Becoming a SoTL Scholar

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Doing SoTL STEM Scholarly Essay

CHAPTER 7

GUIDING PRINCIPLES FOR STEM FACULTY INTERESTED IN SOTL

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Faculty teaching in one or more disciplines in science, technology, engineering, and mathematics (STEM) are increasingly becoming so interested in how students learn in their courses that they want to investigate this learning in a more systematic and scholarly way. This investigation can be a one-time effort, or it may reflect the start of a long-term engagement in the scholarship of teaching and learning (SoTL), as some faculty will make a conscious decision to shift the focus of their scholarly activity to this area. In this chapter I want to introduce some perspectives and considerations that I hope will be useful to STEM faculty engaged in making and sustaining such a long-term shift. From my own experiences as well as working with other STEM faculty, it is helpful to understand how SoTL work can vary significantly both in scope and the level the work is done at. In some ways, SoTL has important similarities to "ecological fieldwork" that are worth keeping in mind. SoTL work done by STEM faculty can also differ in the extent to which the work is focused in a single discipline vs. having a more interdisciplinary focus. Finally, as with traditional STEM research, faculty engaged in SoTL can do this work in ways that vary widely in terms of the degree of collaboration involved.

In *The Scholarship of Teaching and Learning: A Guide for Scientists, Engineers, and Mathematicians*, Jacqueline Dewar, Curtis Bennett, and I defined the scholarship of teaching and learning (SoTL) as (2018, 7):

> the intellectual work that faculty members do when they use their disciplinary knowledge to investigate a question about their students' learning (and their teaching), gather evidence in a systematic way, submit their findings to peer review, and make them public for others to build upon.

This definition was intentionally written to help STEM faculty view engaging in SoTL as less daunting than we found many of them perceived it to be. It also reflected key points made by many of the first-generation leaders in the developing SoTL community, particularly Lee Shulman and his colleagues at the Carnegie Foundation for the Advancement of Teaching.

As Miller-Young and Yeo (2015) point out, SoTL by definition includes a variety of disciplinary perspectives as well as multiple methodologies and theoretical perspectives. At the same time, at the core of SoTL is the goal of deepening our understanding of student learning. While student learning may have been viewed originally as understanding of disciplinary concepts, STEM faculty are now asking a wider range of questions related to student learning. The questions below are examples that I hope will convey the wide range of possibilities that STEM faculty can explore:

- What are students experiencing as they engage in various forms of writing or reading a variety of different scientific texts (textbooks, primary literature, articles in the popular media)?
- How are student experiences in STEM courses related to issues of diversity, equity, and inclusion?
- What are the impacts on student learning of courses or curricula that use more integrative approaches to learning which bring together STEM and the humanities?
- When issues of social justice are incorporated into a STEM course, how does that impact student learning and understanding?

These questions and others like them are particularly well suited to the variety of disciplinary perspectives, methodologies, and theoretical perspectives encompassed by SoTL.

What does this mean for established STEM faculty who are considering a change in the focus of their career from doing "conventional disciplinary research" or being in a teaching-focused position with little engagement in research, to a career focused on SoTL? My hope is that the principles described in this chapter will be helpful in navigating this transition. In keeping with the theme of this book, this chapter is more concerned with the broader question of transitioning a research/scholarly agenda to one focused on SoTL rather than how to develop a specific project. STEM faculty interested in ideas or suggestions for developing an individual SoTL project are encouraged to consult the volume by Dewar, Bennett, and Fisher (2018).

SoTL is not the same as what faculty often view as discipline-based educational research

STEM faculty interest in student learning isn't a relatively new phenomenon. Discipline-based education research (DBER)—with roots stretching back over seventy years in some disciplines and coming to prominence in the 1980s and 1990s—"investigates learning and teaching in a discipline using a range of methods with deep grounding in the discipline's priorities, worldview, knowledge, and practices" (National Research Council 2012a). What is the relationship between these two ways of investigating student learning? The answer to that question is complex, as SoTL and DBER are not mutually exclusive. The two perspectives share some commonalities, and some STEM faculty would consider themselves members of both communities.

