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Inter-disciplinarity and constructs for STEM education: At the edge of the rabbit hole

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Abstract

Research in science, technology, engineering, and mathematics (STEM) is part of an ongoing evolution of innovation that is becoming increasingly complex and nonlinear. Representative of this shift is the trend toward interdiscplinarity. Increased attempts at scientific problem solving in hybrid fields require unconventional skill-sets that are likely to be favored in this new environment. It is worth contemplating how such skills may be imparted by academic programs, what new roles the trainee may play, and whether or not engaging these new paradigms is imperative for contemporary science. The trend towards interdisciplinarity represents a shift in both how knowledge is acquired, and the nature of its consequences. Training interdisciplinary scientists requires new educational formulation(s). To enthuse innovation, future scientists must be trained in ways that foster the intellectual skills to view problems and possible solutions from a more vantaged (and informed) inter- and trans- disciplinary perspective. Academia can retain its vital significance in preparing future graduates by fostering nonlinear information-seeking behaviors and generating awareness of current and future paradigmatic changes.

Key words: STEM, education, inter-disciplinarity, epistemology, training, models

Introduction

Students of science, technology, engineering, and mathematics (STEM), currently find themselves in the training phase of their career trajectory during a paradigmatic shift of how science is being conducted, funded, and considered relative to society. This is part of an ongoing evolution of innovation systems that is reflected over time by institutional arrangements of university-government-industry relations. Models that consider the mutual impacts of government, industry and academia on the conduct of research are becoming increasingly complex and nonlinear (1,2). A symptom of this shift is the trend toward interdiscplinary science (2). As the relationships between the sciences become more complex, hybrid fields emerge at the interfaces (3). These new disciplines not only foster increased attempts at scientific problem solving, but often present new problems that require ethical reflection to safeguard the application of the knowledge generated (4). Considering how these interdisciplinary trends and hybrid endeavors arise provides clues to how to responsibly proceed with science and science education. One model that is relevant to these dynamics is called the "Triple Helix model of university-industry-government relations;" there is substantial evidence that knowledge infrastructures are transitioning to this model (1,3,5-7,9,10). This has specific implications for PhD students as it both identifies institutions and organizations representing new career opportunities, and unconventional skill-sets that are likely to be favored in this new environment. It is worth contemplating how such skills may be imparted by academic programs, what new roles the trainee may play, and whether or not engaging these new paradigms is imperative for contemporary science.

Training for Innovation

In contrast to the complexity of the triple helix model, the paradigm to which most graduate students are exposed is substantially more linear. It typically presents the university as a source of knowledge, funded by industry when that knowledge is highly applicable for technological innovation, and largely funded by government when applications serve the public good(s), such as health, economic growth, or any number of more specific endeavors that the public may require. Governments may influence the direction and progression of research through agencies that fund types of research in general, or through legislative appropriations that may favor more specific enterprises. In such paradigms, there is a relatively clear direction and linear influence whereby policy sets priorities for funding, and funding drives certain research areas more than others. Industry is affected by such policy, and occasionally has the power to influence it through interactions with government and universities. Thus, the paradigm can be viewed as a triangle connecting the interrelated but not necessarily interdependent realms of government, industry, and academia, in which multiple disciplines may be engaged. These disciplines may be within science, reflective upon science (such as studies of science, technology, and society), or involve the humanities, such as sociology, economics, or philosophy and/or ethics.

Arguably, understanding the shifting relationships between universities, government, and industry requires a multi-perspective sense of the historical origins of the present system to enable a multifaceted appreciation of the shifting balance of roles and power(s) assumed by these sectors within an economy of knowledge production. According to Etzkowitz and Leydesdorff (3), "Different possible resolutions of the relations among the institutional spheres of university, industry, and government can help to generate alternative strategies for economic growth and social transformation." However, even without appreciating how the present system came to be, there are certain indicators that afford insight to how it is changing. Such changes may affect graduate education, as an indispensible part of academia's function, and may influence which skill sets are of highest value. At the same time, they may drive the potential career opportunities afforded by a doctorate. Therefore it is relevant to ask, what are these trends, what is the nature of the change(s), and how does it- or should it- affect graduate education?

