Graduate Biomedical Engineers Teaching Interdisciplinary Science through Design at the K12 Level

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Graduate Biomedical Engineers Teaching Interdisciplinary Design at the K-12 Level

Abstract

The purpose of this study is to determine how engineering doctoral fellows enact reform-based methods in secondary science classrooms. As engineering fellows near employment in the role of faculty members, they are well prepared in science, math, and engineering content and practice, however, they generally lack training in student learning and instruction. A pragmatic approach guided the investigation lead by three research sub-questions related to: a) practice alignment with the United States Next Generation Science Standards; b) knowledge of reform-based teaching practices; c) how fellows implement biomedical engineering research into secondary science classes. Surveys, interviews, and lesson plan documents were utilized to analyze the phenomenon from three perspectives in the form of an instrumental collective case study. The National Science Foundation GK-12 program, the context of the study, operated as a community of practice and supported and promoted the utilization of reform-based teaching practices with the help of mentor teachers and university faculty. Reform-based teaching practices, as defined here, are those instructional strategies that facilitate student learning within inquiry learning environments. According to constructivists’ views of learning, students gain a deeper understanding of concepts when actively engaged with science content and practice. At the premier level reform-based teaching practices refer to student-centered exercises pertaining to the investigation of scientific phenomenon and/or the design of products and processes. Inquiry-based practice is a common phrase employed to differentiate this level. The passive dissemination of information in the form of lecture-based strategies exemplifies traditional teaching, a teacher-centered approach. Instructional teaching strategies lie along a continuum from teacher-centered to student-centered. The former features pure lecture without student questioning, and the latter showcases students’ active engagement with investigation or design as the instructor facilitates.

The findings reveal the warranted assertion that engineering fellows communicate biomedical engineering research with science and engineering practices through a belief about student learning. It was an individual personal belief about student learning that determined how fellows constructed modules; activities that represent or parallel dissertation work, and planned related pursuits to facilitate student understanding of the content and practice associated with biomedical engineering. The three participants chosen for explication signify varying approaches to teaching and each are positioned along the traditional/reform-based teaching practices continuum at different locations dependent on specific learning objectives.

Consideration for student learning within a particular context directed how fellows approached lesson planning and module creation. The science and engineering practices were evident and interpreted differently by each fellow. Further investigation into how engineering fellows formulate engineering design tasks for secondary science students could provide insight as to how teachers could approach the Next Generation Science Standard’s engineering practices. In addition this study may inform institution leaders about possible options for faculty pre-development.
Introduction

Rationale

The aim of this investigation is to explore the experiences of three participants, in relation to the interpretation and enactment of U.S. reformed-based teaching practices. So, why examine this issue? The answer to this question is two-fold. First, post-secondary teaching practices are rarely reform-based, relying heavily on lecture due to lack of time attributed to faculty research responsibilities. In the future, engineering doctoral fellows will likely teach undergraduate and graduate courses. An understanding of reform-based practices could empower fellows to be thoughtful about selecting appropriate learning opportunities in their own practice. The findings present an opportunity for institution leaders to consider implementing strategies favorable to pre-faculty development. Second, science educators, untrained in the field of engineering, are baffled by the addition of the engineering practices contained within the U. S. Next Generation Science Standards (NGSS). Knowledge of how engineers execute engineering design tasks could inform the application of engineering activities at the K-12 level.

Faculty Teaching Practices

University science, mathematics, and engineering faculty are inclined to use lecture and recitation on a regular basis as a means of providing students with course content and relevant practices. Some instructors at research institutions tend to value research activities over spending time preparing lessons in hopes of manuscript publication. Junior faculty and those who received pedagogical training in graduate school are more likely to employ reform-based teaching practices and seek outside sources for ideas about instructional innovation. New faculty members are likely to be very teacher-centered relying on PowerPoint to disseminate course content. Sadler illustrated that faculty may make small adjustments to teaching over time, with pedagogical training. These changes included posing questions and facilitating dialog among students, and between instructor and student. Instructors were motivated to use reform-based teaching practices when they felt comfortable with the class. Sadler describes this as “a shift in their way of thinking” (p. 154). This shift moves the instructor toward a philosophy of facilitation and away from the notion of instructor as disseminator of knowledge.

Junior faculty, classified as part of the establishment stage of scholar development, include faculty who spend most of the time teaching and grading. A feeling of immense pressure drives junior faculty to seek a mentor in hopes of gaining a counselor, someone with years of experience willing to help while refraining from judgment. Mentoring from within the department or between departments initiates dialog promoting collegiality and supports respect, integrity, perseverance, and trust among faculty members.

As a result of this support, faculty progress toward the advancement stage where they are more autonomous. Achieving a balance between teaching and research responsibilities generally defines this phase. Once tenure has been attained the scholar reaches a plateau and can gain a sense of relief. Achieving this milestone enables faculty more free time and stability both in work and life.
Faculty members in the maturation stage have a wealth of knowledge.\textsuperscript{11} Individuals nearing retirement enter the withdrawal stage and are primarily responsible for teaching before they eventually leave the profession.\textsuperscript{11} In order to permit the cycle to continue, professors in the maturation and withdrawal stage frequently mentor new faculty members. For this relationship to be successful, the mentor and mentee must fully commit to the goals of the partnership for the bond to be successful. This investigation tries to simulate these mentor-mentee relationships, but instead of senior-junior faculty partnerships the study utilizes teacher-faculty-fellow associations because graduate students are not yet employed faculty members.