DBER investigates teaching and learning in a manner deeply grounded in a particular discipline. It is also very often connected to and draws from science education, educational psychology, cognitive science, and educational evaluation. In the United States where it is well-funded at the national level, DBER is not only concerned with disciplinary knowing/learning, but it also often seeks to establish generalizable knowledge that can apply across individual classes, instructors, and institutions. Faculty engaged in

DBER often draw on similar theories, regardless of their specific STEM field; as the 2012 report from the National Research Council points out, "DBER is heavily influenced by constructivist ideas of learning, which propose that students generate understanding and meaning through experience." However, the extent to which individual DBER studies are connected to broader theories of learning and teaching can vary widely.

SoTL, on the other hand, is concerned with both knowing/learning (within and across disciplines) and classroom practice/experience (almost always at the level of an individual instructor). As a result, SoTL is much more strongly focused on the experience of particular instructors and particular classes as well as presenting that experience in a rich, contextualized manner—using quantitative methods, qualitative methods, or a mixture of both (Divan et al. 2017)—that others can use as a source of insight and understanding. As pointed out by Hutchings and Huber (2008), SoTL has a much more complicated relationship with theory. SoTL projects can be connected to theories within the same discipline or theoretical frameworks from other disciplines, or they may even generate theoretical perspectives. As Hutchings and Huber (2008, 241) write, "Yes, the scholarship of teaching and learning is a knowledge-building activity, but its purpose is not to generate or test theory. The purpose is to improve student learning." And that may, in the end, be one of the important differences between SoTL and what is viewed as DBER in a particular region or discipline.

Many STEM faculty who are new to SoTL often make the unspoken assumption that the goal is always to find knowledge or information that, if not fully universal, is clearly generalizable. While this assumption may be true for work commonly viewed as DBER, the same assumption, and the concerns and anxieties it can fuel, can pose a real barrier for STEM faculty engaging in SoTL. In part, this assumption blurs the distinction between "generalizability" and "applicability." Scholarly work such as SoTL done in a particular context and made public in a rich way can be applicable to other contexts and situations, either in the same discipline or across disciplines. Applicability of SoTL across disciplines is not limited to disciplines that share similar characteristics (epistemologies or methodologies). For example, STEM faculty can learn from the work of Feito and Donahue (2008). Feito is a psychology professor while Donahue is a faculty member in English. The two collaboratively looked closely at students' annotation of complex readings in the interdisciplinary seminars each of them taught at their respective institutions. Their work would be useful for STEM faculty interested in using annotation to help students learn how to read the primary research literature, something that students often find to be very daunting. Another example is the work of Emerson (2017), who draws on experience in English, writing across the curriculum, and writing in the disciplines to provide a thoughtful framework for STEM faculty to think about how they might approach writing in STEM curriculum to help their students develop this critically important skill. Both Feito and Donahue and Emerson demonstrate how SoTL work from one discipline can inform work in other disciplines to improve student learning.

"Ecological fieldwork" is a better analogy for SoTL than laboratory experimentation

Integral to the practices of science is the planning and carrying out of systematic investigations. Part of that planning is deciding what variables can and should be controlled or measured. Many STEM faculty are familiar with the widely held view that the gold standard for demonstrating causal relationships in science is an experimental study with a rigorously designed control. But automatically assuming that the exact same consideration applies to SoTL work is a mistake.

One of the best analogies I ever heard for SoTL came from Spencer Benson, a Carnegie Scholar and microbiologist, who in 2007 commented to me that he saw SoTL as very similar to ecological research. I've thought about his comment since then and have grown to appreciate the wisdom of Benson's analogy. Ecological systems are characterized by patterns that arise from the interactions between organisms or between an organism and its environment.

As Ghazoul (2020, 5) writes, "The environment is the stage upon which interactions unfold." These systems also commonly display what is often called emergent complexity, where individual components of an ecosystem interact to give behavior and patterns that are very different from what these same individual components display in isolation. Often this emergent complexity is contingent on past events and perturbations; the same seed landing in two different locations can give rise to different outcomes.

The similarities between this description of ecological systems and student learning are clear. What and how and why students learn is profoundly shaped by many interacting factors: personal characteristics and experiences of each student, how the classroom learning environment is designed, interactions between students and faculty as well as between students themselves. Faculty routinely comment how different sections of the same course, or the same course taught in different years, can be significantly different experiences with different outcomes. To fully understand the emergent properties and outcomes of the system under study, whether an ecosystem or (for SoTL) a single course or set of courses, many different aspects must be examined. Grauerholz and Main (2013) provide a thoughtful analysis of the near impossibility of controlling in a SoTL project for all the factors that can influence learning.

