Training to Be a (Team) Scientist

Chapter · November 2019

DOI: 10.1007/978-3-030-20992-6_33

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33.1 Introduction

In the early twenty-first century, many have lamented the lack of a sufficient scientific workforce capable of contributing to the modern knowledge-intensive economy (AACU 2007; NRC 2015). At the same time, others have noted the lack of a scientific workforce capable of collaborating across scientific disciplines (NRC 2005, 2014, 2015). More and more it is recognized that the science and technology workforce is being inadequately prepared for careers in the coming century (Crow and Dabars 2015; Duderstadt 2000). In the study of workforce preparation, reports have identified gaps between the knowledge, skills, and attitudes (KSAs) employers are seeking and those held by graduates (HRA 2015; NRC 2017). This includes not just skills in, for example, data analysis and problem solving, but also teamwork and interpersonal skills (e.g., communication across professions), attitudes and abilities to collaborate with non-academic partners and colleagues spanning multiple cultures, geographic regions, and time zones (Brint et al. 2009; Brown et al. 2010; Karlin et al. 2017; Olson and Olson 2014; Stokols 2018). Furthermore, according to a report on career preparation recently commissioned by the Association of American Colleges and Universities, college graduates' "self" perceptions of KSAs are divergent from employer assessment (HRA 2015). For example, nearly 2/3

K. L. Hall et al. (eds.), *Strategies for Team Science Success*,
https://doi.org/10.1007/978-3-030-20992-6_33

of college graduate believe they can effectively work in a team whereas only approximately 1/3 of managers stated college graduates demonstrate this competence. Similarly, over half of college graduates felt they are able to work with those possessing different backgrounds but only less than 1/5 of managers saw this as the case.

The combination of these factors leads to a need to better prepare the scientific workforce for participation in the larger collaborative scientific enterprise and contribute to the needs of society more broadly (Fiore et al. 2018). In service of this, recent reviews describe the rich body of research on teamwork and our understanding about collaboration as it relates to structural (e.g., technology, virtuality; Olson et al. 2008) and compositional features (e.g., ability, faultlines) as well as mechanisms (e.g., conflict, motivation) mediating process and performance (Bezrukova et al. 2009; Mathieu et al. 2017). Still others focus on training to document how researchers have developed a deep understanding of how trainee characteristics and training design influence learning and performance outcomes (Bell et al. 2017). In this chapter we focus on a somewhat narrow aspect of this research—that having to do with training and education where knowledge is diverse and members collaborate to address significant societal and scientific problems. We draw from the aforementioned literatures to distill key ideas about teamwork competencies identified as being foundational to effectiveness for the scientific workforce.

Our overarching point is that we must move beyond traditional forms of learning and education that seek only to train discipline-specific content (e.g., methods, processes, concepts). Rather, we argue that, to successfully meet the scientific workforce need of the twenty-first century, we must also understand how to improve learning and professional development focused on improving collaboration across disciplines and professions. In support of this argument, recent reports from the National Academies of Science noted that there is an increased need to emphasize interdisciplinary and transdisciplinary approaches to learning with more focus on experiential and problem-based learning—whether in the laboratory or in internships and apprenticeships (NRC 2015, 2017). This presents a significant challenge for research on learning in that it illustrates two fundamentally different, but now integrated, learning objectives. One is the acquisition of knowledge sufficient to be an expert in a field, yet sufficiently knowledgeable enough about other disciplines to work collaboratively on complex problems. The other is learning the kinds of teamwork competencies supporting collaboration with others on such problems (see also Nurius and Kemp 2019 in this volume for additional discussion of team science competencies).

The former need has long been recognized as a challenge for interdisciplinary education (Klein 1996). But the latter need is an important part of the new field called the "Science of Team Science (SciTS)," a field dedicated to understanding and improving scientific teamwork (Borner et al. 2010; Fiore 2008; Hall et al. 2008; Stokols et al. 2008; Hall et al. 2018). Considering these in combination, teamwork in science requires both knowledge from multiple disciplines and also collaboration across disciplines and professions. Those engaged in such work often have advanced degrees, creating collaborations among professionals with deep knowledge and experience. Thus, problem solving in such contexts requires not just the application of knowledge from diverse areas, but the teamwork competencies necessary to successfully integrate said knowledge.

Considering this in light of the policy needs previously mentioned, we compare this with traditional definitions of teams—that is, "interdependent collections of individuals who share responsibility for specific outcomes for their organizations" (Sundstrom et al. 1990, p. 120). This concept of interdependence has been foundational to the study of teams, as has been the need for coordination across clearly articulated roles to meet specifically defined and explicit goals (e.g., Swezey and Salas 1992). As such, it aligns well with the context of scientific collaboration. But we argue that, to truly address science and technology workforce needs, definitions of teams must add the concept of interdisciplinarity.

Definitions of interdisciplinary research vary (cf., Repko et al. 2017), but one of the early distinctions was put forth by the Organization for Economic Cooperation and Development in 1972 (see also NRC 2005). The OECD report in 1972 outlined a set of the core ideas that have been used in many definitions of interdisciplinary, noting that such research involves: "The interaction among two or more different disciplines. This interaction may range from simple communication of ideas to the mutual integration of organizing concepts, methodology, procedures, epistemology, terminology, data, and organization of research and education in a fairly large field … a common effort on a common problem with continuous intercommunication among the participants from the different disciplines" (pp. 25–26). Overall, then, we can see the complementarity between teamwork and interdisciplinary research in that they both involve coordination and communication among those with specialized knowledge and clearly defined roles, for the purposes of addressing a shared problem.

At issue is that the science workforce has been, and is still predominantly trained, in a way at odds with an interdisciplinary perspective to collaboration. They have been socialized within a discipline to learn, not just content knowledge but the norms and cultures of a discipline. Furthermore, they receive little, if any, training on how to function as a member of a team. This produces a myriad of problems for scientific teamwork—from terminology differences and challenges with communicating across disciplines, to divergent epistemologies about how to pursue knowledge—often resulting in failures of the scientific team. In short, to train the next-generation workforce, we must understand how to overcome traditional learning and education practices that have narrowly focused on content knowledge and move towards a more interdisciplinary learning environment (cf., Bosque-Perez et al. 2016; Chang et al. 2005). Here, learning would involve not just acquisition of knowledge from varied disciplines, but also the ability to collaborate with those from different fields. For workforce preparation, we argue that science education and professional development must focus on learning how to be a "team" scientist.

Towards this end, in this chapter we draw from the literature on interdisciplinary education and training that has evolved to support changes in scholarship and collaborations across disciplines and professions. The chapter is divided into two main sections. In the first half, a brief review of the literature on learning and training for interdisciplinary science is provided. Here we outline the various educational and professional development programs developed by universities and/or supported by the federal government. In general, these programs have been developed to address science and technology workforce needs via identification of various competencies necessary for success and how to train teams for complex scientific and societal problem solving. The second half provides an integration of ideas from the organizational sciences that serves as conceptual scaffolding for learning how to engage in team science. This is meant to provide some coherence to the varied forms of educational and professional development programs that have identified a myriad number of competencies thought to be needed for interdisciplinary teamwork. We conclude this section with a brief description of notional approaches for training these competencies. These were derived from the literature on team training but adapted for consideration in the context of scientific collaboration and S&T workforce preparation. Our goal is to lay the foundation for research on interdisciplinarity in support of scientific workforce development and helping to produce the next generation of team scientists.