Within engineering education Froyd, Borrego, Cutler, Henderson, and Prince\textsuperscript{13} established research-based instructional strategies (RBIS), also known as reform-based teaching practices or evidence-based practices, were attempted, but frequently terminated. Faculty felt RBIS took too much class and preparation time. In addition, faculty did not perceive RBIS to enhance student learning. According to Borrego, Froyd, Henderson, Cutler, and Prince\textsuperscript{14} faculty reported using some type of active learning; practices they describe as, “[a] very general term describing anything course-related that all students in a class session are called upon to do other than passively watch, listen and take notes”, within engineering science classes (p.1459). Active learning, situated in the middle of the traditional/reform-based teaching practice continuum, represents a combination of traditional and reform-based teaching strategies. Apparently, engineering faculty believe basic concept courses, also called engineering science courses, warrant more lecture and less active engagement.

In some cases faculty are unsure how to structure courses and lessons to incorporate more higher-order reform-based teaching strategies. For example, faculty who value integrating problem-solving skills do permit group work during class.\textsuperscript{14} However, they are unable to conceptualize a different way to support problem-solving skills. If they know how they would be willing to try another method.

The next section describes how U.S. teachers have had success with problem- and design-based learning and student populations. The addition of these reform-based movements could benefit post-secondary science instruction, and therefore it would be advantageous for new faculty to be introduced to these strategies.

\textit{Engineering Design and the Recent U.S. National Science Standards}

Engineering design tasks have the potential to connect science specific knowledge and overarching scientific concepts and to link functional design and creative innovation. Engineering design tasks encourage divergent thinking and stimulate creative solutions to novel problems. These tasks embed factual and conceptual knowledge of core ideas across scientific, mathematical, and technical fields within a specific context. The integration of content and practice enables one to function at higher orders of thinking. Similar to Problem Based Learning (PBL),\textsuperscript{15} Design Based Learning (DBL)\textsuperscript{16} unites science, math, and engineering practices in a context that induces problem solving skills within a cooperative learning environment. An example might be to design a heating system that uses chemical energy to warm a room. The design team’s task is to engineer a solution based on scientific principles and creative design bound by a set of constraints. Core concepts might include: atomic interactions, reactions, and energy changes during reactions.\textsuperscript{17} The subsystems of the problem address core concepts as
defined by the design criteria. Ill-defined, or ill-structured problems are the basis for engineering
design and align more practically with problems encountered in the real-world.

Engineering design tasks are typically neglected in school science due to time constraints. In
the U.S. high stakes testing and national and state science standards drive the curriculum. Even
though textbooks include technological and engineering applications, these activities are often
overlooked to meet assessment goals. Design tasks promote authentic learning because they
aligned with what professionals actually do in practice. School science is typically presented as
a set of individual context stripped problems isolated from laboratory activities.

Recently the NGSS were revealed as the new U.S. national standards for science education.
The NGSS complement the Common Core Curriculum which weave concepts throughout all
subjects at the K-12 level. Soon the standards will be dissected, interpreted, and implemented by
science administrators and educators around the U.S.

Purpose

Biomedical engineering doctoral students were placed in middle and high school classrooms as
coteachers to sharpen communication skills, to practice reform-based teaching practices, and
introduce biomedical research to 6th-12th grade (ages 11-18) students. Under the guidance of
veteran classroom teachers and higher education faculty the fellows conducted investigations
with students, taught science lessons, and acted as resident scientists.

The objective of this investigation is to determine how engineering graduate students (content
experts) conceptualize science teaching and learning from an engineering perspective. To what
extent were engineering graduate students able to carry out inquiry-based practices and formulate
engineering design tasks appropriate in context and level for middle and high school students?

Research Design

Conceptual Framework

The theoretical lens adapted for this study is a community of practice (CoP). Lave and Wenger describe “[a] community of practice [as] a set of relations among persons, activities, and world, over time and in relation with other tangential and overlapping communities of practice” (p. 98). A community of practice is a set of practitioners characterized by common goals, actions, and resources that facilitate the shared practice. Figure 1 illustrates the investigation embedded within the conceptual framework. Developing a community of practice can be an effective means for helping new teachers learn to teach. “Communities of practice are groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in the area by interacting on an ongoing basis” (p. 5). The biomedical engineering fellows were interested in learning about and educating students with reform-based instructional practices. It is anticipated that fellows work together with faculty and mentor
teachers as a community to develop a shared knowledge about the practice of teaching science in
preparation for future careers as tenured faculty members at the post-secondary level.
Crede, Borrego, and McNair\textsuperscript{20} suggested graduate engineers anticipating a career in academia join a CoP with engineering faculty in order to learn how to balance teaching, research, and life. In this study graduate engineers research with faculty and teach with secondary science teachers.