While it is not always possible or necessary to have a "control" in the classical sense for ecological fieldwork research, it is still expected that the research will reflect the practices of science as well as the standards of scholarly work. But this point is not unique to ecology; a similar situation can be found in other areas of science. Astronomers studying distant galaxies or a chemist making a new molecule for the first time are also in positions where having a control may not be possible or necessary, yet the work will still be expected to reflect the practices of science. Poole (2013, 2018) recommends that more SoTL projects ask "what is happening?" or even start by interrogating one's assumptions about teaching, learning, and students. Many of those starting points will lead to SoTL projects that would be very difficult to design an experimental control for.

Finally, in his keynote address at the 2013 conference of the International Society for the Scholarship of Teaching and Learning, Lee Shulman, president emeritus of the Carnegie Foundation, eloquently argued for the value of situated studies that are frequently done in SoTL (Shulman 2013).

I am not arguing against controls in SoTL projects where appropriate. What I'm challenging is the default assumption by many faculty in SoTL workshops I've facilitated who immediately think "I need a control group." I see this assumption as linked to a second assumption often made by STEM faculty, that the only type of question that a SoTL project can ask is what Hutchings (2000) described as a "what works" question, often modified by faculty in their minds to a "what works better" question. But "what works" is only one of several types of questions described by Hutchings, who also pointed out that SoTL projects can be focused on "what is," "visions of the possible," and "formulation of new conceptual frameworks." These types of questions seek to understand/explain or provide new perspectives and ways of thinking about teaching and learning. They often focus on relationships between various aspects of learning and the many factors that can impact the learning process. The projects that come out of such questions are similar to describing an ecosystem, and as a result often don't require controls.

A very nice example of SoTL work in STEM where a control would not have been appropriate or helpful is the work of Chua et al. (2020), which described how the authors developed a rubric to examine more closely the fieldwork journals maintained by earth science students at various points in the curriculum. After providing an overview of the centrality of fieldwork experiences in undergraduate earth science education, the authors provided a thoughtful description of the process they used for developing a rubric that would allow for close examination of fieldwork journals to look for evidence of attributes identified by their institution as the qualities it hopes to develop in students. Their analysis identified both attributes that were clearly present in the journals as well as some for which there was little or no evidence. The authors also identified possible next steps for future investigation of student learning in this context.

SoTL work by an individual isn't isolated from other contexts or work done by others

STEM faculty know from their disciplinary experiences that all research projects build on prior work by others. That's why making work public is such an integral part of any form of scholarship. Building on prior work can involve using relevant theoretical frameworks or experimental methodologies developed and made public by others. Prior work can also provide information that can help contextualize the results of the faculty member's investigation. When faculty begin a research project in a new (to the faculty member) area of science or engineering or mathematics, a significant amount of time is spent finding and reading papers in the new area that have been published in the past. No one is surprised by this. In contrast, many faculty still view teaching as a largely private activity. This carries over to how faculty new to SoTL conceptualize their initial efforts and the questions that drive the work. Their efforts to connect their investigation and the evidence they have gathered to other ideas are often limited, and this ends up limiting how well the work reflects the standards of scholarly work (Glassick, Huber, and Maeroff 1997) such as clear goals, adequate preparation, and reflective critique.

As with disciplinary research, no investigation in SoTL is an "isolated system," completely disconnected either from prior work by others or relevant theoretical frameworks. It is important that both the questions driving a faculty member's SoTL work and the analysis of the evidence collected be grounded in relevant theoretical perspectives whenever possible. The project should also clearly build on prior work by others, and the connections should be clearly communicated in public presentations of the work. One challenge of engaging in SoTL, compared to traditional disciplinary scholarship of discovery, is that the situated studies that characterize SoTL often create a need to connect this work to scholarship done by other faculty who may be in different fields. Chapter 12 in this volume presents a taxonomy for SoTL that may be a useful resource for faculty to think about the characteristics of their SoTL projects, how those characteristics might relate to work done by others, and possible terms that could be useful in searching for work that connects with a faculty member's SoTL project.

