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Research Article

Teaching and Research at a Large University: Case Studies of Science Professors

Jenay Robert[1] and William S. Carlsen[2]

[1]*Department of Chemistry, University of South Florida, Tampa 33620, Florida*
[2]*Department of Curriculum and Instruction, Pennsylvania State University, University Park 16802, Pennsylvania*

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Abstract: Current STEM workforce issues and retention problems faced by postsecondary STEM education have renewed research efforts in this arena. A review of literature on STEM professors indicates that although this population reports difficulties integrating teaching and research responsibilities, there have not yet been any qualitative studies conducted to deeply investigate the complexities of managing teaching, research, and service. This work utilized a set of four phenomenological case studies conducted over a 10-month period to address the following research question: How do individuals in a sample of tenure-track science professors prioritize teaching among their other professional roles and responsibilities? Contrary to literature speculation, the results of this study indicate that the participants make decisions about the way they allocate limited time in an unlimited work environment based on their intrinsic, personal career goals and aspirations and appear to be only minimally affected by external pressures to "prioritize research over teaching." Furthermore, all of the participants in the study indicated that other than research training, they received little to no preparation for their jobs. These findings provide discipline-based education researchers with points of interest for further study and provide professional development stakeholders with data for the design of educational support programs. © 2017 Wiley Periodicals, Inc. J Res Sci Teach 54: 937–960, 2017

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A potential shortage of science, technology, engineering, and mathematics (STEM) professionals from the future American workforce is now recognized (President's Council of Advisors on Science and Technology, 2012), although the magnitude of the problem varies among STEM fields (Bureau of Labor Statistics, 2015). Some worrisome statistics suggest that American universities might not be able to provide a sufficient number of STEM graduates to keep up with this projected demand. Fifty percent of students who begin a degree program in the sciences and 60 percent of students in mathematics drop out of STEM fields by their senior year, compared with 30 percent in social sciences and humanities (Committee on Science and Technology, 2010).

Correspondence to: J. Robert; jenayrobert@usf.edu
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Correspondingly, the United States has recently ranked 27th among 29 developed countries for proportion of students receiving undergraduate degrees in STEM fields ("Rising Above the Gathering Storm" Committee, 2011).

In light of these pressures, there is new interest in attracting and retaining STEM students in higher education, and a general consensus emerging about how science should be taught:

- Research on STEM teaching and learning supports a curricular emphasis on discipline-specific practices and greater attention to principles that cross disciplinary lines.
- Current and prospective STEM faculty need professional development to learn about and enact research-based pedagogical practices.
- STEM colleges need support to transform teaching practices (including assessment) into ones more closely aligned with research on teaching and learning.
- Proposed changes will only take place in environments supported by administration ("top-down") *and* faculty members ("bottom-up").

These developments point to a need for more research on interventions that might improve STEM faculty teaching practices at the college level, but developing interventions and understanding their effects is predicated on better understanding professors' values, beliefs, and priorities, as well as their origins.

The Link to Teaching Practices

Compared to their classmates, freshman STEM majors are not only more likely to change majors, but also to withdraw from college altogether (Higher Education Research Institute, 2010). Seymour and Hewitt (1997) showed that a staggering 90% of students leaving STEM majors cite poor teaching as one of their concerns, motivating educational researchers to investigate the link between teaching quality and retention. Alternatively, STEM professors actively engaged in improving undergraduate education argue that it is not necessary to establish that traditional teaching practices contribute to student attrition; teachers have a responsibility to respond to a growing body of research on the science of teaching and learning by modifying their practices (Bradforth et al., 2015; Eddy & Hogan, 2014; Freeman et al., 2014).

Reasons for the persistence of traditional teaching at the college level remain speculative in the literature. The Association for American Universities proposed that institutional emphasis on research over teaching could partially explain this phenomenon (Association of American Universities, 2011). In one survey of university professors, 48% of respondents indicated that for a new professor hire, "a star researcher with significant research publications but who has no significant teaching experience" would be favorable over applicants with either balanced teaching/research experience or a "superb teacher[s]. . .with no significant research projects" (Savkar & Lokere, 2010). Forty-one percent of respondents felt that their institutions valued research over teaching. Surprisingly, 77% of respondents in the same survey reported that teaching and research were *equally important* missions of their schools. One might speculate that institutions view teaching as an easily attainable skill, a craft best learned by informal professional development, or something best emphasized by faculty in other fields (or non-tenure positions in the sciences). Other reports suggest that professors do believe that their institutions prioritize research over teaching (American Association for the Advancement of Science, 2011, 2015; Anderson et al., 2011). Bradforth et al. (2015) added that "research universities rarely provide adequate incentives, support or rewards for the time that faculty members spend on improving teaching." As issues of postsecondary education culture are highlighted in the literature, there is a need to deeply investigate their nuances to inform further research and practice.

Sociocultural Theory

This research explores the professional experiences of four tenure-track science professors at an R1 (highest research activity) university. The work is informed by a sociocultural understanding of the way individuals experience the world. Participants are not viewed as isolated subjects but rather as members of complex social settings with rich personal histories and connections. Sociocultural theoretical frameworks originate from the work of Vygotsky (1978) and posit that people learn and develop through interactions embedded in social and cultural activities. Such activities take place within "communities of practice" (Lave & Wenger, 1991) in which new members of communities "legitimately and peripherally participate" in culturally valued activities with the purpose of preparing them for "mature participation" (Rogoff, 1995).

Rogoff (1995) describes sociocultural activity from three different but connected perspectives, which she calls "planes of focus": apprenticeship, the community/institutional plane of focus; guided participation, the interpersonal plane of focus; and participatory appropriation, the personal plane of focus. A science professor might act as an apprentice within her department when she asks a colleague for advice. However, in her research lab, she would likely be acting as a mentor to undergraduate and graduate students, post-doctoral researchers, and other personnel who are then her apprentices. Guided participation refers to the "direction offered by cultural and social values, as well as social partners" (Rogoff, 1995, p. 60). The cultural and social influences for science faculty conceivably range from departmental and institutional norms to peer and even student expectations. With respect to teaching, "participation" is problematic because professors do not typically experience each other's teaching, but tend to only hear or understand cultural norms anecdotally and by reflecting on their own prior experiences as students. Finally, Rogoff's participatory appropriation represents "how individuals change through their involvement in one or another activity" (p. 60). Rogoff emphasizes the importance of *time* with respect to this concept. One should not view the past, present, and future as discrete periods; rather, the past informs the present, which guides individuals towards the future.

The Relationship Between Teaching and Research

An oft-discussed aspect of tenure-track science professors' professional lives is the relationship between their teaching and research roles. Work that examines this construct tends to focus on the concept of balance between these two components, particularly with respect to time management. There is general agreement in the literature that professors typically experience a tension between these two components of their career, but it is much less clear how or even why that tension is felt. Existing research suggests that science professors feel pressured to emphasize their research over their teaching. In one study described earlier, which surveyed 450 university science professors who had both research and teaching responsibilities, Savkar and Lokere (2010) concluded that "although scientists personally value education as much as research, they frequently align their decision making, both for themselves and on behalf of their departments, with the needs of research rather than those of education" (p. 3).