**Philosophical Orientation**

Pragmatism positions itself, appropriately, between post-positivism and interpretivism along the continuum of theoretical paradigms. The non-philosophy asserts that knowledge is constructed through an organism-environment interaction.\textsuperscript{21} Pragmatism as a dualism amongst positivism and constructivism permits exploration of problems across disciplinary lines.\textsuperscript{22} The tentative nature of knowledge, meaning, and truth leads to provisional truths based on the combination of constructed knowledge and the reality of the world experienced.\textsuperscript{22} Pragmatism claims homogeneity between theory and practice.\textsuperscript{21,22,23} Research questions guide the selection of methods according to the pragmatist viewpoint.\textsuperscript{24} Hesse-Biber & Leavy\textsuperscript{25} suggest the methodology is the link between the philosophical orientation and design of methods. Keeping with the pragmatist tradition the methodology was chosen as a consequence of method selection in support of the research questions. Table 1 introduces the overarching research question followed by sub-questions linked to the methods. Central to the pragmatist premise are multiple methods, used for distinct purposes such as triangulation, complementarity, development, initiation, and/or expansion.\textsuperscript{26}

**Study Context**

The GK-12 program was a National Science Foundation (NSF) funded fellowship awarded to STEM graduate students with an interest in education. According to the NSF, “[t]hrough interactions with teachers and students in K-12 schools, graduate fellows can improve communication and teaching skills while enriching STEM content and instruction for their K-12 partners.”\textsuperscript{27} Graduate students endowed this fellowship enrolled in a weekly seminar at the University to discuss pedagogy and share classroom experiences.

In addition seminars introduced fellows to examples of successful lesson plans developed by previous fellows. Seminar activities included hosting guest faculty from other departments demonstrating expertise in teaching. These seminars were offered to fellows in an effort to spark ideas for pedagogical enactment. It was at these seminars where graduate engineering fellows received the bulk of their formal pedagogical content knowledge. The purpose of the NSF GK-12 program, in general, was to promote evidence-based teaching practices among STEM graduate students.
Methodology

An instrumental collective case study was chosen to examine the research question, “In what ways do biomedical engineering fellows incorporate reform-based practices into secondary science classrooms?” The objective of this instrumental approach was to gain insight and understanding as to how and why fellows implement reform-based practices. Collective, describes the investigation since multiple cases of the same phenomena are situated within different environments. Multiple-case study enables an in-depth analysis of similarities and differences within and across cases. The findings are more robust compared with a single case, however it can be more costly and time consuming. Case study, as a methodology, is conducive to investigating real-life phenomena in a practical sense.

Methods

Eleven fellows participated in the National Science Foundation funded GK-12 experience for the 2012-2013 academic school year. Of the eleven fellows (Table 2, pseudonyms used) five were purposively selected based on initial data collected from the pre-questionnaire and represented a striated sample. Development, the use of one method to inform another, influenced both participant selection and pre-interview question creation. The research participants represented varying conceptions about how to teach high school science.

Table 1. Research questions and data sources.

<table>
<thead>
<tr>
<th>In what ways do biomedical engineering fellows incorporate reform-based practices into secondary science classrooms?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Questions</strong></td>
</tr>
<tr>
<td>In what ways do biomedical engineering fellows demonstrate knowledge of reform-based teaching practices?</td>
</tr>
<tr>
<td>To what extent do biomedical engineering fellows implement biomedical engineering research into the classroom?</td>
</tr>
<tr>
<td>How do biomedical engineering fellow lesson plans reflect the Next Generation Science Standards?</td>
</tr>
</tbody>
</table>

Table 2. Participants and placements.

<table>
<thead>
<tr>
<th>Fellow</th>
<th>Science Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aaron</td>
<td>AP Physics B</td>
</tr>
<tr>
<td>Alison</td>
<td>AP Physics C</td>
</tr>
<tr>
<td>Cally</td>
<td>Chemistry</td>
</tr>
<tr>
<td>Julian</td>
<td>Middle School Biology</td>
</tr>
<tr>
<td>Mark</td>
<td>General Science</td>
</tr>
</tbody>
</table>
triangulate the data. Complementarity is evidenced by the fact that different facets of the phenomenon were probed. Aspects of how fellows believed they planned lessons versus how they carried them out exhibits inquiry into two facets. Figure 2 outlines the chronology of the yearlong study. The methods chosen correspond to the sub-questions that support the over-arching question. Surveys, interviews, and lesson plan construction comprise the methods used to answer the research questions (See Table 1).

Prior to classroom entry fellows filled out a pre-questionnaire, so researchers could obtain initial beliefs about science, engineering, and teaching. In the fall fellows observed their mentors’ teaching and taught their own lessons in secondary classrooms. Fellows participated in the seminar series, already described, throughout the year accentuating reform-based instructional practices. During the fall semester a semi-structured interview (Table 3) was conducted with graduate fellows regarding classroom experiences, teacher planning, and personal views of teaching.

Throughout the spring the fellows continued their planning and instruction, attended research presentations, and an emphasis was placed upon the development of a formal lesson plan based on the fellow’s biomedical engineering research. Fellows submitted a formal lesson plan (module) and completed a post-questionnaire by the end of the academic year. Post-interviews were conducted with each research participant after fellows completed their module with students, and were structured around the everyday teaching habits of fellows and specific inquiry into the final module construction and implementation.

Research Analytical Methods Statement

“Case study research comprises an all-encompassing method—covering the logic of design, data collection techniques, and specific approaches to data analysis” (loc 609). Options chosen here for analysis include a holistic analysis, analysis of themes, explanation building, within-case analysis, and cross-case analysis. A purposive stratified participant sample was chosen to gather different perspectives on the reform-based practices utilized in high school science classrooms. This complicated multi-case design is more robust and allows for a comparative analysis.
When similar themes were found within and across the data, warranted assertions were propagated.\textsuperscript{31,32} Warranted assertions, according to Dewey, are considered a level of knowledge attained given what researchers know about a phenomenon based on the available data. These assertions are not concrete, but instead flexible claims open to revision as supplemental data reveal additional insights.