33.2 Interdisciplinary Learning

33.2.1 A Brief History of Interdisciplinary Learning

Although much attention was paid to interdisciplinary education in the latter part of the twentieth century, thinking on this topic started surprisingly earlier in the "modern" academy. In one of the earliest mentions of interdisciplinary research, Brozek and Keys (1944) described how Yale University was developing interdepartmental research programs such as the "Yale Institute of Human Relations" in the 1930s to study complex social and scientific issues. They referred to this as a natural result of disparate academic units recognizing their similar interests and the value of pursuing them cooperatively. They cite the pioneering and prescient vision of Yale's president, James Rowland Angell, who had pronounced in 1930 that the purpose of such centers was to "correlate knowledge and coordinate technique in related fields, [such] that greater progress may be made in the understanding of human life from the biological, psychological and sociological viewpoint" (p. 509). What Brozek and Keys (1944) were suggesting is that interdisciplinary research, and its focus on cooperating to solve societal problems, needed to be an accepted form of practice when learning to be a scientist. They argued that such environments are better able to nurture an appreciation for social problem solving via the integration of broad perspectives while still pursuing fundamental scientific knowledge. Specifically:

> "There are two very serious reasons why the inclusion of this new research form should be a part of graduate schools: Numerous problems of a fundamental theoretical character which require a cooperative approach are not likely to be studied by industrial laboratories, the very existence of which often depends upon immediate, practical results. The second reason is still more important. Industrial organizations only very rarely will provide the time and personnel to carry out a training program of high academic standards. There must be a genuine interest in acquainting the student with the full breadth and depth of the interdisciplinary research problems, which implies a full freedom to explore aspects other than those which belong to the student's immediate field of specialization. The most adequate 'climate' for the training of graduate students in cooperative research is a place in which such an approach is actually practiced, because there is no substitute for the method of learning by doing. At the same time, the institution in charge of the training program must be well aware of its scientific and social responsibilities and must provide stimulating supervision which is or should be a distinguishing feature of student-teacher relationship on the graduate level" (p. 509, Brozek and Keys 1944).

Not only was this thinking ahead of its time from the standpoint of interdisciplinarity, it also foresaw what is now an important component of action research; that is, a blurring of the distinction between basic and applied science (see Stokols 2014). As such, these ideas clearly resonate with current perceptions of interdisciplinary learning and training. Further, by trying to do away with the juxtaposition between basic and applied research, they are strikingly similar to ideas in science policy over 50 years later. In his landmark work, *Pasteur's Quadrant*, Stokes (1997) illustrated how important scientific gains were often due to this blending of basic and applied research. Stokes used Louis Pasteur as the model for what he labels *use-inspired basic science* showing how Pasteur's groundbreaking and significant studies in microbiology always had a consideration for use (i.e., disease prevention), yet still produced fundamental gains in understanding. Using such examples, Stokes suggests that both science and science policy can benefit from considering research that has a quest for fundamental understanding and a consideration of use. Others have taken a similar tack when arguing for science as societal problem solving. Based upon the writings and actions of one of our nation's founders, Holton and Sonnert (1999) argued along analogous lines to propose a model of *Jeffersonian Science*. Here, research has as its motivation a particular social problem in which we are scientifically ignorant. As Holton and Sonnert (1999) explain, the purpose is "to remove that basic ignorance in an uncharted area of science and thereby to attain knowledge that will have a fair probability--even if it is years distant--of being brought to bear on a persistent, debilitating national (or international) problem" (p. 62).

We have used this brief historical account on interdisciplinarity and this thinking on science policy to call out a simple yet important point. For these accounts illustrate that the tension identified nearly ¾ of a century ago, is still problematic when discussing interdisciplinary research. They bring to the fore the barriers that rise when training tries to teach a learner to think beyond traditional disciplinary boundaries or consider how knowledge can be applied to solve problems. If we are to successfully solve the significant scientific and societal problems of the twenty-first century, and better prepare the scientific workforce, we must overcome these challenges and understand the processes necessary for learning how to be a team scientist. With this cautionary note as our precursor, we now turn to a discussion of interdisciplinary learning as it was explored in latter part of the twentieth century.

33.2.2 Interdisciplinary Education in the Twentieth Century

Interest in, and attention to, interdisciplinary education waxed and waned in the postwar era (see Klein 1990 for a full discussion). But serious attention to developing interdisciplinary programs began, in earnest, in the health sciences in the 1960s (Lavin et al. 2001). It was at this time that interdisciplinary educators began to develop courses that maximized the learning of broad skills while minimizing discipline-specific skills. Such efforts were not fully accepted as they led to concerns about the shallowness of the educational training. Nonetheless, they are relevant to our focus on team science because it was here that we see initial acknowledgement of *interpersonal competencies*. Scholars studying interdisciplinary education started to discuss the types of communication and group process challenges such as conflict and role ambiguity that can emerge when students from different disciplines are brought together (Hohle et al. 1969). From this, interdisciplinary internships and fellowships began with the goal of teaching students how to communicate when working with other disciplines (Lupella 1972). Others focused on analogous challenges and the need for groups to develop collaboration skills when working with other disciplines (AACU 2007; Brint 2009; Jacobson 1974). As noted by Fiore (2008), in the ensuing decades, while interdisciplinarity increased in popularity, knowledge of how to support it remained relatively static. Specifically, "although interdisciplinary research swelled, there were not proportional changes in the understanding or training of interpersonal issues. But we did see the beginning of minimum competencies being identified as interdisciplinary coursework began to become more prevalent. That is, as interdisciplinary coursework began to pull students in many different directions, curriculum committees and professional organizations began to mandate the minimum level of understandings students within particular disciplines had to master" (p. 264). This illustrated a movement more towards the focus on disciplinary content and the minimum levels of knowledge that should be learned as opposed to the interpersonal factors that arise when working across disciplines.

As training and education research and theory began to evolve in the 1990s, scholars also started to focus on macro-level issues such as how organizations could better support interdisciplinarity (Lavin et al. 2001). Klein (1996) was one of the first to articulate a coherent conceptualization of interdisciplinary learning at this broader institutional and organizational scale. In discussing how departments, centers, and institutes could form a foundation for supporting interdisciplinarity, she described the hurdles that needed to be overcome to address traditional perspectives on practice. Interdisciplinary education requires organizational-level support, minimally, for professional development (e.g., training faculty) as well as protection from disciplinary norms (e.g., tenure reviews that punish work outside one's discipline). Even better, such support can include, for example, mentoring, physical space for collaborations, and cross-disciplinary training. From this, an environment can be nurtured that creates a norm for interdisciplinarity. This includes research and teaching that encourages a broader perspective on problems as well as communication across departmental boundaries. Furthermore, in order for such practices to be sustained, institutional support must be consistent and embedded within the university culture (see Canadian Academy of Health Sciences 2017; Klein 2010; Klein and Falk-Krzesinski 2017; The Academy of Medical Sciences 2016; Vogel et al. 2019).

In sum, there has been a significant amount of attention paid to understanding and improving interdisciplinary learning. But, despite this interest in interdisciplinarity, a notable gap remained. Specifically, little, if any, discussions addressed interdisciplinary *teams*. The majority of this literature considered the intellectual aspects of interdisciplinarity but did not attend to collaboration more specifically. At most, the focus was on the individual who would work in a collaborative environment, rather than on the actual collaborative context. From this arose attention to interpersonal factors required for teamwork. As such, this represented an important development in the context of learning and education for the scientific workforce; that is, the need to teach competencies associated with interdisciplinary collaborations.

As these approaches were evolving to include competencies, another challenge emerged. In brief, there are many different competencies associated with interdisciplinarity, and early discussions in this literature lacked the conceptual clarity necessary to develop educational content and pedagogy. First, there is a level of competency one has to have regarding *disciplinary content* (e.g., how much foundational knowledge in biology must one acquire). But there is also competency required for thinking *across disciplinary content* (e.g., if one wants to understand biophysics, on what should their coursework focus to help them understand how to conceptualize related factors crossing these disciplines). Finally, there is also a set of competencies associated with one's ability to engage in *interdisciplinary teamwork* (e.g., how to address conflict that might arise when working with someone with different disciplinary norms). But discussions in this early literature would often conflate these very real and very important differences.