Connecting to the works of others also helps make SoTL work stronger in that it offers opportunities to connect the work to relevant theoretical frameworks (Hutchings and Huber 2008). Given the situated nature of SoTL, the balance between theory and evidence gathered will vary with different SoTL projects. Miller-Young and Yeo (2015) provide a helpful overview of the multiple theoretical perspectives and methodologies related to them. Faculty who choose to pursue SoTL projects that are more integrative or interdisciplinary in nature will find Miller-Young and Yeo's work a useful overview of these topics.

One challenge for faculty who are shifting their focus to a SoTL research agenda is where and how to search for relevant work by others. Many STEM disciplines have peer-reviewed journals on teaching and learning in the discipline, such as the *Journal of Chemical Education, CBE-Life Science Education,* and the *Journal of Geoscience Education.* These journals are very helpful for projects that are clearly focused in a single discipline. There are also journals such as the *Journal of College Science Teaching* and the *International Journal for STEM Education* that have a clear focus on teaching and learning in STEM while not being limited to a single discipline. But faculty whose SoTL research focuses on questions broader than individual STEM disciplines—for example, how students read texts or write in STEM courses or questions related to the incorporation of humanities or social justice components into STEM courses—will need a different approach to searching the SoTL literature. The ERIC database of education research and information, sponsored by the Institute of Education Sciences (IES) of the US Department of Education, can be a useful tool for faculty moving into SoTL work. MacMillan (2018) approaches the SoTL literature review from the perspectives of both process and product, providing very useful suggestions for helping faculty effectively do both the searching and the writing that the more diverse nature of SoTL often requires. She also presents examples of what she views as well-done literature reviews, along with comments identifying the strengths of each. Colleagues—in the same department, another STEM department, or departments outside of STEM—can also provide valuable suggestions for potentially useful sources. Finally, conferences sponsored by organizations such as the International Society for the Scholarship of Teaching and Learning or the Society for Teaching and Learning in Higher Education will draw individuals engaged in SoTL from a wide range of disciplines. Attending one of these conferences can be very helpful in terms of learning about work that would be relevant to a faculty member's SoTL project.

SoTL can involve diverse methodologies, diverse conceptual frameworks, and diverse contexts beyond a single course

The SoTL projects that STEM faculty choose to pursue are very often focused on disciplinary concepts, practices, and skills. That makes a lot of sense; disciplinary-based investigations have been an important current in SoTL since the beginning. For many faculty, their disciplinary identities are central to how they view their careers and scholarly work. But as with some disciplinary research projects, SoTL projects also offer opportunities to connect to other conceptual frameworks that come from other disciplines or are larger than a single discipline. In recent years, rich descriptions of what characterizes science as a way of knowing have been developed. A faculty member choosing to use as a resource for their SoTL work either the Inquiry Model of Science (Harwood 2004, Robinson 2004) or the "science and engineering practices" developed as part of the Next Generation Science Standards (National Research Council 2012b) will be connecting their question, evidence, and analysis to broader conceptual frameworks that cross STEM disciplinary boundaries. For example, SoTL work done by a chemistry faculty member that connects to these frameworks is likely to be more readily understood and potentially utilized by biology or physics or geoscience faculty in either their teaching or their own SoTL work. When faculty take the time to connect their SoTL work to these broader frameworks, they create new opportunities for the insights from their particular investigations to become "community property" (Shulman 1993) for a larger number of colleagues.

There are other contexts larger than a single course that STEM faculty who engage in SoTL may consider using as part of their work. McKinney, Friberg, and Moore (2019) effectively argue that SoTL work can make important contributions at any of several different levels: program, department, institution, or discipline. As many undergraduate STEM programs share a similar vertically structured curriculum, investigation of teaching and learning in one discipline/department, presented in a rich contextualized manner, can provide ideas and be of use for faculty in other STEM departments.