The final analysis of data interprets the meaning of three cases based on themes generated between and across situations. Attention to context was placed at the local level; within the classroom environment. Since three different participant perspectives were chosen for data report, each participant is presented separately to accentuate individual differences. This approach aligns with Geertz\textsuperscript{33} thick description of data; the detailed rich account of phenomenon. In addition, a warranted assertion about the three accounts of the same phenomenon was constructed to describe the common themes which link the cases to one another.

\textit{Data Analysis Procedures}

The first step in examination of the data was a within-case analysis of each individual participant.\textsuperscript{34} Stake’s\textsuperscript{34} \textit{Track I: Emphasizing Case Findings} analytic approach was chosen to highlight the situational features unique to the individual cases. Each set of interview transcripts were read and reread without any attempt to data code.\textsuperscript{35} The purpose, here, was to gain a sense of the whole, before data coding commenced. The within-case analysis was guided by a hybrid model of inductive and deductive coding.\textsuperscript{36} The open coding, illustrative of inductive work, was based on Boyatzis\textsuperscript{35} while the a priori code was representative of Crabtree and Miller’s\textsuperscript{38} deductive method.

\begin{table}[h]
\centering
\begin{tabular}{|l|p{12cm}|}
\hline
\textbf{#} & \textbf{Question} \\
\hline
1 & Why were you interested in joining the GK-12 program? \\
2 & What science subject and level are you assigned? \\
3 & Describe your involvement with the class so far. \\
4 & How would you describe your mentor teacher’s teaching style? \\
5 & How would you describe the style of science teaching that you had in high school/middle school? \\
6 & Have you had a chance to teach yet? If so, what was the experience like? \\
7 & Do you see an opportunity to create a lesson that infuses your research into the class content yet? If so, please explain. \\
8 & Who do you talk to about the teaching and learning that is going on in the classroom? \\
9 & Is there anything from seminar that impacted you in any way? \\
10 & Do you have any apprehensions or concerns? If yes, explain. \\
11 & Have you discussed the Nature of Science in seminar? If so, what aspects do you think are important to implement in the classroom? \\
\hline
\end{tabular}
\caption{Semi-structured pre-interview questions.}
\end{table}
Table 4 encompasses the steps taken in this initial analysis of interview data. After a thorough read through, a memo was crafted for each participant containing preliminary thoughts about prominent features specific to the individual case. Boyatzis$^{37}$ and Fereday and Muir-Cochrane$^{36}$ suggest using this technique to summarize raw data.

Next open coding ensued and segments of text were highlighted to indicate emerging categories unrelated to a priori codes. Example codes included ‘nature of science’ and ‘flexible module’ to represent the category Research Implementation. Following open-coding the application of a priori coding specific to the predefined categories: Science & Engineering Practices, Reform-Based Teaching Practices, and Research Module, were generated from the research questions. Categorization of the open codes concluded this portion of analysis, and not all codes were used to create categories.

Merging a priori and open codes and categories shifted the hierarchy of components. Research Module became the theme Research Implementation which broadened the scope of the category. Instead of relating only to the specific module, Research Implementation encapsulated all aspects of biomedical engineering research discussed with the students. This included discussions and activities directly related to the module as well as conversations and the application of biomedical research to current science content and student interest.

Table 5 represents the codes and categories developed during analysis. The table is formatted with a label, definition, and description of each category followed by a set of related codes.$^{36,37}$ These definitions and descriptions guided the process of categorizing the codes. The objective of this process was to determine commonalities among the three purposively sampled participants in a decontextualized way with the intention of finding conjoint categories and overall themes. The seven categories developed are interconnected with the three themes: Communication, Student Learning, and Science and Engineering Practices. Each individual participant case is described in relation to the overall themes according to the particular contextualized circumstance specific to the participants’ environment.

Transfer and learning progressions; two identified categories, are recognized in the literature as conceptual models responsible for coherent student learning. Transfer is the idea that after concepts are digested they can be applied to new situations and contexts.$^{39}$ Each of the participants demonstrate evidence of utilizing transfer in order to engage in higher order thinking skills leading to higher forms of knowledge. Learning progressions are carefully and purposively selected science content and practices that reduce the cognitive load enabling students to advance scientific understanding efficiently.$^{40}$ Similar to developmental stage theories, learning progressions are designed to encompass a range of years to accommodate varying developmental levels.

Knowledge, reform-based teaching practices, and research implementation remained categories as identified in the early stages of analysis. Scientific and Engineering Practices, however, moved up to the thematic level because all participants illustrated examples of this component of
NGSS. The other components, Disciplinary Core Ideas (DCI) and Cross-Cutting Concepts (CCC) were not as readily acknowledged. *Attitude, fellow-student interactions, and external awareness* were combined to produce the category *motivating factors*. Numerous codes and categories expressed ways in which motivating factors affected how fellows thought about *Student Learning* and how to effectively *Communicate* scientific content through the *Science and Engineering Practices*.