Other research suggests that professors find it challenging to give what they consider to be adequate time and attention to their teaching due to the cultural climates of research universities (Anderson et al., 2011). Typically, researchers speculate that this imbalance is due to institutional emphasis on research productivity, especially with respect to promotion and tenure (Bradforth et al., 2015; Leslie, 2015; Light, Calkins, Luna, & Drane, 2009; Wright, 2005). One particularly poignant account was coauthored by thirteen scientists who had all received science education funding from the Howard Hughes Medical Institute (Anderson et al., 2011). The individuals worked in a wide variety of institutions of higher education, yet all of them reported that the reward

systems "heavily weight efforts of many professors toward research at the expense of teaching," and that "departmental and university cultures often do not adequately value, support, and reward effective pedagogy" (p. 152).

In a 2010 review of literature looking at faculty performance standards at research universities, it was found that many factors were strongly influenced by discipline (Hardré, Cox, & Kollmann, 2010). For example, STEM evaluations focused heavily on items that could be measured quantitatively, explicitly defined "scholarship" as "research," and in some cases "warned candidates against letting service or other pursuits get in the way of research productivity" (p. 9). The NRC Discipline-Based Education Research (DBER) report similarly acknowledges that science and engineering faculty engaged in educational (as opposed to physical or natural scientific) research will face challenges associated with promotion and tenure committees that might not value time spent engaging in DBER activities, even when they result in science teaching and learning publications (National Research Council, 2012, pp. 40, 188).

This apparent conflict between some professors' professional preferences and those of their departments generates questions about how professors actually prioritize and balance their many responsibilities within research institutions, especially with respect to developing high-quality teaching programs in a research-centered culture. Over the last two decades, research on professors' diverse research and teaching responsibilities has begun to accumulate. Some quantitative studies seek correlations between teaching excellence and research productivity, but this work reports a range of findings (Hattie & Marsh, 1996; Horta, Dautel, & Veloso, 2012; Hurley, Bowling, Griffiths, & Blair, 2013; Marsh & Hattie, 2002; Zaman, 2004).

Hattie and Marsh (1996) explained in a meta-analysis of 58 quantitative studies that there are multiple theoretical models that can be used to explain "many possible permutations relating the quality of teaching and research" (p. 508, also see Cherastidtham, Sonnemann, & Norton, 2013; Zaman, 2004). A *scarcity model*, for example, would assume that given limits on available time and resources, teaching and research activities are necessarily oppositional. Alternatively, Hattie and Marsh describe theoretical models that support the idea that teaching and research are synergistic activities. The *conventional wisdom* model suggests that teaching and research should be complementary, and the *G model* associates similar personal and professional values with good teaching and good research: "high commitment... creativity... investigativeness, and critical analysis" (Hattie & Marsh, 1996, p. 512). In support of zero correlation between research and teaching, Hattie and Marsh describe an *unrelated personality* model (opposing the differential personality model) in which good researchers and teachers are "different types of people, and there may be few personality traits in common" (p. 514).

In contrast, a *different enterprises* model explains that research and teaching are driven by different, not necessary oppositional or cooperative, goals and professional traits. Such a model does not assume teaching and research must have an absolute relationship; that is, the two activities may be mediated by a host of variables. For example, Marsh's (Marsh, 1979, 1984) *compensatory model* argues that whereas some components of a professor's job, such as time spent on teaching and time spent researching, are oppositional, a positive relationship between other variables might compensate for that loss in time. Similarly, Friedrich and Michalak's (1983) *intervening variables model* posits that some variables such as knowledge, ability, intellectual involvement, organization, and others can intervene and alleviate tension between research and teaching. The case studies described herein support the adoption of a different enterprise model, though more data is needed to favor one over the others.

In addition to the work already described, a number of studies discuss aspects of professors' multiple responsibilities. Colbeck's (1998) study used observation and activity logs to measure the amount of time professors spend integrating teaching and research activities. The study did not

probe the complexity of professors' goals when engaging in various activities, nor did it address the reasons behind those goals. Some accounts (e.g., Russell, 2009) on the multiple roles that science professors take on are autobiographical and do not draw upon any formal research techniques. Barrett and Milbourne's (2012) regression analysis of data from 37 public Australian universities reports that research environment (measured by research output, income, etc.) has "a negative effect upon perceptions of good teaching. . .[and] a positive effect on. . .full-time employment, progress rates and retention rates" (p. 77). The work did not, however, propose explanations for why such relationships exist or how they are experienced by individuals in Australian universities. Gess-Newsome, Southerland, Johnston, and Woodbury (2003) studied three science professors creating and implementing a novel curriculum; this study primarily examined the conditions required to support change in professors' teaching belief systems. Indeed, a host of similar studies might be described (Figlio, Schapiro, & Soter, 2015; Galbraith & Merrill, 2012; Hurley et al., 2013). Each in its own way contributes to the field's understanding of professors' careers, but they lack the deeply descriptive power of case study or ethnographic analysis.

Purpose of the Study

It is clear that educational stakeholders in the United States have a strong desire to increase the number of college students entering and being retained by STEM disciplines. Professional and government agencies agree that the quality of university science teaching is a priority for targeted improvement. Furthermore, STEM professors who publish educational research and commentaries on postsecondary STEM education assert that their peers should implement research-based teaching methods as a matter of professional excellence. To that end, educational researchers must begin to investigate new ways to train and support STEM professors as teachers. A logical starting point for the thoughtful design of pedagogical interventions is a thorough understanding of the current state of professors' professional lives. This study contributes to gaps in the literature by gaining a holistic understanding of professors' professional lives. This research addresses this question: How do individuals in a sample of tenure-track science professors prioritize teaching among their other professional roles and responsibilities?

Methods

Research Site

The research site, dubbed "Large University" (LU) herein, is described by the Carnegie classification system as a large, 4-year or above, public R1 institution in a primarily residential area.[1] Participants referred to the large student population and apparent homogeneity of individuals on campus and explained that while most people on campus are "white," there is a range of socioeconomic statuses (from very poor to very wealthy). Participants also emphasized the scientific excellence of their university. For example, one participant highlighted that "many of our science departments are very highly rated" [Ben, Interview 4],[2] with chemistry ranking among the top 25 in the United States. The same participant explained the prominent role sports play in LU's culture, citing statistics about the size of one of the campus's sports venues.

Participants

This research generated case studies of four participants: Henry, Ben, William, and Pierre (pseudonyms). Inclusion criteria for participants in this study were as follows: (1) tenure-track science (physical or natural, pure or applied) professor; (2) leader of physical or natural science research group composed of at least two researchers (post-doctoral researchers, graduate students,

or undergraduate researchers); and (3) teacher of at least one physical or natural science class during the initial data collection phase of the study (Spring, 2015). For this study, "tenure-track" was defined as pursuing or having already attained tenure within the professor's current job. This study did not attempt to focus on pedogically innovative professors, as the goal was to describe a range of cases, whatever they may be, without assuming any degree of pedogical interest or innovation.

Participants were selected in three stages. First, a solicitation with a brief description of the project's goals and time commitment was emailed to 50% of the tenure-track faculty members (randomly selected) within each department of the college of science at LU. Next, purposive sampling was utilized by contacting potential participants known by the first author to have expressed an interest in educational research. Only one of the final four participants (Henry) was a result of this purposive sampling. Though this study did not seek to focus on pedagogical innovation, Henry was selected in order to provide an opportunity for possible points of contrast to arise in the cross-case analysis. From the first two recruitment steps, 13 individuals (11 men and two women) agreed to further discuss the project. One woman was disqualified as she was not going to be teaching classes within the project's timeframe.