First, the trend toward interdisciplinary science cannot be underestimated as this is because it frequently synthesizes the often disparate epistemological approaches of humanities and scientific disciplines. A lengthy discussion of what interdisciplinary really means is beyond the scope of this essay and there is ample literature that explores this concept. An operational definition employed by Evans and Macnaughten (8) in their discussion of interdisciplinarianism in the medical humanities states: "Interdisciplinary…concerns the engagement of disciplines with one another, and more particularly with subject matter that somehow both straddles the disciplines and falls between them—aspects of a question which neither might pursue, or even recognize, in isolation." Thus, it would seem that it is the emergent nature of the problems that a science addresses that compels and sustains the demand for so-called interdisciplinary approaches (8). Accordingly, certain sciences are more likely than others to invite (and cultivate) interdisciplinarity.

This is especially true when the solution to a problem involves an epistemological shift in order to encompass a novel approach to solving a problem. When questions become reframed from those in which linear answers are possible to contexts where more non-linear solutions are required, then it is likely that philosophical as well as technical implications will arise. Hence, the trend towards interdisciplinary science represents a shift in both how knowledge is acquired and the nature of its consequences.

A Triple helix model of innovation accounts for these trends. According to Leydesdorff, they are "indicative of flux, reorganization, and the enhanced role of knowledge in the economy and society. In order to explain these observable reorganizations in university-industy-government relationships, one needs to transform the sociological theories of institutional retention, recombinatorial innovation, and reflexive controls. Each theory can be expected to appreciate a different subdynamic."(3,9) The resulting dynamic is one in which the relationship between institutions is inherently unstable. This characteristic instability occurs because each strand may relate to the other two "and can be expected to develop an emerging overlay of communications, networks, and organizations among the helices (3)." This results in a transition from a model where the sources of innovation are synchronized a priori to one where they no longer "fit together in a pregiven order", generating "puzzles for participants, analysts, and policymakers to solve" (3).

Fields and Focal Application

Such contingent knowledge within and across fields is indicative of the increased complexity of dynamic interactions between elements such as "market forces, political power, institutional control, social movements, technological trajectories and regimes…the operations [of which] can be expected to be nested and interacting" (3). According to Leydesforff and Etkowitz (3), these "subdynamics can be expected to select upon each other asymmetrically… For example, the markets and networks select upon the technological feasibilities, whereas the options for technological developments can also be specified in terms of market forces. Governments can intervene by helping create a new market or otherwise changing the rules of the game."(10,3).

This can evoke multiple consequences. First is the proliferation of consulting firms and think tanks that assume the tasks of generating and applying knowledge and integrating government/military-industry-university activities to advance innovation and cross-disciplinary endeavors. Second is the generation of government- and industry-funded positions to reflect on the focus, scope and progression of knowledge itself (e.g., ethics). Such positions can be both integrated and separate from the academic sector. These and other hybrid organizations represent increasingly viable career options for doctoral graduates, especially in a climate of slimming opportunities for the traditional post-doc- to- junior faculty- to- professor academic career trajectory. Industry career paths are as much in flux as academics, furthering the probability of new scientific career models that are characterized by transition itself. However, such careers might then be expected to be unstable as the system is constantly in a state of transition. In Leyesdorff's articulation of the "triple helix" model and accompanying "code" metaphor, "the helices communicate recursively over time in terms of each other's own code. Reflexively, they can also take the role of each other to a certain extent" (3). This has direct implications for training: it is expected that some graduates must be at least minimally competent in the activities of each "strand" of the helix- government, industry, and academia. This forms a newly imperative skill set that graduate schools must impart if their PhD graduates are to be active participants of the transition- state career model.

