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Ideology and Interdisciplinary Science Graduate Education Reform

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I am submitting herewith a thesis written by Benjamin Harrison Allen entitled "Ideology and Interdisciplinary Science Graduate Education Reform." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Teacher Education.

Mehmet Aydeniz, Major Professor

We have read this thesis and recommend its acceptance:

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Ideology and Interdisciplinary Science Graduate Education Reform

A Thesis Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Benjamin Harrison Allen
May 2014

Dedication

This thesis is dedicated to Melanie - for her timeless dedication, her endless love, her passion, and her willingness to serve the people. Additionally, I wish to dedicate this thesis to my friends, my comrades, and my family, who have stood with me throughout my education.

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Abstract

Over the past few decades, a variety of science education reform publications have emerged from both public and private entities, alongside graduate programs established to provide training for integrating multiple disciplines in research activities. Several documents concerning federal education policy have explored the socioeconomic impacts of reforming graduate education in the sciences and have made recommendations for funding interdisciplinary traineeship programs at U.S. universities. On the other hand, much of the current academic literature concerning interdisciplinary graduate science education considers the subject from functionalist perspectives, aiming to contribute best practices for assessment and curricular programming. In contrast to both of these efforts, this research contributes a critical analysis of interdisciplinary science education reform policy by placing such reform efforts within the context of a changing global socioeconomic landscape. Through tracing the development of the National Science Foundation's Integrative Graduate Education and Research Traineeship program as a product of federal policy, patterns of socioeconomic ideology contained within the political documents associated with the development of this program are analyzed alongside an overview of its curricular content. Discussion of the findings is concerned with developing a critical understanding of the relationship that interdisciplinary science and science education have to ideology as a force of social reproduction. The conclusions of this analysis advocate for a critical, historical, and materialist orientation in science education research and critical education studies, while emphasizing the role of ideology in social reproduction.

Table of Contents

I. Introduction	1
Purpose and Research Questions.....	6
II. Literature Review	7
III. Science, Ideology, and Interdisciplinarity	14
Critical Theory and Science as Ideology.....	14
Althusser on Ideology & Interdisciplinarity.....	19
IV. Methods.....	28
V. Findings and Analysis.....	31
VI. Conclusions	48
References	52
Vita	58

List of Figures

Figure 1 – Modes of determination in contemporary capitalism (Resch, 1992)	21
Figure 2 – Thematic Presence in NSF IGERT (1998-2013).....	39
Figure 3 – Number of IGERT Awards per Year (1998-2013).....	39

I. Introduction

Before the turn of the recent millennium, many policymakers, scientists and educators in the United States began to become aware of emerging scientific, political, and economic realities, which might be addressed through the introduction of educational programming designed for a world undergoing change (COSEPUP, 1995). The emergence of frontiers in scientific research such as sustainability, nanoscience and high-performance computing, alongside major ecological challenges like global climate change and loss of biodiversity, foreshadowed the changing scale and domains of scientific research at the brink of the twenty-first century. Awareness of these changing dynamics in both research and higher education enterprises brought forth much discussion about the need to reconfigure the nature of traineeship for future scientists if these challenges were to be overcome (Brainard, 2002; Sá, 2007). Additionally, the unfolding of precarious global socioeconomic events over the past two decades has greatly influenced how scientists, educators, and policymakers perceive their changing roles in society. As such, many concerns arose about the structure and function of graduate education and whether or not the existing practices were sufficient to train the next generation of scientists to adequately address these new problems (COSEPUP, 1995; Nyquist, 2002). Promoting discovery and innovation in the wake of shifting global scientific, political, and economic forces necessitated an expanded breadth of research capabilities for each newly minted professional scientist coming from a U.S. institution (COSEPUP, 1995; Nyquist, 2002; Brainard, 2002). The shifting focus of research institutions onto problems of global scale provided a background for enhanced interest in promoting collaborative scientific endeavors that crossed disciplinary lines, typically framed as multidisciplinary, interdisciplinary, or transdisciplinary research or education (COSEPUP, 1995; COSEPUP, 2004; Sá, 2007). Awareness of these trends prompted certain entities to make

expansive efforts to reimagine and restructure science education to better train scientists to adapt and thrive in changing research and career environments (Brainard, 2002; Sá, 2007). From these conditions, political movement towards reforming science education to better foster skills for changing career and job opportunities in its fields have emerged. Of particular interest is the emergence of reform movements targeted at changing the way science education is conducted at the graduate level, because this level of schooling represents a final step before taking on a career.

