of the NGSS (currently under development, NGSS, 2015). Pre-post test scores are used to inform achievement of course learning outcomes and to identify major misconceptions held by the students in each course. Data helps instructors reflect on efficacy of their lessons/activities and inform course modifications. In the biology courses, for instance, instructors more deliberately addressed common misconceptions in the second year of the program as indicated by the insignificant learning gains seen in concept inventory results during the first year.

Additionally, the impact of the FLGS program on participant content knowledge, experience, and teaching practices were also evaluated through the administration of self-perception exit surveys. In these surveys, 100% of the participants expressed that their science content knowledge, confidence in teaching science, and use of inquiry-based learning in science had increased. A majority of them also indicated that integration of mathematics and engineering principles in their science curriculum had increased. A minority of the teachers indicated increases in time spent on science instruction, coverage of California science standards, and integration of technology into the science curriculum. This was understandable when considering that most FLGS participants were either K-5 teachers and/or were limited by school/district guidelines and resources. Participants may also have expressed interest in teaching science but were not yet in a science classroom. What most notably changed was their confidence in teaching using project- and problem-based learning activities and their understanding that this approach was essential to engaging their students in more meaningful learning.

In the free response portion of the survey, the participants expressed increased use of more engagement strategies, including inquiry-based learning, scientific experiments and free exploration, and increased use of visuals, technology, and peer-teaching strategies. The teachers commented on the increased interest level of their students, e.g., students asked more questions, and on how they efficiently integrated strategies to more actively involve students without taking up more class time. In addition, teaching practice shifts were indicated by increased use of assessment probes to diagnose and address misconceptions (Keeley, 2005), metacognitive writing (e.g., through interactive note-booking), and using videos and podcasts to connect students to current events in science. Their students were encouraged to understand the results of their own pre-assessments and post-assessments in order to see that their ability to articulate this understanding shifted. Some participants also expressed their appreciation that the FLGS program helped them to update and further develop their content knowledge, to make cross-connections between the different science disciplines, and to help them unpack concepts, which facilitated deeper understanding and, in turn, their ability to teach these concepts.

Table 2 summarizes the most common comments provided in surveys of participant members' experiences in the FLGS program.

Participants in the FLGS program have also reflected on the pros and cons of inquiry- and project-based learning in their classrooms (Table 3). Attention to project-based learning in the classroom appeared to be one of the most compelling struggles experienced, yet provided some interesting perspectives which impacted university faculty pedagogy.

The impact of inquiry on classroom teachers has implications for science and education faculty in how we design new courses, redesign curriculum and restructure how we approach the NGSS Science and Engineering Practices. Having a university faculty with a common understanding of the values and challenges of problem-based learning has informed the work on various other STEM projects. Iterations of FLGS course lab activities have been integrated into the Hands-On Science Teaching Labs (HOST), a program aimed at developing undergraduates with science teaching aspirations. Not only does the FLGS program impact what the students experience and take to their classrooms, it impacts how faculty members prepare their own courses, learn to articulate changes with each other across disciplines, and sustain changes across STEM areas to retain and train majors and future educators.

Emphasis on Improved Pedagogy: Specific Impacts on Science and Education Faculty

Success of the FLGS program has been dependent upon close collaboration of faculty members from science disciplines. Practicing engineers contributed to course development and lab activities. These partnerships are essential to reforming science pedagogy in both K12 and higher education. Here we build a case for these synergistic efforts as they impact faculty pedagogy on campus. Because of common goals and the explicit support of the university, our efforts have stimulated a culture of attentiveness to effective practices in STEM education. During the initial development of the FLGS program, science and education faculty members reflected on the impact of the program on their pedagogical practices. They revealed that participation in the FLGS program resulted in a profound shift in their attention to creating and modeling strategies that are useful to the K-5 educator (who would then be prepared to teach grades 6-8). Table 4 summarizes trends in faculty reflections (in response to open ended,

Table 2
Common comments/ ideas from cohort member surveys (2010-2013)

	Aspects of program that impact science teaching and content knowledge
1	My increase in content knowledge has given me more confidence in teaching science in my classroom.
2	The deeper understanding of content that I have is helping me to focus on making lessons tighter.
3	The combination of greater content knowledge and the application of content to engineering and project based learning [has had a great impact].
4	The focus on hands-on learning in labs and in the implementation of problem-based learning is exciting. My students are already showing more excitement
5	I have a better understanding of how to infuse engineering habits of mind (science and engineering practices, NGSS, 2015) into my regular science lessons as well as into project based learning.
6	My students are more highly engaged in science lessons now that I have more examples of my own of how to implement inquiry.