Initial meetings were conducted with each of the 12 potential participants. The one remaining woman in the pool elected not to participate due to concerns related to confidentiality and promotion. From the remaining eleven professors, a range of subjects was chosen to "select cases that show different perspectives on the" professional experiences of science professors (Creswell, 1998, p. 62). The initial six participants exhibited a variety of scientific disciplines, years of experience, and progress through the promotion process. None of the participants voluntarily withdrew from the study, but two of them were subsequently dropped due to scheduling difficulties. Thus, four cases will be described herein. All four of the final participants in this study described themselves as white men. This lack of gender and ethnic diversity was not an intentional feature of this work.

There were no special efforts made to recruit individuals from underrepresented groups of faculty for this project. Underrepresentation among science faculty is an active area of research (Ceci, Ginther, Kahn, & Williams, 2014; Kaminski & Geisler, 2012; National Science Foundation, 2016; Sheltzer & Smith, 2014; Shen, 2013; Williams & Ceci, 2015), and future work will include targeted recruitment of female and other underrepresented participants.

Interview

Each participant engaged with the first author in four 90 minute interviews (for a total of 7.5 hours) over the course of 10 months. The first three interviews followed (Seidman, 2006) "in-depth, phenomenological interviewing," a combination of "life-history interviewing. . .and focused, in-depth interviewing informed by assumptions drawn from phenomenology" (2006, p. 15). In this strategy, three 90 minute interviews are conducted 3–7 days apart. Occasionally, more than 7 days passed between interviews when it was necessary to accommodate for participants' schedules. The first interview focused on the professional and personal histories of the participants. The second interview focused on the current concrete professional experiences of the participants. The third interview asked the participants to reflect on the meanings of the experiences discussed in the first two interviews. After the first question of each interview, subsequent queries were derived from the participant's words rather than the researcher's hypotheses. Thus, interviews began with prompts such as, "How did you come to work at this university?" Follow-up prompts

sought clarification or further exploration of participants' ideas. Examples of follow-up prompts include:

- Asked after a participant mentioned tenure: "Can you tell me more about the process of applying for tenure?"
- Asked after a participant used the phrase "different types of schools": "Can you tell me what you mean by 'different types of schools?'"

Additionally, "contrast questions" were asked to explore relationships between constructs (Spradley, 1980). Examples of follow-up contrast questions are as follows:

- "You mentioned that there is a difference between expert and novice learning. Can you talk more about that?"
- "You've mentioned two identities so far, astronomer and engineer. What are the unique aspects of an astronomer versus some other type of scientific identity or career identity?"

The fourth interview took place at the conclusion of the study and allowed for follow-up from the first three interviews and member checking preliminary results (Maxwell, 2013, p. 126).

The first three interviews were audio-taped, transcribed, and coded for all participants. Follow-up interviews were not recorded or coded because the intent of the interview was to confirm or clarify the study's conclusions. Field notes were taken throughout all four interviews.

Observation

Participants were observed engaging in professional activities on up to 10 occasions. Each observation lasted one half to two hours and involved either a class session or research group meeting. The first author completed four observations in each category (teaching and research) for each participant, and a fifth observation for each category was completed if theoretical saturation had not been reached. Observations were informed by a guide based on the research question and unique data for the participant being observed (Mason, 2002). A typical observation guide asked: "In what activities is the participant engaged? With whom is the participant interacting? What is the participant's demeanor?" During observations, field notes were hand written and subsequently transcribed and expanded. Field notes included: initial impressions and photos of the observation setting, notes on significant or unexpected occurrences, direct quotes from participants, and initial analytical ideas (Emerson, 2011; Spradley, 1980). Observations were not video- or audio-recorded in order to minimize interference with the regular activities of participants. The primary purpose of observation data was to triangulate and corroborate claims made by participants during interviews.

Document Collection

Before the study began and again during follow-up interviews, participants were asked to provide documents they felt were pertinent to their jobs. Publicly available documents were also retrieved. Examples include: graduate school, job, and award application materials; partial tenure dossiers (within the scope of confidentiality limitations); publications; syllabi; lecture notes and slides; personal and professional websites and blogs; and departmental, college, and university statements on teaching and research. Documents were coded and utilized for data triangulation.

Data Analysis

The software NVivo 10 for Windows was used for the transcription, storage, and organization of field notes, interviews, documents, and photographs. Data were coded by the first author, and NVivo was used to organize codes and theoretical memos. Categorical coding was utilized to answer and generate analytic questions, deconstruct data to manageable parts, uncover themes within and among cases, and contribute to answering the research question. In the tradition of phenomenological research, targeted coding was not utilized to answer the research question. Coding procedures followed a combination of the methods described by Spradley (1980) and Strauss (1987). First, open coding (Strauss, 1987, p. 28) uncovered *in vivo codes* (Strauss, 1987, pp. 28–30) and *folk domains* (Spradley, 1980, p. 90)—concepts labeled with vocabulary used by the participants themselves; *sociological constructs* (Strauss, 1987, p. 34) and *analytic domains* (Spradley, 1980, p. 91)—concepts labeled with vocabulary from existing literature; and *semantic relationships* (Spradley, 1980, p. 89)—descriptions of the connections between coded concepts. Second, NVivo software queries such as word count frequencies and word trees (diagrams which display commonly utilized words as well as their contexts) were used to uncover themes missed during open coding. Third, axial coding (Strauss, 1987, p. 32) was carried out for each code of interest uncovered in steps one and two. In short, axial coding revealed a comprehensive description of major themes. Finally, codes were organized into a cohesive story line for the purposes of answering the research question and communicating findings. For brevity, only the cross-case analysis is reported herein, but the full individual cases are available (Robert, 2016). As a second opportunity for member-checking, participants were asked to read their full case studies before publication.

Limitations

This study must be qualified in at least three ways. As an in-depth qualitative analysis of four professors' cases, the findings of this study should not be viewed as generalizable to the larger population of science professors. Future quantitative analyses can use this study to inform large-scale studies of professors' professional priorities to obtain more generalizable data. Secondly, professors in this study volunteered to participate; thus, the results of the cross-case analysis might be biased in favor of professors who have an above-average interest in postsecondary science education. Finally, with respect to diversity, all four participants in this study self-reported similar descriptions of gender, race, sexual orientation, and other demographic factors. Future work will seek to understand a wider variety of professors' experiences.

Results

Henry

Henry described himself in one source document as a White, 44-year-old male physics professor. Simply stated, he is a teacher above all else: "As a professor, I view education as my primary task. This may be an odd statement to make in a research proposal, but research is, after all, discovery learning at its best" [Henry, Award Application].[3] He joked that perhaps being a teacher is simply a matter of genetics because his parents, sister, some grandparents, and some aunts and uncles are teachers[4]:

> I'm sure my father was a huge influence. . . He would spend every night reading essays and writing responses which are probably longer than the original essay, red ink all over the place and then typed notes, and. . .[he explained] why it's important that the students learn and that his feedback is really important to them. [Henry, Interview 2]

As an undergraduate at a large, private, R1 institution, Henry double majored in physics and a humanities field. Getting a PhD was something he did to become a professor; choosing his specific field of study was a secondary matter. Henry earned his PhD at a large R1 institution with a reputation (according to Henry and other participants) for producing STEM professors. During his first year and a half of graduate school Henry engaged in a wide range of activities: teaching, research, and service endeavors such as writing gradebook software and setting up a Web server for the department. At that point, Henry's PhD advisor told him, "It's great that you're really involved in a bunch of different things. In five years. . .you're not going to be near graduation and you're going to hate me, and so you need to stop doing all these things" [Henry, Interview 1]. Subsequently, Henry focused solely on research until he graduated.