Over the past few decades, a variety of graduate programs have been established with the promise of providing interdisciplinary content in research and education in universities across the United States (Brainard, 2002; Sá, 2007). The National Science Foundation (NSF) Integrative Graduate Education and Research Traineeship (IGERT) program has been by far the most expansive effort by the federal government to promote interdisciplinary research and education for graduate students (IGERT.org, 2014). This program is of particular interest as it emerged as the result of extensive deliberation amongst the political and scientific leadership in the United States, which were consolidated in the form of several joint publications by the National Academies – the primary advisory body to the U.S. government on matters concerning science, engineering, medicine, and research. These publications document the rationale for allocating funds to interdisciplinary graduate training from the perspectives of scientists, science educators, and interested parties who are called on by the country’s political leadership to develop policy for national scientific efforts. Probing into the logic behind funding programs of interdisciplinary research and education graduate programs in the sciences will allow for the development of a clearer image of how socioeconomic ideology has influenced and justified these policy decisions. Likewise, understanding how shifting political and economic dynamics might

correlate to changes in programming for national science education proves important for constructing this picture. Interestingly enough, the NSF IGERT program was defunded during the period of this research, which raises many questions about what factors lead to the termination of the program.

Alongside the emergence of interdisciplinary science graduate programs, a multitude of research concerning interdisciplinary science education has been published in journals of science and education. These studies provide substantial insight into dominant conceptions of interdisciplinarity, best practices for the administration of interdisciplinary programs, and participant perspectives within these programs. Despite providing key insights into the managerial aspects of an interdisciplinary science graduate program, none of these analyses provide thoroughly critical perspectives into the historical development of these programs, or how interdisciplinary science fits into a larger discussion of philosophy of science. Because of this, interdisciplinary science graduate education appears in the literature as something decontextualized from any broader social forces. Similarly, the general value of interdisciplinary in service of scientific inquiry seems to be assumed wholesale in much of the literature, lending an overtly mythical character to the enterprise. Discarding assumptions about the general value of interdisciplinary science and critically examining the historical development and the outcomes of implementing these programs will reveal much more about the nature of interdisciplinary science graduate education in the United States.

Considering that the U.S. federal government has made substantial efforts to implement interdisciplinary science graduate programs at universities across the country, analyzing the political publications associated with the development of these programs will provide insights into how dominant ideological forces shape education policy. Characterizing the socioeconomic

ideology behind these efforts to reshape graduate education in the sciences is the crux of this analysis, alongside extrapolating an understanding of the relationship between programmatic outcomes to continued reforms. As such, this research is grounded in theoretical analysis of ideological drivers in the reform process of science graduate education, especially in the context of interdisciplinary programs. Identification and characterization of the socioeconomic motivations behind the design and implementation of these programs informs the brunt of this analysis. Similarly, establishing the objectives and goals of this particular education reform movement will be important for understanding how the real history of the NSF IGERT program develops in relation to the visions and motivations of education reformers, which may or may not be uniform. Comparing and contrasting these motivations and expectations with the actual outcomes of the program will inform this critical analysis, with aim to give rise to questions about if and how outcomes engage with downstream reforms. To assist with this task, historical data about the composition of NSF IGERT programs across U.S. institutions was compiled, specifically information about the research themes present in the program abstracts and how funding allocations changed over time. Considering that the NSF IGERT program has been terminated as of 2013, this data will serve to inform a comprehensive overview of the program, from start to completion.