Table 3
Benefits and barriers of problem- or project-based learning

Benefits for FLGS teachers & their students	Barriers/ challenges for FLGS teachers & their students
Learners formed reasonable and logical arguments to communicate explanations.	Element of the learner forming reasonable and logical arguments to communicate explanation was difficult for lower grade levels.
Learners became more engaged in science as a process – showed more excitement.	Some classroom students were able to communicate their argument on paper, but not verbally.
Attention to inquiry, NGSS and Common Core makes more sense in the context of implementing engineering design projects and skills.	Materials for project-based science can be scarce.
Integration of STEM and science practices are easier in the context of projects.	There is a lack of context and perspective on how to fully implement project based learning and engineering ideas into classroom science. More training and experience is needed.

written prompts) regarding these shifts in their teaching practices, making content accessible to K-5/ 6-8 educators for use in the classroom and in ways of assessing content and processing skills.

What is compelling about these trends is that it inspires faculty to increase capacity for researching these teaching styles more deeply, understanding how content is made accessible to learners and how to design authentic assessments. These are goals for many of our ongoing and future projects in STEM education in our institution. The faculty members emphasize that key to the success and sustainability of this program, future goals and its mission is more common planning time, ongoing training in assessment, use of CCSS-M and CCSS-ELA, and further integration of NGSS into more science major level content courses. Continued support from university administration for development and implementation of innovative pedagogical practices and conducting rigorous research of the program has been essential in the growth of STEM programs and the academic capacity of the faculty involved in science and math education research. Regular meeting times and release time for additional innovative planning, professional development, data analysis, and program evaluation are essential to sustained consistency and integrity of program outcomes. This is especially important for establishing institutional norms in making commitments to successful STEM teacher preparation beyond grant and foundation support. Currently, this is a priority for our sustained efforts at our university.

Preparing Qualified STEM Educators: Policy Supports Pedagogy

Ultimately, we expect that gains in teacher content knowledge, science practice, experience, and confidence will escalate the quantity and quality of science teaching in our K-8 classrooms. We have developed an inquiry-based program where assessments are geared towards measuring participants' abilities to apply content knowledge to lessons to be used in K-8 science classrooms. We have used existing relationships with community colleges, school district administrators, and local K-12 science coordinators to advertise our program. Webinars and professionally designed flyers have generated a number of inquiries. Additionally, we rely on our graduated cohorts and program alumni to disseminate their experiences and draw new participants. For instance, by requiring them to bring a guest to the final project presentation of the Science Teaching Methods course, we expose other teachers to our program. Through our connection to the Liberal Studies department at CSU East Bay, we make students in that department aware of how the FLGS courses can be used to fulfill their depth of study requirement for their degree program. We have used CSU Math and Science Teacher Initiative (MSTI) funds to offer scholarships to entice undergraduates to take these courses as a path to a STEM teaching career. What is also different about the program is that we recruit individuals who are already involved in a teacher pathway or are current teachers adding a science certification. This is in contrast to programs,

Table 4
Improvements in faculty pedagogy and approach to science education

Teaching Style	Accessibility of Content	Assessment Strategies
Adapts college level courses and lecture materials so that they are applicable to use in the classroom	Delivers content in varied forms (animations, real world examples, case studies, lab activities tied directly to lecture content)	Uses formative strategies to combat misconceptions and to build on prior knowledge
Models pedagogies that are applicable to K-8 classrooms	Identifies common misconceptions and identifies how scientific content addresses them	Assesses for ability to provide evidence for claims made and analyze data
Modifies lessons to address needs of English language learners and special needs students more explicitly	Applies content specifically to inquiry activities and engineering habits of mind to enhance relevance of concepts	Has pre/ post course assessments to reveal areas in need of improvement, where gains are or are not made
Models explicit assessment strategies for content and scientific process	Stimulates frequent communication with students (online lecture setting) to review ideas and concepts that need attention or where understanding is strong	Creates explicit course outcomes aligned more specifically to assessments
Applies content to varied inquiry approaches; Models and assesses practices more explicitly	Using the CER approach (Claims, Evidence, Reasoning) \to make content and scientific thinking accessible	Creates summative assessments that apply content to lesson planning and delivery, project design or inquiry skills

such as the Noyce Fellowship, in which there have been noted struggles in recruiting undergraduate STEM majors into the teaching profession (Schuster, 2013)(although we do recruit Noyce scholars in addition to the FLGS pathway).