Immediately following graduate school, Henry spent two years as a postdoctoral researcher in a government lab—"a fantastic place to work. . .a very different culture than an academic culture. . . They believe that people should go home and be with their families" [Henry, Interview 1]. His first faculty position was at a large R1 institution in the Northeastern United States. During this time, he became involved with a large-scale research-based physics curriculum reform effort in collaboration with his colleagues. This was Henry's first exposure to education research, and he greatly enjoyed the experience. At the same time, he was developing his research program and participating in service. Henry did not receive tenure during this first faculty position. He was asked, "When you were describing your time at [your previous institution] it sounds like you were doing a lot of things outside of your research. . . Do you think that hurt your tenure process at all?" Henry responded:

> No. I mean, the number of people who came to me and said. . . you need to just focus on research, it's the only thing anyone cares about, just buckle down, do research, get it done, certainly I had that conversation multiple times with department heads, other faculty members. So I would say they probably think that's the case. . . I mean this comes down to the question of what my advisor in grad school told me to do, right? Essentially they're saying the same thing that he's saying which is, do one thing and focus on it and do it really well, and then you can get tenure, and then what? And then you keep doing this one thing? . . . The fact that [my research] was controversial and a lot of people didn't believe in it at the time would have still been the case whether I was in there doing the research myself or not, so I don't honestly think it would have really made a difference. Maybe would have had more papers out, but I don't know that that would have changed anything. And I was a lot happier this way, so there's a lot to be said for happiness.

Henry subsequently spent 1 year as a visiting scholar at a large, private, R1 institution before applying to LU and being offered a position with tenure. At the time of the study, he had been an associate professor at L.U. for almost 5 years teaching introductory physics courses; in fact, he has only ever taught introductory courses throughout his career. He explained that he truly enjoys teaching introductory physics and working with freshmen. Furthermore, he recognizes that it is rare for faculty to enjoy teaching introductory courses as much as he does, and so he is happy to continue doing so. Henry also leads a group of researchers (ranging from the undergraduate to the postdoctoral level) in basic physics research; that is, it does not necessarily have a direct application to solving problems but can be used to develop such technology. Finally, Henry serves on the advisory board for a STEM-specific teaching and learning center, an introductory physics course committee, a diversity committee, and others. He expressed that he participates in committee work in order to support the department and improve the culture of the community.

Ben

Ben, a chemistry professor at LU, described himself as a White male raised in a small, White community outside of the United States. Ben emphasized his cultural history, particularly with respect to his understanding of educational systems. According to Ben, schools in his country are well-funded and more rigorous than American schools.

Above all, Ben is a scientist, and he has made most of his educational and professional decisions based on his desire to do great research. He described his family as "very blue-collar" and explained that he was "pretty much the first person in my family who went to university" [Ben, Interview 1]. In the same interview, he said that he "didn't even think about going to graduate school, I didn't even really know what that was when I started my undergrad." However, research experience as an undergraduate student ignited his interest in pursuing a science career, and all of his subsequent academic and career decisions have been governed by his efforts to join labs engaging in research of interest to him.

Throughout Ben's time in graduate school (5 years), he served as a teaching assistant and worked 60–65 hours a week in his research lab. He explained that although he was not required to TA for funding purposes, it was the culture of the university for students to teach throughout their graduate careers. Ben described his time in graduate school as highly productive; he published approximately 10 journal articles as a graduate student and felt that he became an independent scientist during this time.

After graduate school, Ben worked for 4 years as a postdoctoral researcher for a group at a private, very small liberal arts[5] institution in the United States. He reflected on this time:

> The postdoc. . .can be a highlight of a young scientist's life because they don't have to take classes, they don't have to TA. . . And so you don't have all these other worries, and so for your postdoc you just focus on the research and just focus on your own research. [Ben, Interview 1]

After his postdoctoral fellowship, Ben searched for faculty positions that would best match his research interests. He accepted his current position at LU because he felt that the school not only met his research needs, but he also believed that the surrounding area would be a supportive environment for his family. At the time of this study, Ben was in his eighth year at LU and was awarded tenure during the period of this study. Ben often described challenges unique to early career chemistry professors, particularly the need to learn most skills on the job and the drive to attain tenure. He explained that his job has changed over time:

> In the beginning of my time. . . I was much more in the lab more days doing science, doing science experiments, but as the lab grows you're sort of more in charge of more and more people and as well at that point we have to take all the science experiments and start writing research papers, start writing research grants so that we can get money to do more research. . . The best person to write the papers and to write the grant is myself. . . Until recently I've gotten out of the lab more and more doing research experiments myself. . .spending more time just sitting at my computer and doing lots and lots of writing when I'm not worrying about my teaching obligations. [Ben, Interview 2]

In addition to research, Ben teaches undergraduate chemistry and engages in service committees (mainly undergraduate advising and an instrument steering committee).

William

William is an astronomy professor at LU. During this study, William was in his 6th year of teaching at LU and received tenure several months into the study. During the follow-up interview, William described himself as a professor of astronomy who does research, teaches classes, and advises students. He added that he is a husband and father, male, and "I don't know if I'm middle-aged yet. Maybe I am" [William, Interview 4]. William experiences a strong sense of personal and professional identity as an astronomy researcher. He does not come from a family of scientists, but developed an interest in astronomy in grade school through popular culture and textbooks: "Discovery Channel, you know... I mean you read the kids' science books and it says, 'Astronomers know that...' And there it is, that's the job I want. I want that job" [William, Interview 1].

Across his educational career, William continually developed as a researcher with strong ties to his professional community. As an undergraduate, he was an astronomy major and engaged in astronomy research. He attended graduate school at a highly rated, public, R1 institution which he says is known for producing tenure line faculty members. In addition to research and service, William engaged in teaching assistantships throughout his time in graduate school because he enjoyed teaching and knew that the experience would be good for future job applications. During his first semester in graduate school he also took a pedagogy course designed for astronomy graduate students—the only pedagogical training he and his cohort received, "which is more than a lot of students get" [William, Interview 1]. He recounted his first year of teaching as a graduate student:

> I had no idea what I was doing. The first semester they just throw you in... So you've been there just as long as the freshmen have been there, and you're supposed to start going over homework with them...that very first week. [William, Interview 1]

After earning his PhD, William spent a year and a half as a postdoctoral researcher with his graduate school advisor. He subsequently took a postdoctoral position at a private, R1 institution for a year and a half. There, William described a period of significant professional development. This professional development is something that William currently tries to pass on to his own graduate students by presenting similar topics during group meetings: "learning a new computer language...how do you get Hubble space telescope time...how do you make a good conference poster...the stuff you actually spend most of your time on" [William, Interview 2].