While analyzing the structures that govern ideological drivers of educational programming can reveal a lot about the nature of their development, it is also necessary to consider these findings within the context of broader discussions concerning scientific inquiry. Exploring how the lively historical discussion of philosophy of science relates the present emergence of interdisciplinary science will assist the construction of both critical and historical perspectives on the emergence of interdisciplinarity in graduate science education. To undertake

this effort, a brief review of literature concerned with the philosophy of science was conducted and coupled with an inspection of leading theoretical considerations concerning the relation between science and ideology. In particular, both classic and recently translated works from French philosopher Louis Althusser on ideology and the nature of science serve as the theoretical foundation of this critique. Althusser's theses about ideology as a material force lend themselves well to understanding the peculiar circumstances of this kind of educational reform, especially regarding the education and training of professional scientists. Crucially, Althusser's contributions allow for intensive reflection upon the importance and value of interdisciplinarity, the mythological character imbued on interdisciplinary science, and effects of promoting interdisciplinary throughout scientific enterprises. Viewing interdisciplinary science graduate education through this critical lens allows for demarcating of the ideological narratives embedded in the policy surrounding the creation of these programs from the concrete effects of training graduate students in an interdisciplinary environment. This decoupling is important, because at the core of this critique is an understanding of how ideology informs education reform, not necessarily the efficacy of science education curriculum within programs that happen to identify with interdisciplinary mysticism. Indeed, while positive effects of interdisciplinary education on its participants are noted throughout the history of NSF IGERT, it can be demonstrated that these positive effects do not necessarily feedback into the logic of programmatic reformation. Overall, performing a deep exploration of this subject aids not only the development of a clearer image of why the NSF IGERT program came to exist in the first place, but a grounded understanding of the conditions of its termination, regardless of any successes in providing valuable training to several thousand graduate students.

Purpose and Research Questions

The following research contributes to the fields of science education and critical education studies through analyzing the education reform policy documents that are associated with the development of interdisciplinary science graduate education in the United States, specifically those funded through NSF IGERT awards. Likewise, this research contributes to the discussion of philosophy of science and the nature of science within the context of science education. This analysis is primarily concerned with understanding the role of socioeconomic ideology in the education reform process and how iterations of reform in science education programming can be traced alongside ideological reformation. Developing critical and historical perspectives on the role of ideology in education reform will allow education researchers to more closely examine education reforms by demarcating ideological narratives from the real effects of educational restructuring. Questions that will guide this research include:

- 1) What is ideology and what are the material effects of ideology?
- 2) What is the role of ideology in education reform? How does it function in graduate science education reform?
- 3) What are the major socioeconomic considerations that informed federal initiatives to develop the NSF IGERT program?
- 4) What is the thematic character of the education and research content across NSF IGERT programs?
- 5) How successful was the NSF IGERT program in fulfilling its explicit programmatic expectations?
- 6) What factors could have led to the decision to discontinue federal funding for the NSF IGERT program?

II. Literature Review

Studies concerning interdisciplinary science education have become more frequent in recent decades, quite possibly because explicitly interdisciplinary educational programming has become more popular at all levels of education. Considering the breadth of possible subject material that can be framed as being interdisciplinary, it is unsurprising that publications focused on interdisciplinarity can be found in a wide variety of journals. In fact, there are entire reference texts dedicated to considering the profundity of interdisciplinary activities across all education sectors (Klein, 1990; Repko, 2004). It is also worth considering how the growth of research concerning interdisciplinary education relates to larger social forces, in particular the recent STEM education movements (Breiner, et. al., 2012). For the purposes of this research, the selection of literature for review was filtered according to relevance to interdisciplinary science graduate education. This survey will consider a variety of publications related to interdisciplinary science curriculum, assessment, pedagogy, and research at the graduate level. Constructing a vision of the present state of research on interdisciplinary science graduate education will uncover the variety of arguments and perspectives represented in the literature.