*Reflection*, the remaining category entails the revision of lessons, planning, and review, both during and after instruction. The fellows thrived on reflective practice as it is also considered a

<table>
<thead>
<tr>
<th>Category</th>
<th>Explanation</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Learning Progressions</strong>&lt;br&gt;The purposeful sequencing of teaching and learning expectations across multiple developmental stages, ages, or grade levels.&lt;br&gt;The fellow was able to identify what logically comes next in the curriculum to build on prior knowledge.</td>
<td>appropriate pre-knowledge, gauge student learning, student level</td>
</tr>
<tr>
<td>2</td>
<td><strong>Knowledge</strong>&lt;br&gt;Knowledge is displayed though content, practice, and understanding of others knowledge.&lt;br&gt;The fellow was or was not able to adjust the level of instruction to require students to think critically.</td>
<td>declarative knowledge, procedural knowledge, higher-order thinking skills, lower-order thinking skills</td>
</tr>
<tr>
<td>3</td>
<td><strong>Reflection</strong>&lt;br&gt;The revision of teaching practices in an effort to augment student learning.&lt;br&gt;The fellow adjusted the lab after first period completed it.</td>
<td>fellow reflection, fellow knowledge, open to new instructional strategies, supplemental content</td>
</tr>
<tr>
<td>4</td>
<td><strong>Research Implementation</strong>&lt;br&gt;How well does the lesson plan reflect the fellow's research?&lt;br&gt;The science concepts related to the research were relayed in the fellow's lab activity.</td>
<td>interdisciplinary, flexible module, nature of science, reinforce with lab</td>
</tr>
<tr>
<td>5</td>
<td><strong>Transfer</strong>&lt;br&gt;Taking isolated concepts and transferring them to new contexts.&lt;br&gt;The fellow uses real world examples to convey the breadth of a simple science concept.</td>
<td>analogy, everyday examples, simulation, application of science</td>
</tr>
<tr>
<td>6</td>
<td><strong>Reformed-Based Teaching Practices</strong>&lt;br&gt;Any evidence of non-lecture based learning activities.&lt;br&gt;The fellow utilized any of the three levels of inquiry to engage the students in learning a new concept.</td>
<td>inquiry, reinforce with labs, self-discovery, interactive discussions, flexible module</td>
</tr>
<tr>
<td>7</td>
<td><strong>Motivating Factors</strong>&lt;br&gt;Internal and external factors affect fellow decisions.&lt;br&gt;Family support or monetary reimbursement prompts the fellow to teach and teach the way they do.</td>
<td>advisor awareness, enjoy teaching, mentor-fellow collaboration, personal experience with traditional teaching</td>
</tr>
</tbody>
</table>
major component of an engineer’s function. The nature of engineering is described as selecting a problem, generating multiple solutions, and narrowing prospects guided by specific criteria. Even when a final design is chosen, and eventually manufactured, it is still open to revision as new ideas and data are accumulated and evaluated.

Reflection became a category with connections to Student Learning and Science and Engineering Practices. Alison discussed early on her fear of not knowing what the students’ know; an aspect related to student learning. She described quickly assessing the class for current content knowledge of the lesson topic and having to ‘step up or step down’ to reach their level. Effectively, she prepared multiple lesson versions in order to appropriately target student comprehension and engage students. On the spot Alison was able to determine student level and proceed accordingly. As she observed the lessons, taught by the teacher, she reflected on the concepts and how they related to engineering in the everyday world and specifically to her field. Tension in physics, for example, was first applied to bridges because of student familiarity with the physical world. She then transitioned into somewhat unfamiliar territory with an application to cells. Here students were presented with an opportunity to apply the laws of the physical world to living things.

Alison’s module, the human-eye, linked concepts of refraction with lens ray diagrams through the conceptual link between optics and the real-world application of far- and near-sightedness. First attempt with the module was one of open-inquiry. Alison wanted students to explore, find the focal point and relate focal distance to different types of lenses. Upon reflection she tweaked the module before the next class. Alison realized students needed at least minimal guidance in order to be successful.

Findings

Connecting categories to other categories is the process of pattern recognition for the purpose of discovering themes. Themes were generated across cases, that is, they apply to each individual case, but perhaps are expressed differently depending on the specific context of the situation. Figure 3 illustrates the three main themes surrounded by the categories that were created through data coding. Themes are represented in black while categories appear grey. The categories are shared among multiple themes as indicated by the lines connecting categories to themes. Each theme corresponds to one of the three research questions posed in Table 1.

Thematic Findings

The qualitative findings provide support for the warranted assertion that engineering fellows Communicate biomedical research with Science and Engineering Practices through an understanding of Student Learning. This statement articulates what was discovered as a result of analysis. Table 6 parses out the specifics concerning each case and theme. Each fellow had a varying conception of student learning grounded in prior experience and specific classroom context. The following series of accounts reinforce the aforementioned warranted assertion. The subsequent remarks also impart the findings in terms of the overarching research question, “In what ways do biomedical engineering fellows incorporate reform-based practices into secondary science classrooms?”
Alison: Physics

Each year many biomedical graduate students at Alison’s university apply for a limited number of GK-12 fellowships. Why would a graduate student immersed in engineering research want be bothered with planning and teaching lessons to secondary students? What specifically drew Alison to the GK-12 program?
I always tutored my classmates and was a tutor for a physics class. (Alison, line 18-19, Interview 1)

..so far I’ve found a real passion teaching others. I really enjoy um I guess talking with younger students um helping them understand concepts that they kind of struggle with. (Alison, line 7-9, Interview 1)

She was clearly intrinsically motivated to help others. She was so enthusiastic about the opportunity that she shared her classroom experiences with family and fellow doctoral students at the university.

A couple of my lab mates will talk about comparing the curriculum. They will say, “Oh what are you up to?” And then they will help me and give me input or ask how it went the next day. Also my family, they are really excited that I have this opportunity. They know how much I like teaching. When I come home excited about how the day went and how I enjoyed what I did I definitely tell them. (Alison, line 121-126, Interview 1)

Alison’s outlook, in relation to Student Learning, drew upon her prior experiences as both a formal and informal tutor. In her own life, as a student, Alison was lucky enough to experience reform-based teaching practices allowing her to reap the learning benefits.