During his time in graduate school, William met Karen (pseudonym), who he married shortly after graduation. William's relationship with his family plays a significant role in the way he manages his career. When applying for jobs after graduate school, he explained, "The two body issue guided everything" [William, Interview 1]. William is also more cognizant of his time management now that he has children. He chooses not to work between 4 and 7:30 PM because this is family time. William does not engage in personal activities at work and only works at home after the children have gone to bed when it is absolutely necessary.

As for his current job responsibilities, William engages in research, teaching, service, and interaction with the greater community of astronomical researchers:

> I advise students and postdocs and research associates. I teach, and I do some service for the department sometimes, the college or university. Advising students is most of the research I do, but I do some research on my own... I also collaborate with other people and interact with the rest of the astronomical community... I think that hits all the main pillars of what I do. [William, Interview 2]

William's research program is the cornerstone of his professional life, and his identity as a researcher can be seen in all aspects of his career.

Pierre

Pierre (pseudonym) describes himself as an early career interdisciplinary scientist whose research is a combination of laboratory and international fieldwork, and as a White male in his mid to late 30 s. During this study, Pierre was in his fourth year at LU and not yet eligible to apply for tenure. Because of Pierre's unique combination of fields of study, they will only be referred to as a humanities and a biological science to protect his confidentiality. Pierre more closely identifies with his humanities field: "Although [a biological science tool] is my primary research tool, I consider myself a [humanities researcher] rather than a [biological scientist], which I hope is apparent from my research approach" [Pierre, Document 02].[6] Thus, references to Pierre's field of study pertain to his humanities specialization. Pierre is an assistant professor in both of these departments and advises graduate students from multiple disciplines.

As an undergraduate student at a medium-sized, R2[7] institution, Pierre began his studies as an undecided major before switching to his humanities field: "I had never heard of [my field], and I took an introductory class... And I was like, 'This is just amazing'" [Pierre, Interview 1]. Although he was excited about research, he decided to take a break from academia to work in a corporate job before attending graduate school at a large, public, R1 institution:

> As an undergrad I did some research and got experience. I was like, "I think this is what I want to do for my career." But I wasn't ready to do it yet... I wanted some other experience first. [Pierre, Interview 1]

He was a consultant for three years in a "great job... worked with great people in a much more teamwork-oriented environment than what you find in academia" [Pierre, Interview 1]. Finally, Pierre went to graduate school: "in the end it was about making money for whatever company I was consulting for...and you know I wasn't passionate about that" [Pierre, Interview 1].

Unlike most graduate students in his field, Pierre initiated research during his first year of study: "I [wanted] to learn things in the lab, so then I practically did that rather than as kind of a requirement or a standard" [Pierre, Interview 1]. His first year also involved taking courses, and it was through this experience that Pierre discovered his interest in the biological sciences. From that point, Pierre was able to pursue multidisciplinary work. After earning his PhD in his humanities field, he took a postdoctoral fellowship in his biological science of interest at a large, well-funded lab at a private, R1 institution because he wanted to learn new skills in that area. Pierre indicated that overall, he valued the experience he gained as a postdoc because it helped him build the foundation for his career as a research professor.

During the last few years of graduate school and into his postdoctoral fellowship, Pierre explained that a combination of his intrinsic motivation and external influences drove him to take on more and more work as time went on:

> I was super passionate about what I was doing... I had some confidence because I knew that I was doing pretty well, but you never know. You start realizing how rare these jobs are, etc... But then... You never know if it's enough...to get hired. You never know if you're doing enough... And that sort of realization seeps in and becomes this stress that reinforces more work, but it gets too much. [Pierre, Interview 1]

After his postdoctoral fellowship, Pierre decided to work at LU in a joint appointment in both of his fields of interest. He described his motivation for becoming a professor:

> Just the passion for the questions. I always wanted to, from the time I got into [this field] know more. I have these questions, and doing science and being an academic and so on, that was the way to answer this question. . . I wanted to make a difference in people's lives. I think that was the motivation. . .and I saw teaching as a way to do that. And I wasn't thinking at the time about outreach and so on, and now I'm thinking more and more about that, but teaching is a way to do that in a way that my professor had made a difference in my life. [Pierre, Interview 1]

Cross-Case Analysis

Intrinsic Motivation: Participants' Career Decisions are Motivated by Intrinsic Goals and Desires Rather Than External Factors Such as Institutional Culture or Peer Expectations. An initial aim of this study was to see whether and to what extent the research-intensive R1 culture would influence the way professors chose to allocate their resources across the various aspects of their jobs. An unexpected finding of the study was that the participants consistently reported that the cultural backdrops of their departments and colleges and the university did not actually impose much influence on the way they engaged in their jobs.

Henry indicated that even in cases where his goals do not align with cultural norms, he pursues his own interests rather than conforming to those norms. For example, he explained that at his previous institution many colleagues encouraged him to focus solely on his research to the exclusion of teaching and service activities. However, he chose not to follow their advice: "I don't want to do one thing. I want to do three things. I wanna teach, I wanna do service, I wanna do research" [Henry, Interview 1]. Apart from the way Henry allocates this time, he feels that in many ways his goals for his teaching and research are in alignment with his institution's goals: both Henry and the institution want classroom students to learn and want research students to become independent scientists. The difference between Henry's goals and the institutional culture only lies in Henry's emphasis on student happiness; Henry indicated that the institution tends to emphasize productivity and efficiency.

Ben indicated that there was very close alignment between his goals for teaching and research and his institution's goals. As Ben feels that the institution favors research productivity over teaching efficacy or service work, evidence of the alignment of Ben's goals with this culture can be seen in his personal desire to focus on prioritizing his research above all else:

> I think our department does a really good job of supporting assistant professors. . . They try to limit the amount of service work. You're still teaching, but they set you up with the course that you teach a few times to sort of help. [Ben, Interview 2]

During the follow-up interview, Ben was explicitly asked about this intrinsic motivation theme. He confirmed that the way he has managed his career has been driven by his personal goals and that those goals happen to be in alignment with academic culture rather than imposed by academic culture. He reiterated: "research number one, teaching number two and everything else number three" [Ben, Interview 4].

William's prioritization of research over the other components of his job is very similar to the way Ben prioritizes his work. This is evidenced in William's statements regarding research as well as tenure. As William talked about the way he has structured his time as a pre-tenure professor, he indicated that he made research a priority and that his department supported this effort: "The pre-tenure faculty are busy earning tenure, so my department head was just very conscientious of not giving me too many new teaching assignments and not overloading me with committees"

[William, Interview 2]. When asked if his goals were in alignment with the university's goals, he explained:

> I think they're well aligned. I think they were pretty clear. Especially just coming from tenure, I have a good sense of what they appreciate. The university wants to see me having an active research group, publishing papers, graduating students, and getting citations. The university wants to see me bringing in grant money and supporting people. [William, Interview 3]

During the follow-up interview, William was asked to confirm that academic culture did not heavily influence his career choices. He indicated that he largely agreed, though in some cases he did modify his behavior in order to attain tenure. He provided one example: before he received tenure, he spent more time traveling to give research talks than he would have liked because this activity would bolster his tenure application. He said that other than this instance, his intrinsic motivations and goals are in alignment with the culture of his institution.