Much of the initial studies on interdisciplinary research consider interdisciplinarity in the abstract in order to construct a theoretical framework to evaluate interdisciplinary educational programming. As such, interdisciplinarity is considered to be, “a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline of profession,” by attempting to openly integrate a multiplicity of disciplinary perspectives into a comprehensive theoretical framework to perform this function (Klein and Newell, 1996, p. 395; Szostak, 2007, p. 6). However, there is debate amongst interdisciplinarians about the transformative process that disciplinary insights are supposed to

undergo when they are integrated into an interdisciplinary framework. Certain perspectives consider critically oriented disciplinary insights as the driving force behind interdisciplinary research, rather than integration itself as the definitive process (Lattuca 2001; Moran 2001). Alternatively, conceiving interdisciplinarity as a synthetic process allows for the capabilities of disciplinary insights to be considered from the perspective of interdisciplinarity as it can be applied to a given subject, making the interdisciplinary process one of finding common ground (Repko, 2007; Szostak, 2007, p. 7). Additionally, it should be noted that the discussion surrounding the definition of interdisciplinarity has given rise to a broader framework of considering research as disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary, depending on how the research relates to a variety of factors; these factors include the integration of a variety of vocabularies into the research, the level of interaction between researchers, the definition of the problem at hand, the epistemological approach, the methodology, the generation of knowledge, and the products of the research (Morse et. al., 2007, p.4). Although finding a firm definition of interdisciplinarity seems elusive given the fluidity of the subject, considering each of these perspectives offers a lens to evaluate the strengths and weaknesses of a given program by assessing the conditions of interdisciplinary collaboration within the program. Indeed, these studies would prove useful for administrators concerned with creating social and environmental conditions to stimulate collaborative activities.

Given the role of collaboration in facilitating interdisciplinary research, seeking to understand the structural features that enable or hinder collaboration in a research program offers an opportunity to extrapolate points of analysis for the development of an evaluative methodology (Repko, 2008, p. 44). Considering that the graduate student is the subject of a graduate program of education, special attention ought to be paid to their expressed concerns

regarding their own education and training. Graduate students that have engaged in interdisciplinary work have reported three stages in the progression towards earning their doctoral degree in an interdisciplinary program: naissance, navigation, and maturation (Graybill et. al., 2006, p.760). Naissance describes the period in which the interdisciplinary graduate student is “establishing solid theoretical footing and fulfilling dual programmatic requirements in home departments and in the interdisciplinary program,” usually within in the first two years of their participation in the graduate program (Graybill et. al. 2006, p.760). The navigational period is defined by “the responsibilities of team research, individual disciplinary coursework, and other goals or requirements (general exams, dissertation proposals, fieldwork, fellowships, publications),” wherein the graduate student is steering towards a particular research direction according to their experiences in these activities (Graybill et. al., 2006, p.760). Finally, the maturation period occurs when the graduate student is nearing the end of their research and is confronted with questions regarding publications, dissertations, and career options (Graybill et. al., 2006, p.761). Indeed, a major concern among observers and researcher of science graduate education is the time taken to complete a doctoral degree. In recent years, the amount of time required to complete a doctorate has increased, due to a variety of factors (Tuckman, Coyle, & Bae, 1989). Shortened time to earn a degree is correlated with a high transfer of research skills, in that better researchers in the science and mathematics are more likely to complete their doctorates in the time allocated to them (Millett & Nettles, 2006). By utilizing the temporal scale as perceived by the graduate student, the strengths and weaknesses of a program can be better understood according to how graduate students relate to specific events throughout this timescale, in addition to how much attention the program administration gives to tuning its activities around this timescale. Likewise, for administrators and faculty, shortening time to

completion of a graduate degree would likely prove useful in terms of resource provisioning and budgeting, although it does not seem particularly wise to place primacy on this consideration for programming strategies, as graduate students represent a diverse body of experience with a wide variety of needs to be met in order to foster adequate training (Austin, 2002).

From the administrative perspective, there are additional concerns that need to be addressed in order to establish best practices for achieving desired outcomes in interdisciplinary graduate education. Indeed, much intervention can be required to create collaborative environments where differing perspectives for approaching a particular scientific problem can be reconciled through research. Quite certainly, Maura Borrego from Virginia Tech and Lynita Newsander from the University of South Dakota have proven themselves to be thorough and prolific academics when writing on these subjects. Administrators are encouraged to dismantle the barriers to interdisciplinary research by transcending disciplinary structures that prevent shared education and research practices (Borrego & Newsander, 2008). Likewise, faculty must make strident efforts to reach out to other research colleagues to increase mutual awareness of the epistemological issues related to conducting research (Lattuca, 2001; Borrego & Newsander, 2008). In particular, successful implementation of interdisciplinary research has been tied to adequately facilitation engagement through “supporting diversity, participation, connections, and interactive teaching and learning” (Newsander & Borrego, 2009, p. 551). Such engagement is fostered through a combination of engaging diverse participants, building participatory cultures, developing interactive teaching and learning, and having access to adequate resources, such as recruitment and funding (Newsander & Borrego, 2009). Additionally, conditions of resource acquisition and allocation, in terms of recruitment, funding, spatial and temporal management, must be considered, as access to resources has been identified