We return to this problem in the concluding section and offer some theoretical clarity to move our understanding of interdisciplinary learning forward. But we next describe some of the work that sought to more precisely identify the varied types of competencies necessary for interdisciplinary teamwork. This is broken out into two sections. The first focuses on research examining interdisciplinary programs where learning was designed to cover content from multiple disciplines. The second focuses on programs specifically developed by federal organizations to support education and training for the next generation of the scientific workforce.

33.2.3 Educating Individuals for Interdisciplinary Collaboration

Reflecting on what is necessary for success in the twenty-first-century workplace, we can minimally state that interdisciplinary collaborations differ in the degree to which they require teamwork as well as the integration and application of knowledge; that is, from understanding how to work with people and methods from other disciplines/professions, to synthesizing concepts and theories to produce actionable knowledge (Nash 2008; Repko et al. 2017). In the modern workforce, the challenges of interdisciplinarity are often dealt with on an ad hoc basis where leaders or managers address conflict or communication problems as they emerge. Although this might succeed in the short term, more is required to ensure a scientific workforce capable of addressing complex scientific and societal challenges (Brown et al. 2010; Crow and Dabars 2015, 2019; Stokols 2018). What is needed is not only sufficient training for collaboration across disciplines, but also consideration of how the competencies necessary for effectiveness in teams could be instilled through educational experiences. This includes interdisciplinary experiential learning that comes through both coursework (e.g., group projects) and internships at the undergraduate, graduate, and post-graduate levels, to produce what Stokols (2014) referred to as "an enduring intellectual orientation among students and scholars" (p. 58). The goal is developing the intellectual and interpersonal capacity for effective collaboration on interdisciplinary work.[1]

In this section we provide discussion of the types of programs that have been embedded in educational practice to meet the aforementioned goals. Our review includes those efforts that

[1] Note that Hirsch Hadorn et al. (2008), Rosenfield (1992), Stokols (2018), and others have written extensively about transdisciplinary education and research. For example, Misra et al. (2015) developed and tested a scale for assessing attitudinal, behavioral, and intellectual dimensions of scholars' "transdisciplinary orientation." Because many of the concepts and approaches are relevant to interdisciplinary education and training, this distinction is not addressed in this chapter.

target both graduate and undergraduate students and range from individual courses to curriculum-wide efforts. We focus on studies of interdisciplinary learning that examined the types of competencies supporting interdisciplinarity. Although much has been written about interdisciplinary education, our selection is driven by studies that have provided at least some form of quantitative summary of their findings. A notable gap is that there have been few field studies of interdisciplinary collaboration (see Hall et al. 2008, Stokols et al. 2005, and Vogel, 2012 for examples), with the majority of research on interdisciplinary learning relying on surveys, interviews, and archival analyses.

Perhaps one of the earliest recognitions of the need to delineate the competencies associated with interdisciplinary education and practice came from Stokols (1998). In discussing interdisciplinarity in the context of "Social Ecology," Stokols (1998) identified the "knowledge, skills, and attitudes" (KSAs) necessary for effective collaboration. These ideas were built upon and expanded in a comprehensive review of KSAs necessary for cross-disciplinary educational programs, with emphasis on preparation for work in the health and medical sciences (Nash et al. 2003). By drawing from Stokols' observations, Nash and colleagues linked these with theorizing on interdisciplinarity more generally, and graduate school pedagogy, in particular, to categorize competencies for scientific collaboration. It was here that we begin to see important distinctions being drawn between the varied types of interdisciplinary competencies. Furthermore, Nash et al. suggested how these could be developed through the use of particular methods available in graduate school. For example, it was suggested that attitudinal competencies, such as valuing collaboration across disciplines, or risk taking to venture outside one's discipline, could be instilled through activities such as coursework, seminars and workshops, mentoring, and the institutional environment. Knowledge competencies, such as understanding core theories and methods from other disciplines, could be learned through the above-mentioned activities as well as from group work such as journal clubs. Skill-based competencies such as taking a methodologically pluralistic approach could be learned through all of the above (see Table 33.1, adapted from Lattuca et al., 2013a).

Table 33.1 Primary set of interdisciplinary competencies identified by Lattuca et al. (2013a)

Interdisciplinary competence	Defined
Interdisciplinary skills	Ability to consider and apply perspectives from outside one's own discipline and to more generally make connections across varied disciplines
Reflective behavior	Ability to recognize when general approach to thinking about an issue needs to be altered or when specific problem-solving approach may need reconsideration
Recognizing disciplinary perspectives	Understanding content, methods, and boundaries of disciplinary knowledge and how these can be differentially applied dependent upon situational needs

Others have similarly examined the issue of competencies, but have done so via the perspective of experts experienced in interdisciplinary collaboration. Using a consensus study of expert opinion, Holt (2013) identified what are seen as critical individual competencies for effective performance in these environments. Similar to earlier analyses of competencies, Holt found that experts viewed as important, *Intra*personal Competencies (e.g., broad intellectual curiosity, recognize personal strengths and weaknesses with regard to interdisciplinary research), Disciplinary Awareness and Exchange (e.g., awareness of assumptions of own discipline, engage colleagues from outside disciplines), Processes of Integration (e.g., develop shared interdisciplinary vision, modify work based upon influence of others), Teamwork, Management, Leadership (e.g., build communication strengths, manage conflict, trusting value of teammates), and Competencies of Fruition (e.g., presenting research at interdisciplinary conferences, partner with those in other disciplines on proposals).

Research also provides a more in-depth analysis of particular graduate programs designed to foster interdisciplinary learning. For example, University of California-Irvine's "School of Social Ecology" offers a doctoral seminar specifically developed to expose students to a broad range of disciplines relevant to this field and in preparation for working in this area. In order to examine how such coursework led to a broader perspective on the integration of disciplines, Mitrany and Stokols (2005) conducted a content analysis of doctoral dissertations produced by the school. This involved, for example, analyzing the range of methods and concepts within the dissertations and their integration, and showed that students in this program demonstrated an interdisciplinary orientation in their scholarship. Further, department size and diversity had an influence on the degree of interdisciplinary learning. When students came from smaller departments made up of diverse faculty, the dissertations were rated higher on interdisciplinary factors. They suggest that this more intimate collegial context provided an environment supportive of such research, noting that "collaboration on the basis of shared interests rather than shared institutional affiliations is perhaps more readily achieved in smaller and more diverse departments" (p. 446).

Mentors have also been found to play an important role in interdisciplinary learning and the development of the attributes fostering collaboration competence. Mentors, or even supervisors, who encourage learners to acquire and synthesize knowledge from a broad base, help them acquire skills and attitudes supportive of interdisciplinary work. Furthermore, in line with the idea that interdisciplinarity often blurs the distinction between basic and applied research (cf. Stokes 1997), research suggests that, when trained in institutions that take a problem-focused approach to scholarship (e.g., a center for research on environmental sustainability), learners are come to "avoid the conceptual biases associated with *disciplinary chauvinism* and the *ethnocentrism* of traditional academic departments" (p. 66, Stokols 2014; cf., Campbell 1969).

As noted at the onset, teamwork in the modern scientific workforce requires collaboration across disciplines and professions. This includes teamwork consisting of those with a range of education and training. Because such teamwork often involves employees without post-graduate degrees, research has also examined interdisciplinary learning at the undergraduate level. For example, some have studied the effects of student exposure to not just the scientific and technical content, but also the broader societal context of the problems in which their profession would eventually work (Lattuca et al. 2013a). These initiatives focus not just on learning science content, but also on the larger social, environmental, and economic perspectives in which scientific and technical problems are embedded. Echoing the words of Brozek and Keys decades earlier, Lattuca et al. argued that this required students understand theory and concepts from outside their own disciplines in order to collaborate with team members from varied professions. Towards this end, they set out to identify the nature of the competencies necessary for students to manage interdisciplinary collaborations. Based upon a large-scale study of over 5000 undergraduate students across over 30 institutions, they identified three overall categories of interdisciplinary competencies (see Table 33.1 for a description).