Pierre's career goals were similarly aligned with those of the institution. As Pierre is currently working towards achieving tenure, he is acutely aware that he must prioritize his research productivity for this purpose. He reported that he chose to work at a research-intensive institution with "eyes wide open" [Pierre, Interview 3] because the institutional culture is in alignment with his personal career goals. He explained:

> There is a match between – it's not perfect, it's not linear – but there is a match between the university and department and how they set you up to succeed in your career and in your research career. The resources available, the quality of the grad program, the funding opportunities, the clearing of the bullshit that keeps you from being successful. There is a near linear relationship, imperfect but a strong positive relationship between that and the expectations of the university. . . Ultimately for me part of it was that my particular research program. . .is very expensive. . . Either I go all in and do it the way I think it needs to be done or not at all and do something pretty different. [Pierre, Interview 3]

Thus it is evidenced that not only are Pierre's goals in alignment with his institution's goals, but he chose his institution based on that alignment.

Students: The Participants Support All Types of Students at Their Institution. All four of the professors who participated in this study indicated that helping students (at all levels) is one of their primary professional responsibilities. Henry was perhaps the most student-centered professor in the study. Henry's characterization of the similarities between his teaching and research goals provides an apt representation of this theme: "I want to help these students get to where they want to go. . . Similar aims, helping people basically" [Henry Interview 3].

Ben was less explicit about this priority in his career, but it was evident in many of his actions. For example, in his research lab, Ben emphasizes helping his research students become independent scientists instead of enabling them to "keep asking well what should I do, what should I do, what should I do" [Ben, Interview 1]. In the classroom, Ben appears to be a reflective practitioner, as he expressed that he is always seeking ways to improve his teaching. Finally, Ben explained that he chose to work with undergraduate students as part of his service responsibilities even though most new professors prefer to work with graduate students for recruitment purposes. He did this because his experience as an undergraduate student at a largely undergraduate institution instilled in him a passion for assisting undergraduates to find research opportunities and for providing them with career advice.

William's emphasis on student support can most clearly be seen in his commitment to the scientific community at large. From the time he was in graduate school, William saw value in fostering a sense of community with his colleagues, and as a professor he views his students—at least his research students—as his colleagues. When asked how he scheduled his days, he made it clear that his research students' needs come first:

> Students are important. Even if the particular thing they're working on isn't important, they are important and so if the student were knocking on my door, I always try to answer it and deal with it. So if I'm looking at my inbox to try to figure out what thing to deal with next and the door [knocks] and it's a student, the student comes in. [William, Interview 2]

William's respect for students also extends to his classroom, where he emphasizes the importance of providing students with the tools to either make career decisions or learn important professional skills (depending on the course).

Pierre's commitment to his students is similar to William's. With respect to research, Pierre prioritizes training his students to be independent researchers, and in the classroom he teaches his students to think like scientists. In the third interview, Pierre summarized this theme: "Training students is both an important part of the job as a research professor and educator." Pierre also seeks to assist students by engaging in service work that will help both undergraduates and graduates have a better experience at the university.

Throughout the observations of all four of these professors, their actions suggested that they could all be described as student-centered teachers. Each of them consistently made efforts to engage with their students during class by asking probing questions, making eye contact, following up on student questions, checking for understanding, etc. All four of these professors indicated that they received positive feedback from their classroom students and that this feedback was an important metric for them to reflect upon their practices. Similarly, during observations of the participants engaging in research meetings with their students, all four of the professors exhibited student-centered behavior. It was typical for the professors to ask questions about the students' research, but the tone was always supportive and conversational; students never appeared to feel uncomfortable or defensive. Instead, research students appeared to be relaxed as they engaged in scientific discussions with their advisors. Thus, all four participants not only claimed that they desired to support students during our interviews, but the interactions observed during classes and research group meetings supported the participants' claims.

Lack of Pedagogical Training: Participants Had Little to No Training for Any Professional Activities Other Than Scientific Research. Whereas all of the participants in this study acknowledged that they are highly trained research scientists with positions in competitive science departments, they also volunteered that they experienced little to no preparation for any of the other responsibilities of professors, such as teaching and managing research groups.

Even though Henry had tutoring experiences from the time he was in high school and engaged in service and research activities from the time he was an undergraduate, he explained that none of those experiences prepared him to be a professor. He expressed dissatisfaction with the lack of training professors receive to do anything other than research:

> I mean we talked about the fact that preparation for teaching for example is pretty lamentable. And preparation for being a group leader is not existent, so definitely there's a difference between, as a researcher, as a graduate student, where you can just worry about the problem and as a professor where you have to worry about how am I going to fund the problem (laughs), how am I going to pay for my students, where are we going next. I can't

> really be thinking about this problem because I gotta be thinking about what are we gonna be doing in six months so that we can keep going and things like that, so yeah there's a big difference in that way. [Henry, Interview 3]

Ben expressed a very similar sentiment. He said that sometimes he feels like other professors have all the answers, but he is still trying to figure things out. He explained:

> Well as I said you know physical science you are taught your graduate work and your postdoctoral work primarily teaching you to be a bench level scientist, so coming in and becoming a professor you have all these things that there's no formal teaching about. So I talk about me being a manager of scientists, dealing with these social interactions, so not just thinking about the science but thinking about the people doing the science. But then there are things like coming up with a budget, no one ever taught me how to come up with the research budget before I came here, and again you know coming in you know I never taught a full course before. . . You're not taught how to teach. You're just you're taught how to do research on a bench and then you're given all these other responsibilities and hopefully you learn. [Ben, Interview 2]

Of all the participants, William is the only one who expressed having any training in anything other than engaging in research. He stated:

> [My postdoctoral advisor] taught me a lot about how to be – a lot about the details of doing astronomy: how to be shrewd about getting proposals accepted, how the money works, how money flows, what overhead is, and the things like that that I had no exposure to [as a graduate student]. [William, Interview 1]

On the topic of professional identity, William was asked if he quit his job tomorrow, would he still identify himself as a teacher? He responded: "No. No because my training's not in teaching. I have almost no training in teaching. So I haven't spent years of my life learning to be good at it. It's definitely a profession and not an identity for me" [William, Interview 3].

Throughout Pierre's interviews, the only career preparation he discussed was research training. When he was a graduate student he was concerned that his lack of teaching experience would impede his job search:

> I actually never TAed in grad school. . . I was a little worried about that at the time. I said, "Is this something that's going to hurt me when I apply for jobs?" And my advisor and advisors. . .were like, "No, not having any TA experience doesn't matter. People are gonna hire you based on your research you're producing, good papers, etc. Just keep focusing on that." [Pierre, Interview 1]

Pierre did not explicitly address a lack of preparation for leading a research group, but he often made references to the fact that he has been trying multiple methods for mentoring his students and is still learning what works and doesn't work.

Time Management: Prioritizing Professional Responsibilities and Managing Time Are Common Challenges for the Participants. All of the participants in this study consistently commented on the time cost associated with various activities. They are all actively aware of their limited time resources in an environment where their workload is truly endless.

During Henry's interviews, he described how being a professor is not a 9-to-5 job because being a professor is more an identity than a job:

> I have friends for example who have jobs where it's like five o'clock, that's done, now I can go be myself. And that is definitely not my life in any way, shape, or form. And partly because I am doing physics at 2 AM and I take it home and I think about it all the time and think about how to teach better, think about how to solve some problem in the lab, how to write some paper. That consumes me. So partly it's that, but it's – I love it. [Henry, Interview 3]

While discussing what he would have to do in order to take on more responsibilities, he remarked:

> I do a lot of things. In order to do more things, I have to give up something. It could be sleep I suppose, but I'm already giving up a lot of sleep, so I'd have to figure out what to jettison, or change anyway, shrink. [Henry, Interview 3]

Henry never seemed dissatisfied with the amount of time he spends working; he is simply aware that he has many responsibilities and a limited amount of time.