Finally, there is growing recognition of the contributions that SoTL can make to assessment efforts. Assessment and SoTL share a common goal of improving student learning and doing so in an evidence-based manner. However, there are some important differences between the two. SoTL is rooted in the classroom experience, whether of a single teacher or a group collaborating in their inquiry. And the results of that inquiry are made public in some way. In contrast, assessment operates largely at a program or institutional level and the results are often not made public but shared only with certain parties. But these differences don't mean that bridges can't be built between SoTL and assessment. For example, assessment work may raise specific questions about some aspect of student learning that one or more faculty members may decide to use as a starting point for their own inquiry work. Faculty who are interested in pursuing a path in SoTL which includes clear connections to assessment work are encouraged to look at the work of Dickson and Treml (2013) as well as the volume edited by Friberg and McKinney (2019) for more detailed explorations of this area.

SoTL can be disciplinary, multi-disciplinary, or interdisciplinary

When SoTL began, it was very much disciplinary-based. A significant fraction of current SoTL work (e.g., signature pedagogies, decoding the disciplines) is still clearly rooted within individual disciplines. Signature pedagogies are ones that instruct novices in "critical aspects of the three fundamental aspects of professional work—to think, to perform, and to act with integrity" (Shulman 2005). Work by STEM faculty to describe signature pedagogies in disciplines such as biology, mathematics, computer science, and physics can be found as individual chapters in the volume edited by Gurung, Chick, and Haynie (2009). Decoding the disciplines is a process for examining the mental operations required by a particular discipline, where undergraduate students encounter bottlenecks in carrying out those mental operations, and how faculty might model these mental operations and provide feedback to students on their efforts. The volume edited by Pace and Middendorf (2004) provides examples of this approach used in astronomy and genetics/molecular biology; Miller-Young and Boman (2017) describe how decoding methods can be used in a faculty community of practice. Additional examples of disciplinary-based SoTL work by STEM faculty can be found in the volume by Dewar, Bennett, and Fisher (2018).

But STEM faculty are now asking questions that move beyond the boundaries of a single discipline. The report from the National Academies of Science, Engineering, and Medicine (2018) on integrating science and engineering with humanities documented a number of questions about the impact of this integration on student learning. Many of the questions presented in that report were not simply variations on "did the students learn science concepts better" but asked about the impact of such integration on student preparation for work, life, and citizenship. Investigating these questions will require STEM faculty to engage with colleagues in disciplines such as those in the humanities and use methodologies from outside their home discipline.

There is growing interest in learning more about student experiences in relation to considerations of diversity, equity, and inclusion. Romo and Rokop (2022) describe an honors seminar course they developed which aimed to highlight the discoveries of scientists from historically marginalized communities. Students in the course (60% of them STEM majors) read selected articles from the primary literature focused on discoveries by scientists from these marginalized groups as well as biographies of some of the same scientists. The students also had opportunities to interact with guest speakers and choose scientists to highlight in final papers and presentations. In addition, an increasing number of STEM faculty are asking questions about the relationships between social justice, disciplinary content, and student understanding and perspectives that are developed through courses for STEM majors. Morales-Doyle (2017) has described what he calls "justice-centered science pedagogy" and presented a high school advanced placement chemistry course as a case study of this approach. Fisher (2012, 2019) has outlined a "vision of the possible" for how undergraduate chemistry education could incorporate the challenge of sustainability across the curriculum. Leydens, Johnson, and Moskal (2021) used focus groups and student interviews in a control systems course for undergraduate engineering students to explore student perceptions of social justice in the context of engineering. Ali, Harris, and LaLonde (2020) incorporated social justice themes into a sophomore organic chemistry course by looking at the history and social impact of key compounds, surveying students to see how this incorporation affected student awareness and engagement. Finally, Miller-Young, Jamieson, and Beck (2023) studied students' sense of belonging in a large, first-year engineering course.

SoTL work focused on questions that connect student learning in STEM courses with diversity/equity/inclusion/social justice perspectives can reach across disciplines in several different ways. McKinney (2013) uses a typology developed by Lisa Lattuca to describe these different ways: informed disciplinarity, synthetic interdisciplinarity, transdisciplinarity, and conceptual interdisciplinarity. I will focus on the first two categories for illustrative purposes in this chapter, but that is not to suggest that SoTL can't involve the interdisciplinarity of the other two categories in Lattuca's framework. Informed disciplinarity is where "disciplinary questions may be informed by concepts or theories from another discipline or may rely upon methods from other disciplines, but these disciplinary contributions are made in the service of a disciplinary question" (McKinney 2013, 4). In contrast, synthetic interdisciplinarity is where "research questions bridge disciplines. These bridging issues and questions are of two subtypes: issues or questions that are found in the intersection of disciplines and issues and questions that are found in the gaps among disciplines. . . . In both subtypes, the contributions or roles of the individual disciplines are still identifiable, but the question posed is not necessarily identified with a single discipline" (McKinney 2013, 4).