Relevant to understanding effective outcomes from interdisciplinary collaboration, Lattuca et al. identified an additional distinction that needs to be taken into account. Specifically, in their review of the literature on interdisciplinary learning, they found that the field often conflates the distinction between interdisciplinary *processes* and interdisciplinary *products*. For example, an interdisciplinary process could be something devised to help the learner comprehend how to integrate varied concepts from disciplines to create a new product or solve a particular societal problem. An interdisciplinary product is some artifact (whether it be material or conceptual) that has effectively synthesized ideas from varied disciplines (e.g., a conceptual model that draws from, and integrates, varied disciplines to solve some problem).

As an exemplar for disentangling interdisciplinary processes and products, the University of

California-Irvine's "Interdisciplinary Summer Undergraduate Research Experience" program (ID-SURE) was developed to combine coursework and research fellowships to cultivate the kinds of skills that support conceptual integration. In a study of the program's effectiveness, Misra et al. (2009) examined the relationship between the curriculum strategy and transdisciplinary processes and products and how the transdisciplinary orientation of the mentor influenced these. Curricular strategies included activities like team projects, laboratory research, and journal club meetings and products included projects, papers, and grades. Process measures encompassed attributes such as interdisciplinary perspectives, behaviors relating to collaborative activities, and participation in team projects. Results showed that the program increased scientific appreciation and transdisciplinary perspectives, as well as increased the amount of interdisciplinary collaborative activities in which the students engaged. Further, team-focused projects were found to be instrumental to these changes.

In a similar vein, others have studied whether interdisciplinary programs produce changes in cognitive processes as the learner progresses through the curriculum. For example, Lattuca et al. (2013b) studied the influence of interdisciplinary programs on a set of learning outcomes relevant to thinking across disciplines. In a longitudinal study of about 200 students, they compared students majoring in traditional disciplinary programs with those in interdisciplinary programs. In looking for changes in scores measuring critical thinking, need for cognition, and attitudes towards learning, they found no real differences that could be attributed to either a particular major or the structure of the program. But their data suggest there are already selection biases occurring at the undergraduate level. Specifically, students in the interdisciplinary majors showed the lowest change scores in the need for cognition measure and attitudes towards learning. What's important here, then, is that students choosing interdisciplinary programs may already be predisposed to prefer complex and abstract thought and appreciate learning across disciplines.

Finally, Stokols (2014) complements the focus on training competencies with a discussion of cultivating a more general intellectual orientation. This moves us from discussions of just coursework or educational activities. And it speaks more broadly to the need for developing a rich interdisciplinary experience that fosters a culture for nurturing one's intellect and the application of interpersonal competencies in service of team science. Stokols argues that a well-developed intellectual orientation enables one "to communicate more effectively with fellow team members who represent diverse disciplinary and philosophical perspectives, and to identify more readily with the collaborative and integrative goals of the team" (p. 61). In this vein, he explicated a set of attributes that characterized an intellectual orientation ideal for collaborations that span multiple disciplines (see Table 33.2). In the context of preparing the scientific workforce, this distinction is important in that we can think of the aforementioned competencies outlined by Nash et al. (2003) as specific targets for instruction while Stokols (2014) provides us with strategic goals for interdisciplinary education more broadly.

Table 33.2 Attributes of an intellectual orientation suited for collaboration across disciplines (adapted from Stokols 2014; see also Stokols' 2018 and Misra et al.'s 2015 discussion of a transdisciplinary orientation)

Attributes	Description
Values	The values that motivate one to acquire knowledge from other disciplines that are relevant to scientific problem solving
Attitudes	The attitudes that predispose one to integrate knowledge from a varied set of disciplines
Beliefs	The beliefs that such efforts are necessary and can lead to effective outcomes
Skills and knowledge	The skills and knowledge that are critical to think across disciplines in order to synthesize varied concepts and theories
Behaviors	The behaviors that support activities for integrating perspectives and working with others outside one's discipline

In sum, the key points that need to be considered from this brief review of the literature on interdisciplinary education are as follows. First, when assessing interdisciplinary learning, researchers need to clearly delineate between processes and products. This will help better understand and measure the pedagogical practices designed to teach "how" to integrate across disciplines and "what" the outcomes of such practices should be. Second, research must work to identify the particular competencies that support this. Researchers have begun to delineate the variety of competencies that support interdisciplinary collaborations, but such studies are still the exception. Furthermore, we still have little empirical evaluation of which learning activities are best suited for particular competencies. Finally, research must help more fully examine the developmental trajectory of these competencies. From this, we can better determine when and how to implement programs differentially devised to target particular interdisciplinary processes and outcomes and better prepare the scientific workforce.

33.2.4 Federal Programs in Support of Interdisciplinary Education

In addition to programs that evolve out of interest within universities, other educational initiatives are created more strategically to meet national workforce needs. In this vein, the National Science Foundation developed a funding mechanism specifically aimed at interdisciplinary learning in science and engineering. The NSF Integrative Graduate Education and Research Traineeship (IGERT) program was created to support university efforts aimed at producing scientists who can engage in teamwork that crosses disciplinary borders. Although this program has been in existence for a number of years, relatively few systematic studies of its efficacy have been done. To redress that gap, and in order to examine the degree to which funded projects aligned with existing pedagogy on developing interdisciplinary scholars, a qualitative study of proposals was undertaken (Borrego and Newsander 2010). This examined the learning outcomes that were explicitly articulated across 130 successfully funded proposals. This involved studying the narratives provided by proposers and categorizing how they characterized their graduate training.

First, although IGERTs are, by definition, interdisciplinary, 50% of proposers still stated that graduate student trainees would gain grounding in a specific, or "traditional" discipline. What is important about this finding is the recognition of the continuing challenge of breadth versus depth in interdisciplinary training. As described by Borrego and Newsander (2010), one proposal explained this issue quite well: "It is not feasible to expect tomorrow's scientists to have expertise in both social and aquatic systems, but what is feasible is to create an appreciation of the intellectual challenges faced by the respective disciplines, the methodology used to pursue these challenges, and the ability to formulate and solve interdisciplinary problems effectively" (p. 73).

Second, 30% of proposers argued that their graduate programs would encourage integration and broad perspective on scientific challenges. This was described as a form of systems thinking where graduate student trainees would be taught to take a broader view on the scientific challenge while still working to integrate concepts from relevant disciplines. This aligns with arguments that solving complex problems requires one to adapt a systems theory approach for integrating multiple levels of analysis to build a more thorough understanding of science collaborations. But this perspective also moved beyond scientific borders as 24% of proposers noted that they would encourage students to take perspectives encompassing societal and global issues. This type of graduate training, then, complements what some consider as an important element of action research—that of including stakeholders and pursuing translational outcomes (something argued in early discussions of interdisciplinary research; see Brozek and Keys 1944).

Third, 41% of proposers stated that their center would create a culture of teamwork. This was found to be the most clearly articulated learning outcome. As described by Borrego and

Newsander (2010), one proposal specifically noted that they wanted to train a generation of scholars who are able to "communicate with researchers from other disciplines, and to work collaboratively, creatively, and productively together" (p. 75). Finally, 24% of proposers noted that their projects would emphasize the importance of interdisciplinary communication. This included both an understanding of the language and concepts from participating disciplines and the ability to communicate complicated concepts to nonscience audiences.