Ben expressed similar feelings about his limited time resources when asked about collaborating with other educators on campus:

> The issue is I have a variety of different responsibilities, and maybe it's an excuse, but I only have so much time in the day. If I really wanted to I think I would have to focus a lot more attention on what's going on. I mean certainly we do have resources [here], like the [science teaching and learning center]. There's other centers. I guess I could reach out to other departments. I know there's reading through say Science magazine or Chemistry and Engineering News... I'm sure there's more information within the education-based journals, but I just haven't found the time to further search them. [Ben, Interview 3]

He further explained:

> There's only so many hours within the day. I know that I do consider the research to be a little bit more important to get the grants written, getting more and more funding, supervising the lab and so on. And so sometimes I have to think about how I want to divide my time and what will push the science forward. And so sometimes again there are these time constraints. [Ben, Interview 3]

William also expressed the need to manage his time carefully. As he talked about managing his research group, he explained that he didn't want his group to become so large that he would not have time to provide individual attention to all of his students: "It's hard, the group just keeps growing and I need some people to graduate to free up some time so that I can give people more individual attention" [William, Interview 2]. William indicated that it is harder for him to manage his time when he is teaching classes: "Summertime is better. I tend to have more time on the whole because no teaching. Like this last fall was dead because I had to do new class prep, and that just eats up all the time" [William, Interview 2].

Pierre's comments on time management were typically connected to his desire to balance his workload. He explained that there was a time as a graduate student when he was working almost constantly, but that he has recently been learning to manage his workload: "I'm learning how to manage what I say yes and no to and the consequences of starting a new project, how that's gonna pile on together 16 months from now or something" [Pierre, Interview 2]. Later, he offered a detailed description of the challenges associated with managing time as a professor:

> All that stuff during the school year that adds up on top of the teaching and everything else. . . I've got my class schedule, I've got my teaching, I do these other major things, like the department stuff, this stuff that you know just has to get done. . . meetings, that sort of stuff. I work on my emails. I literally mean that. I get my emails that come in every day and I've gotta manage that process right? Like small amounts of work associated with these emails is my work. Email is kind of like my to-do list, and in fact I send myself emails. . . And then I try to carve out time half an hour here 15 minutes here an hour here to work on the science productivity. . . Making comments on a paper that my postdoc has drafted, advancing my own papers and analyses. . . I kind of make sure that I'm prioritizing that and I'm moving forward. . . The sum total of that makes it hard to fit everything into a day without letting it bleed into the evening or the class prep for the next day bleed into the evening and so on. So that's probably not a very unique answer on what it's like during the semester but that's, that's the truth. [Pierre, Interview 2]

Answering the Research Question. The purpose of this study was to answer the research question: How do individuals in a sample of tenure-track science professors prioritize teaching among their other professional roles and responsibilities? A sociocultural theoretical framework (Rogoff, 1995) was utilized to interpret case study data through the lens of understanding individuals as members of communities and social events. The first three cross-case themes described above offer the answer to the research question. For all of the participants except Henry, it was clear that their professional priorities were research, teaching, and service—in that order. This prioritization was a result of multiple factors. First, the participants in the study all expressed an intrinsic motivation to engage in scientific research. Again, with the exception of Henry, the participants were simply more interested in their research than they were in their teaching. This is not to imply that the participants were not at all interested in teaching. On the contrary, the second cross-case theme (a desire to help all types of students) explains why the participants still made efforts to be what they considered good teachers, even if it was a second priority. Thus, Ben, William, and Pierre expressed that teaching was their second priority after research because they are intrinsically motivated to pursue their research first. In contrast, Henry expressed that teaching, research, and service were all equally important to him because he enjoys engaging in all three of them equally.

Considering Rogoff's framework for understanding social phenomena, it is notable that the participants in this study did not report that their institutions, departments, or even colleagues had any appreciable impact on their daily choices. None of the participants implicated *current* sociocultural influences such as disciplinary or institutional norms, promotion and tenure guidelines, or professional development as explanations for the way they prioritized the components of their jobs. There is some evidence to suggest that for Ben, William, and Pierre, a lack of early experiences with pedagogical training (the third cross-case theme) or research-based teaching could partially explain their lack of interest in such endeavors now. Henry's case is again distinctive as he was engaged in the culture of teaching at a very young age within his own family and again at early stages in his career. In this way, all four cases point to the notion that early apprenticeship and guided participation might have had a more significant impact on participants' current goals and desires than any recent experiences.

The fourth cross-case theme concerning time management does not directly serve to answer the research question. That is, given the importance of intrinsic motivation for the participants, even if they had more time available, they would likely still allocate it in the same manner they do now.

Discussion

This set of case studies deeply examined the professional lives of four science professors in order to gain a better understanding of the way they prioritized and engaged in teaching among their many other roles and responsibilities. This work was based on a sociocultural framework for understanding the way individuals interact with each other and their environments. A cross-case analysis of the data revealed that the participants: made professional choices based on intrinsic motivations and desires, emphasized the importance of helping their students in all areas of their jobs, identified a lack of pedagogical training despite extensive scientific training, and maintained an awareness of limited time resources while engaging in unlimited work activities.

Two of the findings from the cross-case analysis are in alignment with some literature described earlier. First, participants in this research indicated that their current and previous institutions placed a greater emphasis on research activity than on teaching responsibilities, confirming assertions from literature discussed above (Bradforth et al., 2015; Leslie, 2015; Light et al., 2009; Wright, 2005). This was particularly evident as they discussed their lack of training to do anything other than scientific research. Other comments regarding their current institution's goals and promotion and tenure processes also supported this conclusion. The second finding of this study that is aligned with previous literature is the participants' comments regarding time limitations. In essence, professors' jobs are composed of three pillars of activity: research, teaching, and service. However, each of these roles presents limitless opportunities for the introduction of new work. That is, professors are always able to do more research, interact more with their students or course work, and engage in more service. Thus, in order for a professor to engage in a new professional activity, there is almost always the need to eliminate or reduce an existing activity. In fact, with the exception of competing time commitments, participants in the study rarely described any situations or constructs to suggest that teaching and research have any particular relationship to each other. This finding supports a different enterprises model as described previously (Hattie & Marsh, 1996).

Two of the themes revealed in this study's cross-case analysis are novel in light of previous literature speculation. First, contrary to assumptions that departmental or institutional culture exerts a significant influence on professors' career decisions (Anderson et al., 2011; Hardré et al., 2010), the participants in this study indicated that they made decisions based on their intrinsic goals. Although their choices were typically in alignment with institutional norms and goals, they viewed this alignment as incidental rather than causal. Second, whereas previous literature has largely been silent on the role of professors' relationships with students in professors' decision-making regarding career management, the participants in this study all emphasized the importance of their students' success in every aspect of their jobs. The disagreement between these findings and previous work presents an opportunity for future researchers to question assumptions made about how and why various sociocultural factors influence typical professors' beliefs and practices.