Requisite Skills for Interdisciplinarity

What are these skills? If the environment is akin to a triple helix, and equally as complex, then nonlinear models of information-seeking behavior must be emphasized accordingly. Allen Foster (11) described a model of non-linear information-seeking behavior that excellently reconceptualizes the core processes of information acquisition and contextual interaction needed to suit a triple helix career reality. According to the model, while information seeking exists within a context it remains a cognitive activity and therefore not a linear process consisting of stages and iterative activities. Rather, it is a never-ending process that cycles through three core phases: "opening," "orientation" and "consolidation." Within each of these phases are actual behaviors that facilitate the gathering, assembly, and articulation of knowledge that are each contingent and therefore not static. Examples of "opening" include forms of browsing, networking, chaining, and active skills for handling sereditpity and expressing eclecticism. Chaining, for instance, is where important ideas (in addition to citations/references) are linked from one source to another, taking researchers "from single leads in known areas to a broader information horizon" (11). In a very real sense, what is called for (and made possible by Foster's model) are a set of skills for "falling down the rabbit hole" productively and usefully. As to be expected from the metaphor, there is never an endpoint to a discrete volume of information, but only a process of accommodating and linking information in such ways that it can be recombined and called forth when a particular cognitive innovation is necessary.

Arguably, the education of a PhD student teaches one how not to fall down the proverbial 'rabbit hole'. In an academic model of hypothesis-driven science, progress is carefully anticipated and accordingly incremental. A common criticism of a grant undergoing the peer-review process is that it seems to present a "fishing expedition", connoting a blind search for any affirmative result that can be pursued as a secondary course of action. However, if true innovation is to occur, it sometimes seems that a fishing expedition—and accompanying serendipity, of course—is exactly what is required. In an increasingly "triple helix" model of government-university-industry interaction, there may be an increase in available funds for such "fishing expeditions," with the caveat that they will require articulation of a plan with which measurable outcomes can be assured. This would be a scientific translation of endeavors that seek funding to generate new ideas and contemplate innovations by bringing together diverse groups of experts to "cross-polinate" questions, methods and possible answers. Cross-pollination is also often the goal of interdisciplinary science, but such approaches encounter the problem posed by researchers of different fields that at best lack a technical orientation to a question, problem or solution, and at worst may be ground to a different epistemological orientation. Individuals competent in non-linear information-seeking behavior may bridge such gaps. This skill set can be fostered through education, but requires substantial creativity to implement. This requires a nonlinear, almost metaphorical conception of the relationship between disciplines (8).

It is crucial to foster multiple understandings of the relationships of the sciences to one another. This makes it imperative to impart knowledge that might be considered in the realm of the humanities, such as philosophy, in order for there to be a cogent palette and set(s) of tools with which students may draw connections between scientific disciplines and activities (12). As well, the unpredictable and powerful changes that may result from such an approach demands that students more articulate in both the sciences and humanities (particularly, perhaps philosophy, history, and ethics) than is currently the case. Put simply, if we are to produce interdisciplinary scientists, we must formulate interdisciplinary education. This requires a more in-depth examination of theories of knowledge and how innovation occurs, so as to elevate the role of those fields that reflect upon the sciences themselves.

Conclusions

In sum, to enthuse an increasingly nonlinear relationship between the forces that encourage the development of innovation, we must train future scientists in ways that foster the intellectual skills necessary for inter-disciplinarity. While doctoral graduates may not be multidisciplinarily "fluent", they can- and should- be intellectually open to disciplinary plurality and possess the ability to prescind and view problems and possible solutions from a more vantaged (and informed) inter- and trans- disciplinary perspective. In a triple helix model of knowledge innovation, academia can retain its vital significance to prepare future graduates for a nonlinear career trajectory by fostering nonlinear information-seeking behaviors, and generating awareness of- and preparation for- current and future paradigmatic changes.

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Competing Interest

The author declares that she has no competing interests.

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