as a potential barrier to the successful implementation interdisciplinary graduate research (Morse, et. al., 2007, p. 8). By understanding the organizational capacity and resourcefulness of a graduate program, the efficacy and sustainability of the program to produce highly-trained interdisciplinary doctoral students that value their educational experience can be assessed (Borrego & Newswander, 2010). Additionally, defining the desired learning outcomes of an interdisciplinary program allows for navigating the challenges associated with bringing people together to collaborate in an environment, and permits reflection and critical awareness of the process of integrating insights from a variety of disciplines (Borrego & Newswander, 2010).

Facultative and administrative perspectives of interdisciplinary graduate education offer key insights in the development of an evaluative methodology for successfully implementing such programs. Indeed, the first step to implementing one of these programs is securing funding to organize interdisciplinary science graduate education. An analysis of 130 successfully funded NSF IGERT programs demonstrated that funded proposals paid special attention to the development of program level assessment goals for technical training, broadened curriculum, and developing communications and collaboration skills (Borrego & Cutler, 2010). The overall success of a program is also dependent on the ability of the graduate student to establish themselves as a valuable researcher after they complete their degree within a program (Rhoten, 2004). This factor is of key importance to the establishment of interdisciplinary graduate research programs, as many potential graduate students express concern that performing interdisciplinary research in graduate school will hinder their ability to perform research or gain tenure after they have graduated (Rhoten, 2004). Likewise, understanding the full range of subjective factors that draw individuals towards engaging in interdisciplinary research in the first place and their perceptions of the value and efficacy of such a program during and after

competing their graduate research and degree can provide for an expansive qualitative analysis of an interdisciplinary graduate research program. Current literature suggests that factors such as finding an advisor for the student, ensuring that the student is able to master knowledge while reconciling conflicting research methodologies, finding an intellectual community for the student to engage in sharing ideas with, and overcoming the fear that interdisciplinary research will not have value must be addressed and overcome in order to successfully implement an interdisciplinary graduate research program (Rhoten, 2004; Golde & Gallagher 1999). By understanding how an interdisciplinary graduate research program addresses and overcomes these challenges, its efficacy in fostering successful interdisciplinary collaborations can be established.

The establishment of interdisciplinary programs reflects the perceived need to address problem sets or research themes that neither established disciplinary doctrine nor division of labor amongst various disciplines (multidisciplinary research) have the capacity to thoroughly divulge. Therefore, interdisciplinary research is supposed to embody not only collaboration, but also integration and synthesis of new perspectives (Morse et. al., 2007, p.4). As such, it seems intuitive that research would indicate that there is a significant correlation between the degree of interdisciplinarity and the levels of collaboration between researchers of differing academic backgrounds in a given research project (Qin, Lancaster, Allen 1997, p. 899). To some, the hope provided by interdisciplinary research programs is that they may afford a vehicle by which new scientific disciplines are organized and established by successfully facilitating collaboration between researchers outside of the confines of traditional disciplinary organization (e.g., a department of chemistry), in addition to fostering new approaches and perspectives that, when synthesized, will form the logical and cultural structures that are associated with disciplinary

frameworks (Repko, 2008). This is acknowledged by Allen Repko from the University of Texas at Arlington, another well reputed scholar of interdisciplinarity, who notes that “interdisciplinarity is often a collaborative process” and that “an expert interdisciplinarian is one who is able to integrate the input of others to address an issue, which may include coordinating team members” (2008, p. 44). Likewise, it has been recognized that the organization of interdisciplinary research programs involves placing researchers of various backgrounds and research experiences into an environment where their distinct skill sets and knowledge bases will lead to a new interpretation of a common problem that cannot be solved when confined to the theoretical boundaries of a single discipline or by division amongst multiple disciplines (National Academies, 2004).