Relevant to consideration of the need for the modern scientific workforce to work across both disciplines *and* professions, an important finding from this research is how "integration," as a learning outcome, is viewed differently between scientists and engineers and those in the humanities. In particular, while integration across disciplines was a commonality, those in the humanities additionally considered "critical thinking" as crucial while those in science and technology considered "teamwork" as fundamental. Borrego and Newsander argued that critical reflection on disciplinary inconsistencies and limitations was a particular strength that could be put to use when solving complex problems. They suggested that, if the sciences incorporated the humanities conception of critical awareness, it could greatly extend how science and engineering conceives of interdisciplinarity. Specifically, they stated that, although "engineering and science faculty members avoid criticism of disciplinary structures, they would certainly say they value graduate students' critical thinking about the problem at hand and the value of various disciplinary approaches to it" (p. 78). Overall, though, what we see in this analysis is specific articulation of a need to train collaborative competencies. That is, while all noted the grounding in disciplinary education, just as important was the need to cultivate the particular competencies that supported integration of ideas across disciplines.

While programs such as the IGERT target training at the graduate level, other federal programs consider how training should be developed at that post-graduate level when students are entering the scientific workforce. Such efforts are created to support complex research while also fostering the collaboration competencies necessary for success. As an example of how such programs have been systematically devised, the National Cancer Institute's Transdisciplinary Research on Energetics and Cancer I (TREC I) initiative set out to develop competencies enabling teamwork. These centers supported a variety of training activities converging on the goal of enhancing interpersonal and intrapersonal competencies along with training scientific competencies (Vogel et al. 2012).

Activities ranged from transdisciplinary research courses, journal clubs for members, and writing retreats to develop skills in collaborative writing and research. They also included not just traditional mentoring, but co-mentoring and multi-mentoring to expose trainees to multiple disciplinary perspectives. These programs also worked to strengthen collaboration across centers. Here, a coordinated effort was created to support professional development activities (e.g., visiting mentors at other centers), learning across centers (e.g., Internet-based seminars), and thematically related workshops at annual meetings.

An analysis of training effectiveness for the TREC centers, using a cross-sectional design, found changes in attitudes towards working across disciplines (i.e., enhanced transdisciplinary orientation), improved ability to work across disciplines (i.e., intrapersonal/interpersonal competencies for collaboration), as well as increased scientific competency to work with other disciplines (i.e., development of scientific skills for transdisciplinary research). Importantly, there were also changes in scientific output with increases in scholarly productivity for trainees affiliated with TREC as measured by number of publications/presentations and number of collaborative authors. Multi-mentoring experiences were also associated with greater transdisciplinary orientation and positive perception of one's center (Vogel et al. 2012).

Federal programs have also focused more specifically on developing sophisticated mentoring strategies to foster the development of interdisciplinary career paths. NIH's "Building Interdisciplinary Research Careers in Women's

Health" (BIRCWH) program is designed for junior faculty interested in advancing research in women's health. Through establishment of mentoring teams, the BIRCWH program provides participating scholars with multiple perspectives on a range of scientific and career issues. One indicator of success in such programs is idea generation in the form of grants submissions in the area of women's health. A study of the program showed that a majority of scholars applied for competitive grants after completing the training and that approximately half were successful (Nagel et al. 2013). More detailed analyses of the program identified the need to develop written contracts between participants to manage mentoring expectations (Guise et al. 2012). Also important was the need to clearly articulate roles for the mentoring team such that some focus on career issues while others focus on scientific content. Comparative analysis shows that scholars participating in the BIRCWH program have a grant-funding rate of 38% compared to the NIH average of 29% (see also Guise et al. 2017).

Nonetheless, while mentoring has consistently been identified as a crucial component of interdisciplinary education and training, it is too often lacking for scholars. In a recent survey on the "Global State of Young Scientists," the unavailability of mentoring was one of the top four career obstacles identified (see Friesenhahn and Beaudry 2014). Similarly problematic is the lack of training junior scientists receive on "how" to engage in training and supervision of students and post-docs. This was likened to parenting in that it was never explicitly taught in their graduate education; rather, it is something reported as being learned along the way (Friesenhahn and Beaudry 2014).

In sum, a small number of university curricula and federal programs have examined learning and education for interdisciplinarity. Many have identified the kinds of competencies necessary for success in the scientific workforce. Further, some have delineated between learning scientific content from various disciplines and learning how to work on a team with those from other disciplines. Nonetheless, rigorous empirical research on the efficacy of such programs is still lacking. More problematic, though, is that nothing is known about the success of such programs to the scientific enterprise, overall. This includes a lack of longitudinal studies on the graduates of such programs and a comparison of their interdisciplinary scholarship to other scientists. But it also includes a lack of research on how the introduction of such programs has influenced the production of knowledge, overall. This points us to a significant gap in understanding when it comes to learning how to be a team scientist and what this means for the success of the scientific workforce. In the next section we discuss a way forward for research on interdisciplinary learning and training in the context of scientific teamwork.

33.3 Addressing the Challenge of Interdisciplinary Teamwork

Fully addressing the challenging dimensions of interdisciplinary science requires that we go beyond the extant literature. While much can be gained by directly adopting some of what has been studied, either in education or in training research, there are still notable gaps when it comes to understanding how these methods can be used to improve the performance of science teams. What is also lacking, though, is conceptual grounding in how to understand the relationship between the various educational and professional development programs devised for interdisciplinary learning. In the final half of this chapter, we redress this gap and provide conceptual and theoretical guidance that can be used to more precisely develop and study learning and training approaches supporting interdisciplinary collaboration. First, we discuss the lack of conceptual clarity in terminology used in the literature on education and training for interdisciplinary scholarship. Second, we provide a framework integrating the varied competencies that have come out of the study of interdisciplinarity. Third, we review notional training approaches that fit within various facets of this competency framework. Our goal is to provide a form of conceptual scaffolding that provides both short-term and long-term guidance for training the next-generation scientific workforce on how to become a team scientist. In the short term, existing approaches for interdisciplinary learning can be improved through a more rigorous adoption of concepts from the organizational sciences. In the long term, research that builds from these suggestions could make a significant contribution to our understanding of how performance improves across the life span of science teams and how this affects the scientific enterprise.

33.3.1 Coming to Terms with Terms

What is clear from the review of interdisciplinary learning programs is the fuzziness of terminology used to describe the education and training. Specifically, education and training are two general terms that are too often used with little specification as to what is meant. While the context of the discussion can often be used to discern a given meaning, the tremendous variety of settings in which education and training can take place still leaves much room for error. Training can be used to describe an hour-long presentation on a given scientific topic or a method for managing conflict within one's team. It can also be used to describe a workshop spanning hours or days where one receives more intense exposure to, for example, new methods for visualizing complex data, or how to lead and manage members of a scientific team. Education might be used when discussing a guest lecture from a noted scholar, or to describe a particular course developed to teach team-based projects for working with students from different disciplines. It might also be used when broadly discussing a curriculum centered on interdisciplinary learning.

These examples are meant to illustrate two fundamental distinctions that emerge and must be accounted for when trying to bring some coherence to discussions of training and education for team science. First is the content of the material to be learned. The examples above were purposely dichotomized to illustrate a fundamental distinction made in the literature on team training and one to which we return at the conclusion of this chapter. Specifically, when team training research began to evolve, it was recognized that an important distinction needed to be made between taskwork and teamwork (Salas et al. 1992). Taskwork is a label for the activities in which one engages that are pertinent to achieving the goals and objectives for which the team is formed (e.g., running a procedure for data collection, completing a particular statistical analysis). Teamwork describes the activities involved in interacting with members of one's team and that are necessary for success (e.g., communication; back-up behaviors). Second is the duration of the learning activity. The literature on training and education might discuss short courses lasting hours or days or entire curricula that might span months or years. Table 33.3 provides a rudimentary illustration of this breakdown. While it is certainly possible for an educational or training experience to teach both taskwork and teamwork, our point here is that it is important not to conflate these as the content has a direct bearing on the pedagogical approach.