One example of informed disciplinarity is the work of Bennett and Dewar (2013), who chose to use think-alouds as a method for gathering evidence of how students thought about the concept of mathematical proof. Think-alouds are a method developed by psychologists where participants are directed to verbalize out loud their thoughts as they complete a task. Using a method from a different discipline allowed Bennett and Dewar to collect evidence that eventually allowed them to develop a taxonomy of mathematical knowledge-expertise. A second example of informed disciplinarity would be a STEM faculty member using the "difficulty paper" developed by Mariolina Salvatori for use in literature courses as a way of gathering rich evidence of where students in a STEM major have difficulty reading papers from the primary literature and details of those difficulties. While not situated in a STEM course, Cisco (2020) provides an example of how using the difficulty paper in a "Great Works" course helped students address their confusion without dismissing it. At the end of the paper, the author provides an example of how the difficulty paper might be used in the context of understanding a mathematical equation.

One example of synthetic interdisciplinarity is the work of Manarin, Carey, Rathburn, and Ryland (2015). They examined critical reading by students in four different courses, including a STEM course for non-science majors. Another example of synthetic interdisciplinarity is the conversation between Takayama (a microbiologist) and Reichard (a historian) documented in the chapter they contributed to the volume edited by McKinney (2013). The overarching theme of their conversation was exploring student learning through unconventional genres (from the perspective of their respective disciplines). Reichard incorporated research posters (widely used in STEM disciplines) into a history course final project, while Takayama asked students to create a "Bug Book" (reflecting the much more creative approach characteristic of the humanities) to supplement the lab notebook maintained by students in a microbiology course. The chapter captures key points in the cross disciplinary dialogue between the two that developed over time.

Inquiry in SoTL can be individual, collaborative, or collective

In terms of the last two guiding principles that I've presented in this chapter—the importance of frameworks outside the faculty member's discipline and the multi-disciplinary/interdisciplinary possibilities within SoTL—I want to call attention to Richard Gale's argument for the importance of collaborative and collective inquiry in SoTL (Gale 2008). He first describes the possibilities for collaborative inquiry, where two or more faculty work together in some way on questions related to student learning. Those questions could be identical, linked in some way, or sufficiently similar to be comparable. Gale then moves to describing what he calls "collective scholarship," where the process of inquiry is shared among an entire department, a single institution, or a system of higher education. One example of this type of inquiry is the work described by Goldey and collaborators (Goldey et al. 2012). They worked on transforming the first-year biology course from a content-driven course to one that focused on developing both core knowledge and core skills through diversified pedagogical practices. I think STEM faculty looking to change their career focus to SoTL work could be well served by thinking deeply about Gale's suggested approaches. There are many questions related to student learning in STEM courses that cross the boundaries between sections of the same course or different courses in a single curriculum and that would lend themselves to collaborative inquiry.

Conclusion

A change in career focus from traditional research in a STEM discipline or teaching with little or no scholarly activity to active engagement with SoTL can be both unsettling (Kelly, Nesbit, and Oliver 2012) and exhilarating for individuals trained in STEM disciplines. At the same time, faculty considering a shift in research/scholarly focus from a traditional disciplinary area to SoTL will, I hope, be well served by reflecting on the principles presented in this chapter early in that process. Such reflection will be helpful for considering the larger trajectory of this change in an individual's scholarly work. While any transition in an individual's career can involve some stress and challenges in the beginning, there are also rewards to focusing one's professional activity on SoTL. My hope is that the principles outlined in this chapter will help faculty make this transition in a rewarding and productive way.

Reflection Questions

- How would you describe your SoTL work at this point in time?
- Based on your description, which of the guidelines presented in this chapter would be most relevant now?
- Based on how you see your SoTL work developing over the next five years, which of the guidelines presented in this chapter would become important to keep in mind at some future point?

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