So, I think in high school I had one science teacher who was very active like Jeff. So he would bring in cool real world applications and stuff like that, but the teachers I had were more just lecture based. Kind of like the normal teaching style and I really struggled with that. And so that is kind of why I enjoy this kind of more adaptable teaching style because I know that for me at least that would have been a lot more helpful. (Alison, line 79 – 84, Interview 1)

<table>
<thead>
<tr>
<th>Fellow</th>
<th>Student Learning</th>
<th>Communication</th>
<th>Science &amp; Engineering Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alison</td>
<td>Self-discovery</td>
<td>Facilitated student learning with guided questions</td>
<td>Modeling</td>
</tr>
<tr>
<td></td>
<td>Whole class discussion to address misconceptions</td>
<td>Hands-on</td>
<td>Mathematics</td>
</tr>
<tr>
<td></td>
<td>Demonstrations followed by book questions</td>
<td>Lectured about biomedical research before the module</td>
<td>Problem Solving</td>
</tr>
<tr>
<td></td>
<td>Analogies</td>
<td>Demonstrated what should happen for students before vasculature design</td>
<td>Design (one solution)</td>
</tr>
<tr>
<td>Julian</td>
<td>Engaging activity</td>
<td>Multiple Representations (Video, Pictures, Schematics)</td>
<td>Modeling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PowerPoint</td>
<td>Mathematics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Problem Solving</td>
</tr>
<tr>
<td>Mark</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Hands-on activities enabled Alison to self-discover science concepts on her own which she deemed valuable. However, even with this belief, Alison still considered prior knowledge essential to student learning and required for transfer. Alison expressed this when she became nervous about teaching a new topic. Since she had not taught the previous lessons she was unaware of the level of student’s knowledge. She was, in a way, Reflecting on her practice before she even attempted to instruct students.

Alison was familiar with the concept of Learning Progressions\textsuperscript{40}, or the understanding that curricula are logically sequenced to maximize concept retention. She had planned hands-on activities to apply concepts in new situations, but she was unsure if her plan would work; it all depended on the prior knowledge of the student.

...the teacher is like, “Hey you know could you please design a lab or come up with some demos”, and I’m never quite sure 100% where the students are. So usually when I go into the classroom I’ll have to quickly evaluate where they are based on their understanding and I’ll have to step up or step down what I’m talking about to basically reach their level. So sometimes I’m a little worried that I can’t do that, but so far it has worked out pretty well. (Alison, line 150-56, Interview 1)

As evidenced by Alison’s module she valued inquiry activities and utilized such practices on a regular basis. She appeared to like to have students’ figure out things for themselves in an effort to understand concepts before any math is applied to the physics. In this instance students investigate lenses for the first time.

But when they actually got to play with the lenses and figuring out how they worked I heard several of them say things like, “Wow, this is so cool, I did not know that it worked like this” and like “look it’s upside down” you know. (Alison, line 290-93, Interview 2)

The current dialogue links directly with how Alison Communicated her biomedical engineering research with secondary science students. She believed inquiry is a useful tool for student learning and, coupled with her intrinsic motivation, she feels the best way to negotiate her research is to facilitate an activity that emphasizes basic science concepts rather than those associated with her research. Alison was placed in an Advanced Placement Physics class where students were genuinely interested in the material; however, they were not well versed in nonlinear optics. Therefore Alison was unable to completely introduce her research to students. Instead she used a very basic, rudimentary concept related to her research and built upon it. The final product was a real-world relevant application; the human eye.

It would be quite difficult to teach them nonlinear optics. There’s also some biology components um, that I would need to teach and this was not a biology class or even a chemistry class. If it were I would steer it towards the cell part of my research. This was the most accessible component I think. (Alison, line 551-54, Interview 2).

Alison reflected on revising the module while students worked with the model. She adjusted the module to lessen ambiguity in order to reduce student aggravation before the next class worked with it.
Well, um, the first class that I did this with was a little bit frustrated because I did not tell them how far to put the lenses from each other. So they actually managed to put them in a position where they would form and image and they would say, “Yes, that’s focused”. So for the next classes I told them the distances so they could see with their eye and try to get it focused. (Alison, line 371-75, Interview 2)

Three of the **Science and Engineering Practices** evident in Alison’s module were asking questions and defining problems, developing and using models, and planning and carrying out investigations. This excerpt illustrates Alison’s view of knowledge and her role as facilitator in helping students define a problem and carry out an investigation with the aid of a model.

> And the way I gave them ideas was not ones that they would necessarily test, but to give them the concept of coming up with an idea to test. So for example I would come up with something like, “what would happen to the image of the eye if you took a marker and scribbled all over the lens?” You know, that is one you won’t actually want to scribble on your real eye. (Alison, line 425-29, Interview 2)

**Julian: Middle School**

The GK-12 program offered Julian an opportunity to practice his English, as well as, assist low SES children learn science concepts. Growing up without a mentor, someone he perceived as successful who left the community for opportunities most were not afforded, intrigued him. Julian was motivated to **Communicate** these STEM opportunities with students. He believed students should consider a better life.

> In Puerto Rico basically they have the same like what’s the word, the economics in which for like high school students have the ability to go to college. This mentor program for college students and this is the point that bonded with me. I think that I can motivate other people to continue high school to go on to college. (Julian, line 9-13, Interview 1)

Originally from Puerto Rico, Julian’s school experiences were much different than what he observed in modern U.S. classrooms. He was disheartened to find that students were ungrateful. He valued education and sensed that U.S. students do not.