We continuously improve all courses in the program based on assessment data, student feedback, workshop discussions with practicing engineers, and discussions with faculty and science educators at other institutions. Course development by faculty members is no longer compensated, because post-development course improvements are considered standard instructional practice. However, we continue to leverage new grant awards in sustaining the elements of the original FLGS program development which is crucial to sustaining our mission to train quality STEM teachers (Table 5 contains a description of qualified STEM teachers, Appendix).

Attention to and sustenance of improved science pedagogy would not exist without commitment to university solidarity and policy in support of such reforms. We continue to brand ourselves as a regional hub for STEM education and research. This is made possible via the concerted efforts of faculty to envision and implement innovative learning and research. And although our FLGS program is one of several pathways to preparing more effective science teachers, we know there is a need to support more of the various pathways in our institution to diversify and strengthen options for those gaining added science pedagogy and content skills. We know that to sustain collaborative efforts within the university and with partnering school districts, policy at the university level, and ultimately at the state level where CSU campuses are supported, require ongoing commitment to time and resources allocated to these programs (faculty time, effective teaching spaces, materials, staff support for grant implementation and research capacity among faculty and classroom educators).

Various programs across numerous universities and community colleges have worked to address the need to prepare highly qualified science teachers by developing pathways for undergraduates, and even high school students, to become interested in science, technology, engineering and mathematics (STEM) teaching careers. Recruitment of future mathematics and science teachers occurs in other pathways including the Noyce Teaching Fellowships and undergraduate pre-scholarship preparation programs (NSF, 2010; Schuster, 2013). However, even as Monk (1994) has indicated, individuals with a strong

ADDITIONAL BACKGROUND INFORMATION AND RATIONALE FOR THE FLGS PROGRAM

Table 5
Developing and retaining high quality mathematics and science teachers

	Aspects of program that impact science teaching and content knowledge
1	Attract and retain precollege science and mathematics teachers: resources must be provided to compensate teachers of mathematics, science and technology comparably to similarly trained science and engineering professionals in other economic sectors.
2	Provide quality, sustained professional development experiences for all K–12 science and mathematics teachers that will: increase and deepen content knowledge, promote a variety of pedagogical approaches and develop questioning strategies, which will advance higher order thinking of all their students.
3	Encourage higher education leaders to strengthen K–8 teacher education programs to provide a deeper understanding of the content knowledge necessary to teach mathematics and science.
4	Invest in research on teaching and learning that will better inform development of science and mathematics curricula and pedagogical approaches.
5	Review teacher education programs focusing on the extent to which prospective teachers are grounded in academic content in the subjects they will teach.

background in math and science have been difficult to recruit into science teaching positions because of their capacity to find employment in other more monetarily lucrative careers. Since then, Darling-Hammond (2000) and various others (Hill, Rowan & Ball, 2005; Rice, 2003) add that high quality teaching and student achievement are linked and addressing teacher preparation is essential for that achievement. These issues confound the need for excellent science teachers and drive changes to programs that prepare future teachers.

Additionally, the U.S. Department of Education (D.O.E.) has identified areas of teacher shortages and content areas in high need. Their reports spanning from 1990 to 2014 have consistently indicated (across all 50 states) the need for science teachers (predominantly life and physical sciences) in K-12 schools (U.S. D.O.E., March 2014). The following (Table 5) summarizes several recommendations from the National Science Board of the National Science Foundation (2014) in order to develop and retain high quality mathematics and science teachers.

The FLGS program and the resulting collaborative and synergistic efforts among leadership and faculty members have addressed these recommendations in Table 5 in various settings and projects with various targeted efforts to recruit and prepare more highly qualified science teachers. We present one approach to these needs via a narrative of a program that builds a science teacher pathway with the overarching objective of training more confident and "highly qualified" (No Child Left Behind Act, 2001) science teachers. In 2010, we began recruiting current educators to enroll in a yearlong program that builds their science content knowledge to a level suitable for the Added Authorization in Foundational Level General Science (FLGS). The goals of the FLGS program go beyond increasing the science content knowledge of program participants (typically K-5 teachers adding authorization to teach 6-8th grade science or become lead science teachers in their K-5 setting). The development of the FLGS program stimulated sustainable discourse that facilitated teachers' and faculty members' abilities to integrate science practice and active, inquiry-based pedagogy into their curricula and design additional programs that foster these practices.

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