An additional complicating factor is the context in which the term is being used. When in academic settings, the term training is most often used to describe any learning experience that occurs outside of the classroom, while education is the term typically used to describe in class learning experiences. This distinction may seem relatively simple and somewhat robust when

Table 33.3 Illustrative breakdown of content and duration of learning experience

		Nature of the content	
		Taskwork	Teamwork
Duration	Short	A one-day workshop teaching a specific statistical test	A weekend retreat teaching methods for conflict management
	Long	A course teaching attendees methods for conducting network analyses	A course utilizing group projects to teach attendees how to collaborate in science teams

talking about students. For example, doctoral seminars are clearly educational and guidance by one's adviser in a laboratory is construed of as graduate training. But, what do we label the experience when doctoral students attend a colloquium describing a new finding that has a significant bearing on their research? Is this still labeled "education" even when not in a classroom? If so, how is it described if a post-doc is attending? Since they have completed their Ph.D. program, do we now label it "training?"

To answer this, perhaps we might fall back on the recently developed term of "continuous learning." This term has come to mean a form of education where professionals are acquiring new knowledge, but which is, in reality, coursework that would be considered training by others. Thus, this distinction loses clarity depending upon where one is in their career. It is problematic in that the difference between education and training might merely depend upon where one is in their career. Or, perhaps we can adopt what some in organizational psychology suggest; that is, we could state that education is generally used to describe more general exposure to content whereas training is used to describe exposure to specific content. While this scheme might be useful when discussing professionals (i.e., those no longer in school), the fuzziness, again, becomes apparent when applied in academia. For example, students taking a short course on a particular statistical technique might have the experience labeled as education, whereas a postdoc or faculty member in the same course might view it as training.

Our point is that the use of the terms education and training can sometimes be arbitrary in the literature and dependent upon the scholar conducting research in this area and/or where the research gets published. This discussion is not mere semantics or academic wordplay but something that must be addressed in light of the policy challenges associated with developing the scientific workforce. Specifically, the clarity with which such terms are used has a direct bearing on how programs around them are designed, how processes and outcomes are measured, and how funding around them is allocated. As such, this has a bearing on the design of scientific curricula, the development of training for scientists, and on the development of science policy. Despite these important distinctions, for the sake of order to the literature, in this chapter, we use the terms adopted by the papers being reviewed. But we stress that the above distinctions need to be kept in mind so that some degree of coherence can be developed for team science in both science policy and science practice.

33.3.2 Understanding Team Competencies for Science Teams

What is also clear is the wide variety of competencies thought to be needed for effective performance in interdisciplinary collaborative environments. In this section we discuss how a competencies framework developed in the organizational sciences can be used as a theoretical framework for classifying these competencies. Specifically, Fiore (2008) built off earlier theorizing to suggest a competency framework that could be adapted to support training research in science teams. He argued that more careful consideration of the knowledge, skills, and attitudes supporting teamwork is necessary for team science. This, he suggested, can be accomplished through the use of the competency framework put forth by Cannon-Bowers et al. (1995). Within this framework, collaborative competencies can be decomposed into a 2 × 2 framework whereby they vary in the degree to which they are team-generic or team-specific and task-specific or task-generic. As shown in Table 33.4, by combining these, four types of competencies are produced

Table 33.4 Types of team competencies (Cannon-Bowers et al. 1995)

Team competencies		Relation to task: Specific	Relation to task: Generic
Relation to team	Specific	Context-driven	Team-contingent
	Generic	Task-contingent	Transportable

(i.e., context-driven, team-contingent, task-contingent, transportable).

We suggest that, when considering learning and training for the scientific workforce, the situational and environmental context needs to drive the determination of which competencies are necessary for a given team (cf. Bowers et al. 2000). In particular, Fiore (2008) argued that this breakdown can provide a nuanced understanding of the training requirements for differing science teams depending upon their experience with each other and the type of scientific problem on which they are working. Furthermore, attending to these distinctions can help us precisely classify the variety of university developed and federally sponsored interdisciplinary learning programs just discussed. For example, context-driven competencies are those required by a particular task and team involved on a specific scientific problem. Teams that have stable membership and perform a small range of tasks that are similar in their nature tend to require these types of competencies. Team-contingent competencies are team-specific but are applicable across a wide variety of tasks. This would be the case for a laboratory team who know each other well, but who are working on a variety of scientific problems. Task-contingent competencies are specific to a particular task, but transportable across teams (i.e., not dependent on the particular make-up of the team). This is the case when considering a scientific problem, irrespective of makeup of a team. Finally, transportable competencies are both team- and task-generic (i.e., they apply across a wide range of teams and collective tasks). These are the general kinds of competencies that benefit all forms of scientific teamwork. In short, this framework provides an important foundation for understanding how to conceptualize the competencies to be trained for scientists more generally, and for specific teams in particular. But it additionally helps us to understand how differing educational and professional development programs—ranging from workshops to seminars to entire curricula—can be developed in support of targeting particular collaborative competencies.

Within this competency framework, we can go further and delineate the knowledge, skills, and attitudes (KSAs) attributed to science teams. From this, learning outcomes for science team training can be better specified. For example, when thinking about KSAs for scientific teams, knowledge can be construed of as long- and short-term memory that is drawn on to recognize and utilize environmental information supporting the scientific problem at hand. In the domain of training for team science, this effectively refers to any stored or dynamically obtained information that is required by the team. But this can be broken down further using the taskwork and teamwork dimensions. For science teams, task-relevant knowledge can be specific to a particular context (e.g., a given laboratory), or generically related to a given goal (e.g., experimental procedures). Team-relevant knowledge can also be specific to a particular scientific context (e.g., understanding the idiosyncrasies of members in a given laboratory), or generically related to a given team goal (e.g., roles played on differing scientific teams). If knowledge represents the information that individuals and teams require to perform tasks, skills are the means by which they do so; that is, "how" to do something (Cunningham 2008). Skills are developed both generally and in-context, and are acquired through practice and training (Ericsson 2004). For a science team, task-relevant skills can similarly be context-specific as well as generically related to a given goal. Team-relevant skills can also be context-specific or -generic for teamwork. Finally, attitudes pertain to the values and individual differences pertinent to a team and their task (Cunningham 2008). In relation to a task, attitudes refer to how a scientist views, for example, a particular methodology (e.g., surveys vs. interviews). In relation to the team, they can pertain to how one feels about working on a scientific team (e.g., collaborative orientation). Task-relevant attitudes might be specific to a particular context (e.g., pursuing a given laboratory's methodological approach), or generically related to a given goal (e.g., values associated with doing applied research). Team-relevant attitudes can also be specific to a particular context (e.g., how one feels about working on an interdisciplinary team), or generically related to teamwork (e.g., collective orientation).

In sum, this approach moves beyond current conceptions of science team competencies by clearly distinguishing between generic and specific team and task competencies and delineating the particular KSAs associated with these. This can help to better address the training challenges arising from complex scientific teamwork (cf. Cummings and Kiesler 2005). In particular, the interdisciplinary nature of modern science teams necessitates we better understand the competencies required for effective teamwork. By specifying the form of the competency required for a given team, we are able to target particular challenges faced by teams. But it is not always the case that such specific training need be developed. The above framework helps us to more broadly conceptualize education and training initiatives and determine when these varied forms of training may be helpful. To that end, in Table 33.5, we provide representative examples of the varied types of KSAs that can exist in science teams, but categorized using the generic versus specific team and task breakdown (Fiore and Bedwell 2011).