> (Laughing), uh it is very different than in Puerto Rico. Like uh, here I think it is less polite. Sometimes the teacher will have group control, but they have this freedom to laugh to start talking, go in and out of the classroom. Like, uh, it is very difficult to hear. There are some class discussions, but the students don’t listen or participate in anyway, it, it is different. It annoys me because I am very serious. I came here to pay attention. (Julian, line 43-48, Interview 1)

Julian’s serious nature and the lack of student discipline exhibited in his mentor teacher’s classroom are not conducive to his teaching style. He believed students learn best when they sit and listen silently. Despite his view he did try to exercise some of what he learned in the seminars given at the University. Collaborative groupings did seem to help when students paid attention.
So they have one group for example one would have people better for etc. etc. An one group was one with less ability to get the concept. So what I tried to make the classroom very economic so like one group would teach the others. It was very funny because one of the times it was like you have all these what do you call it? - hyperactive kids in the class, so sometimes I tried to get the attention...(Julian, line 228-232, Interview 2)

He often acted as a resident science and expanded course material with engineering applications. He tried to include examples that he thought would engage students.

So anytime we had a new topic I would explain an example that we use the actual knowledge in the lab. (Julian, line 201-203, Interview 2)

So the module was based from kind of show them the features that I do. Um, I tried kind of, um, extrapolate based on what they have, so I started with basic concepts and how I um would try to like do research on blood deposits in the brain. But also yeah I have this invitation so see what the interest of the students have in the class. (Julian, line 222-227, Interview 2)

Julian said he started by determining the level of prior knowledge the students had, but he did not formally or informally pre-assess them. It seems he assumed students were “blank slates” and only considered the previous curriculum. From there he created a plan to construct a higher level of knowledge indicative of learning progressions however, words and phrases were often too high in level for students to understand.

I little anecdote from this one time. I was teaching at this high level and so someone was paraphrase all of the principle concepts I was trying to say about Alzheimer’s, inflammation... I did an quiz and like multiple people were getting like 10 freaking points... She handed me the paper and the board was like everything blood flow and catheters in the brain and blood clots. And at least I get the main idea. Kind of like transfer my knowledge to her, you know. You know very high level for the kids (Julian, line 237-240, Interview 2)

It appears Julian was unable or unwilling to reformulate a lower level approach appropriate for a middle school audience. Perhaps the fact that English is Julian’s second language prevented him from using alternative vocabulary, since he had been relatively confined to the language used at the University.

Julian’s module mimicked his research in relation to blood flow and Alzheimer’s disease. Students were able to design and redesign vasculature in preparation for blood clot simulation. The iterative nature of design was captured here illuminating a quality of Engineering Practice.

I designed, um, the best model that I know would work efficiently and then I showed them, right, the previous class how different models and design and this is how it is supposed to work. I added die and showed them. The next day each group designed their own model and then they made correction and then they did the scientific method, etc., etc. (Julian, line 282-286, Interview 2)

Even with hands-on demonstrations students still found the concept difficult to comprehend. Julian realized that the students in the class were of varying ability levels and some need more
direct instruction than others. He followed the reform-based practices introduced in seminar, but quickly realized that not all students would follow and understand. Different approaches are needed for Student Learning in order to facilitate transfer of scientific ideas.

...about sixty percent of them said there would be no flow while others said there would be flow on one side of the occlusion. I tried to explain to them what would happen with blood pressure and that the blood would flow through one of the other branches with less pressure. Some students found it difficult to think that blood would flow through smaller sections. (Julian, line 330-335, Interview 2)

Mark: Vocational Science

...it’s kind of interesting because the kids that go to vocational schools are there to do whatever vocation they are interested in such as electrical work, woodworking, carpentry, hair design, stuff like that. So when they go to the science class they are not really that interested in what’s going on. (Mark, line 29-33, Interview 1)

Mark mistakenly referred to his classroom as “middle school”. This suggested he identified the students as low level intelligence high school students. He described the course as a general science class with some biology interspersed. Again, he viewed his students as unmotivated to do anything.

...they were working on rockets, something completely hands on, um there was competitions for the rockets that launched the farthest. He had a few kids interested, but some kids even though he was not lecturing were falling asleep at their desks. They just did not want to build a rocket. If you don’t want to build a rocket I don’t know like what you want to do. (Mark, line 50-54, Interview 1)

Mark was placed with a mentor teacher who utilized reform-based practices on a regular basis. During one of Mark’s initial visits to the class he observed students working on an engaging hands-on activity related to energy. To his dismay students were not interested. He wondered what he could do to get students interested in anything, let alone science. Mark realized that in this particular environment students needed to be motivated in some way.

I see [Dan] and I wish I had a teacher like that back in high school, for me it was completely different so for me it was like even though these kids don’t appreciate it there are more teachers like out there practicing new things that is really going to be good for science in general. (Mark, line 62-66, Interview 1)

I’ve learned a lot of interesting things from the speakers that have come during seminars. I can see how it incorporates well in all certain types of classrooms, uh, however these vocational students I know flat out that some of these techniques presented in seminar will flat out not work. It’s really going to take some thinking outside the box to teach these students science because basically they are at the end of their high school career... (Mark, line 113-118, Interview 1)

For Mark the challenge was too great. He did not enter the classroom many times during the year. He had decided there was little he could do in the amount of time he was willing to devote to the GK-12 program. Mark practically gave up on Student Learning. From his perspective
not all students could learn; not if there was no incentive or motivation. He did fulfill his obligation to create and teach a module related to his dissertation research. The best way Mark thought he could Communicate his research about a microfluidic chip was with a macro-scale designed model using gelatin, syringes, and colored water. Modeling is an example of a Science and Engineering Practice. The microfluidic chip design had step-by-step procedures to follow except for specifics like emptying a syringe. Below Mark described how students were able to manipulate the syringe.