It was apparent that early apprenticeship and guided participation may have been more influential for participants in this study than recent experiences. Future research should more deeply investigate the relationships between professors' choices and the diverse components of their past *and* current professional settings. This holistic view of past and present circumstances is in accord with Rogoff's participatory appropriation (1995). For example, what types of past and present experiences influence science professors to adopt more research-based pedagogies? Only one of the participants in the study described herein (Henry) self-identified as actively engaging in research-based pedagogy. From Henry's case, researchers might speculate that early career or even family experiences could be highly influential in forming professors' desires to pursue

research-based pedagogies. Longitudinal phenomenological work or case studies that begin tracking participants in graduate school would give rise to a better understanding of the relationship between early-career apprenticeship/guided participation and later career prioritization.

The diversity of activities within professors' teaching duties is another factor which warrants further consideration. Beyond classroom instruction, participants in this study also engaged in mentoring and training graduate students and postdoctoral scholars, advising undergraduates, and sponsoring independent study. Further empirical and theoretical work is needed to refine the field's scholarly definition of "teaching" at the postsecondary level. Considering the various types of teaching as sociocultural constructs within Rogoff's participatory appropriation developmental process would allow researchers to understand how engaging in various types of teaching changes practitioners and their career goals. A more complete description of teaching activities could also lead to practical implications such as integrating a wider variety of teaching activities into promotion and tenure guidelines, yearly teaching requirements, etc.

Expanding the field's understanding of professors' teaching activities is in alignment with the Carnegie Foundation's evolving concept of the scholarship of teaching. The scholarship of teaching was first identified as one of four major functions of university professors (along with the scholarships of discovery, integration, and application, Boyer, 1990) in *Scholarship Reconsidered: Priorities of the Professoriate*. Boyer described teaching: professors must, "above all," be well-versed in their own content knowledge areas; professors plan and constantly reexamine discipline-specific pedagogical activities intended to stimulate active learning; professors are learners in the sense that teaching is "not only transmitting knowledge, but transforming and extending it as well" (pp. 23–34). In a follow-up to Boyer's work, Hutchings, Huber, and Ciccone published the Carnegie Foundation report, *The Scholarship of Teaching and Learning Reconsidered* (2011). The modification of vocabulary here reflects a change that has taken place on a widespread level; the community has evolved from thinking of a university as a provider of knowledge to thinking of a university as a place of learning (Barr & Tagg, 1995; Hutchings et al., 2011, p. 4). As this understanding has been refined, so too has the community's understanding of the ways in which this scholarship of teaching and learning can be utilized. One of the most valuable applications for a scholarly approach to the role of teaching for science professors is improving their own teaching practices. Hutchings et al. (2011) hope the scholarship of teaching and learning can bring to higher education classrooms "a set of practices that have traditionally been missing. . .habits of inquiry, analysis, exchange, and knowledge building" (2011, p. 41) by challenging the assumption that the only preparation professors need to teach is expertise in content knowledge.

The differences between the findings reported herein and previous work also support broadening the scope of discipline-based education research to include more descriptive, phenomenological studies. Whereas it is a clear goal of discipline-based education research to advance the teaching and learning of science and engineering, this field has expressed relatively little interest in generating socioculturally informed understandings of holistic human experiences (Coppola & Krajcik, 2013; National Research Council, 2012). Descriptive studies offer a deeper understanding of participants' naturalistic experiences, and this is rarely a feature of interventional designs which, by nature, seek to change a situation and then measure or study that change. Without a baseline understanding of participants' authentic lives, interventional studies risk failure based on false premises and assumptions. As this work shows, previous assumptions about professors' careers do not hold true for at least some professors. In particular, many of the models described by Hattie and Marsh assume significant tension between teaching and research activities (e.g., intervening variables, differential personalities, and divergent rewards as described above).

In this way, descriptive methods (phenomenology, case study, etc.) provide a means for researchers to learn more about participants and design more targeted interventional studies.

Professional development stakeholders can use the knowledge gained in this study to inform investigations into the types of pedagogical and professional development interventions science professors would be willing to utilize. There is no silver-bullet solution to the challenges faculty face when attempting to balance the diverse components of their jobs. However, creatively designed pedagogical support can help them excel at teaching without compromising their core values. For example, given the insights into participants' desires to help their students, it seems that science professors might be more willing to adopt interventions that are clearly designed to be student-centered. Furthermore, understanding that science professors at large research universities are likely unwilling to detract time from their research activities, creatively designed interventions that do not require large time investments might be more popular among these professors. The participants' stories point to the possibility that more formal efforts to integrate research and teaching activities could prove to be one entry point to providing professors with more pedagogical support. All of the participants described efforts to use their research to inform their teaching or use their teaching roles to strengthen their research activities. These efforts were exhibited in different ways for each participant, but across the cases, synergistic connections between research and teaching at both the undergraduate and graduate levels were seen. This natural synergy indicates that efforts to coordinate research and teaching might be well received by science professors at large. Beyond these specific connections, a more general implication of this work for professional developers is to design socioculturally informed training and support for professors. This approach is analogous to (and could be coordinated with) current efforts to implement the socioscientific issues framework in STEM classrooms (Zeidler, 2016).

This work also has implications for the preparation of new science professors. The training of future professors during the graduate or postdoctoral years should be considered separately from support for the existing professoriate. Some recent research suggests that professors who are exposed to research-based teaching strategies at earlier stages in their careers (e.g., graduate school) are more likely to utilize those strategies later (Lund & Stains, 2015). In light of the cross-case themes reported herein, it is possible that this phenomenon is a result of early experiences exerting an influence on professors' intrinsic goals and motivation. Future faculty training could make significant advances toward reducing traditional teaching practices in favor of research-based pedagogies by explicitly targeting long-term goals and motivational factors. Other cross-case themes from this study suggest that training programs should also consider emphasizing student-centeredness and time management skills. Furthermore, it is of interest to note that this study only examined the positive cases: individuals who received doctoral degrees in physical and natural science and now maintain careers in the professoriate. More information could be gained by studying individuals who began an academic career track (i.e., obtained doctoral degrees) and at some point chose not to pursue (or discontinued) careers in the professoriate. Future studies might ask whether the diverse demands of professors' careers serve as a barrier for qualified candidates and whether programs aimed at training new professors might mitigate that barrier. For example, might we better support our professoriate by encouraging them from earlier stages to engage in a wider variety of professional activities? After all, in Henry's words: "I wanna teach, I wanna do service, I wanna do research... And I was a lot happier this way, so there's a lot to be said for happiness."

Notes

[1]http://carnegieclassifications.iu.edu/. Only 40 US institutions match this description, so further geographical data are not included here.

[2]Bracketed citations represent references to transcripts, documents, and field notes.

[3]To protect participants' confidentiality, documents will be given generic labels that have been mutually agreed upon by the participants and the researchers.

[4]The word "teacher" is used here because that is the vocabulary Henry used. Throughout this study, participants used the words "teacher," "professor," and "mentor" interchangeably. To the greatest extent possible, wording is matched to that of the participant.

[5]The Carnegie classification for the school is Baccalaureate Colleges–Arts & Sciences.

[6]Documents associated with Pierre's case have been labeled with a generic numbering scheme instead of more specific identifiers as in other cases. This has been done to address a specific confidentiality concern unique to Pierre's case.

[7]R2 is the Carnegie description for Doctoral University (higher research activity).

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