Note that these competencies have to do with what we see as teamwork in the context of complex problem solving as in science. A gap in the literature, though, has to do with the kinds of competencies necessary for multi-team systems. In the study of teams in organizations, a multi-team system (MTS) describes a set of interdependent "component" teams that are collaborating towards some common goals (Marks et al. 2005). Asencio et al. (2012) discussed MTS in the context of science collaborations and what are the particular challenges they face in terms of collaboration and coordination. But what is additionally needed is specification of any unique competencies required for MTS. For example, the challenges of participating in a MTS would seem to require an additional, "trans-team" set of competencies. This could be something such as effective boundary work among the leaders and members of the various teams that comprise the system. This is like Obstfeld's (2005) concept of the "tertius iungens" scholar who is able to effectively link the members from multiple teams. In addition to the boundary-spanning competencies of effective MTS members, there is also the ability to share leadership roles among those who lead the component teams within the systems (DeChurch and Marks 2006). This could include, for example, behavioral and interpersonal competencies associated with shared versus singular leadership roles.

Building on this, Fiore (2013) argued that interdisciplinary collaborations would benefit by learning and education programs targeting the quadrant labeled "transportable" team competencies. In the organizational sciences, these are often referred to as interpersonal competencies but they are often used without precise operationalization, leading to conceptual confusion. To address this problem, findings from a number of papers on interpersonal training were synthesized to develop taxonomy of competencies (Klein et al. 2006). At the most general level, these were

Table 33.5 Types of KSAs associated with science team competencies

Representative science team competencies		*Relation to task* – Specific	*Relation to task* – Generic
Relation to team	Specific	Context-driven • Knowledge—team objectives and resources • Skills—particular analyses • Attitudes—collective efficacy	Team-contingent • Knowledge—teammate characteristics • Skills—providing teammate guidance • Attitudes—team cohesion
	Generic	Task-contingent • Knowledge—procedures for task accomplishment • Skills—problem analysis • Attitudes—trust in technology	Transportable • Knowledge—understanding group dynamics • Skills—communication and assertiveness • Attitudes—interdisciplinary appreciation

defined as goal-directed behaviors, including communication and relationship-building competencies, that are employed during interaction episodes. These interactions are characterized by a need for complex perceptual and cognitive processes, dynamic verbal and nonverbal exchanges, and diverse roles, motivations, and expectancies (Klein et al. 2006). When considering scientific workforce development needs, these align quite well with a number of the competencies discussed earlier. Fiore (2013) adapted this approach for consideration within interdisciplinary education. He described how they can be used as learning objectives for educational and professional development designed to support interdisciplinary science teams (refer to Table 33.6).

Note that these competencies only address interpersonal factors associated with teamwork in scientific collaboration. A notable gap in the literature is specifying what are the intellectual capacities needed in team science partnerships. This could be the ability to conceptualize problems systemically and at multiple scales (e.g., accounting for genome × exposure interactions in health science). This could also be associated with competencies needed to bridge disparate "knowledge cultures" (e.g., Brown et al. 2010). For example, in the widely divergent world views of science and society, these need to be carefully negotiated and navigated in translational partnerships among scholars, lay citizens, community professionals, elected officials, policymakers, etc. Stokols (2018) referred to this as "transepistemic," a particular type of transdisciplinary action research necessitating integration of knowledge and world views held by scientists and a variety of stakeholders. As such, we must address the competencies needed to help science teams deal with the challenges of not only doing inter- or transdisciplinary integration across different academic fields, but also linking academic and non-academic knowledge cultures.

Table 33.6 Interpersonal competencies applied to science teams

Communication competencies	
Active listening	• Carefully attending to what is said • Asking other party to explain exactly what is meant • Requesting that ambiguous ideas or statements are repeated
	In interdisciplinary learning, this competency targets "listening to learn and understand" and "listening to contribute and integrate to problem solving"
Oral and written communication	• Sending verbal and written messages clearly • Speaking/writing constructively • Speaking/writing critically in appropriate ways
	In interdisciplinary learning, this competency targets the ability to "express yourself clearly to others outside one's discipline" (e.g., avoiding jargon) and "effectively conveying intended meaning of other disciplinary perspectives"
Assertive communication	• Directly expressing one's ideas and opinions • Addressing conflict purposely and openly • Addressing differences without intimidation
	In interdisciplinary learning, this competency targets the ability to "propose ideas," to "defend one's disciplinary values/methods" and to "be directive and appropriately assert your needs and views"
Relationship management competencies	
Coordination	• Understanding how to work with others as a team • Being mindful of interdependencies and how to pace activities • Offering help/back-up as needed
	In interdisciplinary learning, this competency targets understanding importance of "awareness of shared scientific goals" and "monitoring and feedback"

(continued)

Table 33.6 (continued)

Interdisciplinary appreciation	• Appreciating differing disciplinary theories and concepts • Respecting varied disciplinary methods • Encouraging input from across disciplinary perspectives
	In interdisciplinary learning, this competency targets learning "acceptance of, and openness to new ideas" and "sensitivity to disciplinary perspectives"
Collaborative orientation	• Predisposition to provide help to others • Intellectual curiosity in service understanding others • Building rapport with others
	In interdisciplinary learning, this competency targets the ability to "elicit ideas for purpose of understanding" and "offer solutions in support of problem solving"

33.3.3 Learning and Training for Team and Task Competencies

In the final section, we provide representative examples of the kinds of training that can be used for developing these varied forms of competencies. Although these have not specifically been conceptualized within the aforementioned competencies framework, their approach aligns well with each quadrant. Furthermore, even though not all have been tested in the context of science teams, the approaches are generalizable to numerous contexts. As such, we offer these as notional interventions that can be introduced for educational or professional development in support of training the next generation of team scientists.

33.3.4 Training for Context-Driven Competencies

As described earlier, context-driven competencies are those required by a particular task and team involved on a specific scientific problem. Problem-based learning (PBL) is a method that is optimal for these competencies. In PBL, facilitators or tutors are used to guide small group learning (Barrows 1996) on specific problems. With the use of problems derived from the actual domain to be learned and representative or real-world situations (i.e., "authentic problems"), students are first encouraged to produce their naïve understanding of the problem, identify similarities across the group, and generate potential hypotheses and solutions (Gijselaers 1996). A key part of this process is that students discuss any lack of understanding they have and what knowledge needs to be acquired to solve the problem. From this, learning goals are identified and students work in and out class to gather and integrate the knowledge necessary to produce a solution. Finally, a reflective component is built into the process where students debrief on what they have learned. Although some debate exists as to the specifics of the strategies employed within PBL (Dochy et al. 2003; Hmelo-Silver 2004, for reviews), meta-analyses find that small group learning was related to academic achievement (Norman and Schmidt 2000), and that group debate improved the development of shared knowledge and problem solving (Hmelo-Silver 2004). But these reviews suggest that there be a flexible amount of self-direction dependent upon where in the learning trajectory students are (Hmelo-Silver 2004; Vermunt and Verloop 1999). Perhaps most important were the outcomes contrasting knowledge acquisition versus application. First, traditional classroom-based instruction, when compared to PBL, showed some benefits on factual knowledge and standardized tests (Vernon and Blake 1993). But PBL showed some benefit for knowledge application and retention (Dochy et al. 2003).

33.3.5 Training for Team-Contingent Competencies

As noted, team-contingent competencies are team-specific but are applicable across a wide variety of tasks. Fitting with this is an approach coming out of research in philosophy. The

Toolbox project was developed to overcome the communication challenges experienced by scientists working across disciples (O'Rourke and Crowley 2013). This relies on probing statements that participants complete before and after a Toolbox workshop. These are devised to elicit fundamental assumptions team members have about science, particularly from the perspective of their own discipline. During the workshop, these are used to guide discussion about the views scientists hold and share them with team members so that differences can be made explicit. This forces members to reflect on their idiosyncratic epistemologies as well as the values they bring to the science team. As such, it uses a form of philosophical dialogue to target development of the knowledge, skills, and attitudes supportive of interdisciplinary communication. Studies of workshop participants find that, after engaging with the Toolbox facilitators, there is an increase in awareness about the varied scientific approaches pursued by other team members and that this process enhances their appreciation for diversity in research (Schnapp et al. 2012).