I would say half of them could figure this out on their own and the other half we had to show them how to do this. (Mark, line 322-323, Interview 2)

Attention to detail was not a priority in the module. Students had never worked with syringes before and many Jell-O molds were destroyed before they were used because no thought was given to the structural support. Mark did reflect on these challenges, recognizing that he needed to not only consider student engagement level, but also the developmental characteristics of students.

Discussion

Based on the evidence gathered in this study biomedical engineering fellows demonstrated knowledge of reform-based teaching practices in relation to how they think about how students learn. It is the theme, Student Learning, that prompted fellows to select appropriate reform-based practices for use in the classroom. Specifically, fellows discussed ideas of learning progressions and transfer, even though these were not explicitly stated. The fellows reflected on these learning models during the planning stages, throughout instruction, and in the course of module implementation.

The second research question dug deeper into inquiry and how fellows applied biomedical engineering research in the secondary science classroom. Each fellow expressed an interpretation of his or her research to students in the form of a module, or lab activity; but, each fellow communicated aspects of his or her research differently. Some fellows chose to explicitly discuss their research outside the context of the module while another did not. The decisions fellows made about student learning impacted how science concepts and research were communicated, or executed, in the classroom. Motivating factors added to this theme as elements paved the way for explaining why fellows felt compelled to participate in the GK-12 program. For two fellows it was an intrinsic motivation and genuine desire to help students learn, while it was extrinsic motivation supplied by a $30,000 stipend for involvement that tempted another. These factors, as well as others, drove how seriously fellows thought about student learning in order to communicate science and engineering concepts. The theme, Communication, acts as a bridge joining Student Learning to the Science and Engineering Practices.

The strongest component of NGSS expressed by participants was the Science and Engineering Practices, so it formed a theme. The third research question asks, in what ways do the fellow’s teaching practices represent the current national standards for science education. The fellows presented an interdisciplinary facet to science in the form of engineering, but none chose to focus on any overarching idea as conveyed in the cross-cutting concepts. The disciplinary core ideas
were almost lost within the modules in order to concentrate on topics or themes within the research. The categories of transfer and learning progressions evolved as the role of Student Learning influenced the application of scientific and engineering concepts. The module was interpreted as an isolated project with no relation to the curriculum in two cases. In the other instance the fellow emphasized science concepts, sacrificing attention to the biomedical engineering research. None of the fellows truly integrated the curriculum with current research.

Limitations of this study possibly include: not asking sufficient questions to elicit aspects central to the phenomenon, missing important components of the phenomenon, and distance to the research site. As researchers we can only infer from the analyses of the data. Something might have been experienced, but we were unaware of it, because the most appropriate question was not asked. As a result, other facets of the phenomenon might be absent from analysis. Lastly the researcher and participants were hundreds of miles apart and classrooms were not directly observed. The researcher had to rely on mentor teacher and fellow accounts, questionnaires, phone interviews, and lesson plan products.

Conclusions and Implications

Previously published work on the GK-12 program has primarily focused on what the program can do for the fellow and not what the fellow can do for student learning. This study has illustrated a varying conception of how to utilize reform-based teaching practices. All participants were aware of the practices and felt they were important, they just needed more time to practice them. Even beginning full time teachers do not become experts, it takes years. The foundational elements of reform-based instruction were evident. With a little intrinsic motivation two of the fellows really tried to make the fellow/mentor teacher partnership work. All participants were placed with mentor teachers that utilized reform-based practices.

Additionally, what would happen if doctoral students were placed with reform-based teaching faculty for the purposes of promoting student learning? Would this help new faculty achieve higher levels of personal or work-related satisfaction while trying to balance teaching and research responsibilities? Instead of struggling to acquire or develop appropriate instructional strategies independently, which requires time that competes with research, new faculty could gain an understanding through pre-faculty development before they become employed.

Recently Jaimison, Kolmos, and Hogaard shared a model for engineering education which fuses scientific and skill-based learning to further the profession. Termed the Hybrid Model, this brand takes a contextual, transformative, collaborative, and situated approach to learning. Rather than separating skill from theory the two interlock and facilitate a deeper understanding of concept related to specific circumstances.

An interesting finding related to the Science and Engineering Practices was the variable way in which the science practices were employed in relation to the engineering practices. Alison was able to balance the two, giving equal weight to each. Julian preferred to use the engineering practices only. And Mark, who did not have much contact time with his class, did not display much use of the nature of engineering other than with a model. It is unclear whether or not fellows were explicitly aware of the exact nature of the science and engineering practices. When asked, do you know what the nature of science is?, fellows replied that they had heard of it, but did not know what it meant. This is an interesting topic for further study, as science teachers will
need to implement engineering practices according to the NGSS. If fellows were implicitly using engineering practices in the science classroom, what might they be capable of creating, if they were explicitly asked to add them?

References

6. Achieve (2013). *Next generation science standards.* Achieve, Inc. on behalf of the twenty-six states and partners that collaborated on the NGSS.