33.3.6 Training for Task-Contingent Competencies

As described, task-contingent competencies are specific to a particular task, but transportable across differing teams. Training research on knowledge building is well suited for this competency. Knowledge building is foundational to complex problem-solving as it is critical to solution generation (Fiore et al. 2010). It is particularly important when teams consist of members with varied forms of knowledge and expertise. Interdisciplinary science teams are, by definition, made of members holding diverse forms of knowledge. When collaborating, these members must integrate that knowledge to generate solutions to complex problems. This is challenging because performance problems emerge when team members do not share task mental models. Furthermore, research finds that teams rarely discuss information held uniquely, and, rather, tend to communicate only about the knowledge they share (Wittenbaum and Park 2001). In order to address these problems, Rentsch et al. (2010) conducted a study explicitly focused on team training for knowledge building. This consisted of a schema-enriched communication (SEC) component as well as a knowledge object component. For the SEC component, team members were trained to engage in communicative processes that elicit the structure and organization of their knowledge, as well as the assumptions, meaning, rationale, and interpretations associated with each member's knowledge. The knowledge object component consisted of utilizing an external representation (i.e., an information board) that allowed for team members to post and organize their knowledge in a common space that allows them to visually manipulate that knowledge, more easily remember it, as well as to draw attention to specific information as appropriate. This has been used to test the effectiveness of knowledge building training on a problem-solving task requiring resource allocation. Results show that knowledge building training improves knowledge transfer (i.e., the exchange of knowledge from one team member to another), knowledge interoperability (i.e., knowledge that multiple team members are able to recall and use), cognitive congruence (i.e., an alignment or matching of team member cognitions), and higher overall team performance on the task (Rentsch et al. 2010; Rentsch et al. 2014).

33.3.7 Training for Transportable Competencies

As noted, transportable competencies are applicable across a wide range of teams and tasks, that is, generic to both the team and the task. Team reflexivity training has evolved to provide a robust approach for training general team competencies. Team reflexivity training requires that members engage in some form of reflection on prior performance episodes. This reflection encompasses focusing on the objectives that were or were not met, the strategies used, and the group processes engaged. The goal is to adapt team processes to improve future interaction

(Gabelica et al. 2016; Gurtner et al. 2007). Although individual methods of reflexivity interventions may differ, the general procedure includes the following steps after a team performance episode: (1) reviewing the task performance of the group (e.g., "How did you ask for information? How did you pass on information? How was the team organized?"; Gurtner et al., p. 132), (2) thinking about potential improvements in the processes and methods used to complete the task (e.g., "Are there alternatives to your chosen task performance procedures, and if so, what are they?"; p. 132), and, (3) creating suggestions for future work such that the next time the task is done the processes and outcomes are improved. Gurtner et al. found that teams trained using the above steps had interaction mental models more similar as compared to a control. Furthermore, the reflexivity intervention had a direct effect on SMMs and was also partially mediated by the commander's communication of strategies. Additionally, SMMs influenced strategy implementation, which then impacted performance. The study demonstrated that shared mental models can be improved by reflecting on what work has been accomplished so far and reflecting on how performance could be improved in the future. Van Ginkel et al. (2009) found that reflexivity training also improved team shared task understanding and decision quality.

33.3.8 Summary

These strategies represent examples of the form of training that can support learning to be a team scientist. But much empirical work needs to be done in the field (i.e., in actual classroom and work settings), to determine the effectiveness of these methods for the scientific workforce. In support of this, we next identify core features of training for teams, adapted from Gabelica and Fiore (2013), that need to be more systematically integrated across these. From this, we can better understand how to implement these core elements in a coherent way and test if and how they improve individual and group learning (see Table 33.7).

Table 33.7 Core features needed to examine the effectiveness of learning approaches for competencies training

• Use small groups
• Provide immediate and regular feedback (from instructors, peers, or professional guests)
• Use formative assessment allowing for refinements and adjustments of ongoing work
• Ensure regular communication of ongoing work
• Use complex and real-world problem solving
• Support meta-discussions (via metacognitive techniques)
• Ensure multi-interactions among learners and instructors
• Provide explicit training of problem-solving skills
• Use scaffolding/modeling from the trainer

Finally, what is also necessary is more consistent usage of assessment measures that tap teamwork. To achieve this, we suggest there be a more systematic integration of methods from the organizational sciences on team training with the educational and professional development programs devised for training scientists to work in teams. More importantly, such research must adopt and integrate existing measures of taskwork *and* teamwork into curricula for team science to better understand and assess how differing KSAs are acquired and used. This includes consideration of self-ratings of soft skills (Kantrowitz 2005), and peer- and self-ratings like that found in the Comprehensive Assessment of Team Member Effectiveness measure (Ohland et al. 2012). This latter assessment includes general categories of team member involvement like contribution to the team's work, keeping the team on track and appropriately interacting with teammates. Also recommended is implementation of measures using behavioral observation scales that focus on observable skills and use behavioral referents assess interpersonal skills like collaborative problem solving and conflict resolution as well as self-management processes like planning and task coordination (Taggar and Brown 2001). In short, our goal is to help integrate research on team training and team competencies with research on interdisciplinary learning to examine the efficacy of these interventions focused on learning to be a team scientist.

33.4 Conclusions

We began this chapter with a discussion of the pressing needs for scientific workforce development and the apparent failure to adequately train for teamwork and communicating and collaboration across scientific and professional disciplines. Although educational programs supporting interdisciplinary learning have been developed in a number of universities, empirical assessment of their efficacy is lacking. Similarly, federal research organizations have instituted various programs devised to support educational and professional development for interdisciplinary science. But robust assessment of their effectiveness is also lacking. Furthermore, there is little, if any, understanding on how these are affecting the scientific ecosystem overall. Across all of these, though, is lack of attention to "teaching" teamwork with little emphasizing the KSAs that could improve collaboration.

Despite these limitations, we focused on research examining interdisciplinary learning and education and the particular competencies identified as necessary for success in scientific teamwork. An important similarity to our review of educational practices and interdisciplinarity is that training research has also focused on KSAs as learning outcomes. Drawing from the decades-long tradition of learning research in psychology and education, Kraiger et al. (1993) were some of the first training researchers to argue for a taxonomical breakdown of learning outcomes along the lines of knowledge, skills, and attitudes. This provides a conceptually meaningful framework that is also at a useful level of granularity for developing both interventions and assessments. We adapted this for science teams and added the team/task, generic/specific competencies framework coming out of the training literature.

We also reviewed methods of training showing promise in helping scientists to acquire the collaborative competencies necessary for interdisciplinary teamwork. These interventions approach learning in complementary ways. Some focus on helping team members understand how to learn through reflection and provide feedback for them to diagnose what processes led to effective and ineffective outcomes. Others focus on learning the specific forms of communication that ensure teams share the information most relevant to their task needs. These meet the needs for successful science, in that teams must understand not just how to do their tasks, but must also know how to collaborate. We suggest that, for knowledge-intensive organizations to succeed, greater emphasis must be placed on the combination of these competencies in the educational pipeline and into professional development. In this way, we can understand how to augment education and training so that learning is not simply about acquisition of knowledge for developing task competencies. Additionally, we can include methods devised to foster interdisciplinary collaboration, that is, education for learning how to be a team scientist.

Acknowledgments The writing of this paper was partially supported by Grant NNX16AO72G from the National Aeronautics and Space Administration. The views, opinions, and findings contained in this article are the authors and should not be construed as official or as reflecting the views of the University of Central Florida or the National Aeronautics and Space Administration.

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