Cumulatively, these studies provide substantial insight into dominant conceptions of interdisciplinarity and best practices for the administration of interdisciplinary programs. However, the insights provided by much of these research initiatives reveal only surface level characteristics of interdisciplinary graduate science education. Indeed, seemingly absent from the discussion of fostering interdisciplinarity in education and research is an interrogation of why and how this concept has been pushed to the front of the science education lexicon. This deficiency can only be rectified through a deeper probing into both the broader discussion of science and ideology coupled with a historical perspective on the emergence of interdisciplinarity. Synthesizing the findings of these interrogations will allow for an adequately grounded critique of interdisciplinary science graduate education reform.

III. Science, Ideology, and Interdisciplinarity

Critical Theory and Science as Ideology

The beginnings of contemporary attempts to unravel the complex relationship between science and ideology can be traced to disputes within philosophy of science and sociology circles during the 1960s and '70s regarding epistemological character of scientific knowledge. During that period, many prominent philosophers of science and sociologists were engaged in a series of debates and discussions concerning the scientific tradition known as positivism, which in its earliest expressions encapsulated the idea that what could be known about reality is both observable and measurable (Ray, 1979). The emergence of the social sciences, which sought to understand experiences outside of sensory information, proved incompatible with the epistemological traditions of logical positivism. Realizing the deficiencies in positivism, the efforts to reform positivism began with two notable undertakings. The first is that of Karl Popper, who sought to reform positivism along the lines of its burden of proof, seeking to establish the methodological primacy of falsification and probability instead of truth via verifiability, alongside advocating for unity in scientific method (Frisby, 1972; Ray, 1979; Fuller, 2004). The Popperian critique of positivism sought to reform its basis of knowledge, rather than provide an alternative model of understanding knowledge outside of the empirical-analytical epistemological tradition. On the other hand, Thomas Kuhn sought to expand the realm of positivist epistemology in terms of temporal, spatial, and sociological tendencies (Fuller, 2004; Kuhn, 2012). Rather than extrapolating the basis of knowledge, Kuhn sought to demonstrate how knowledge changed based on epistemological ruptures, or paradigm shifts, and as such represents a very different post-positivism than Popper's, in that knowledge could be understood in terms of its sociocultural development (Fuller, 2004). As such, it is questionable that much of

Kuhn's thought stems from the positivist movement or is an effort to reform positivism, as much as it is an exploration of how scientific revolutions are social projects, informed by new paradigms of thought and inquiry.

The efforts to reform positivism in the middle of the twentieth century saw in turn the development of new critiques of empirical-analytical epistemological traditions. In particular, what came to be known as the Frankfurt School of critical theorists arose in part to challenge what they saw as the defects in Popper's reformation of positivism on the grounds that it maintained the idea that all science is unified in method, that value and fact must be separated alongside reason and decision, and that criteria falsifiability are necessary to access truth (Ray, 1979). Of the Frankfurt School practitioners, Herbert Marcuse, Theodor Adorno, Max Horkheimer and Jürgen Habermas were the most vocal anti-positivists - perhaps listed here in descending order in terms of general radicalness - with verbal and textual disputes with the likes of Popper and his defenders. In a sense, these critical theorists saw themselves continuing the work of Karl Marx in breaking with empirical-analytical epistemological traditions through deployment of dialectical analysis, offering a reflexive understanding of knowledge as a product of the interaction between social relations and the material world (Ray, 1979). However, unlike those who aligned themselves with what is considered to be an orthodox interpretation of Marx, the critical theorists attempted to employ dialectical analysis outside of the historical context, indeed considered by many to be the originators of "post-Marxism." While not a direct confrontation with positivism, arguably the most famous early expression of the positionality of the Frankfurt School is Horkheimer and Adorno's *Dialectic of Enlightenment*, originally published in 1944. Providing a solid foundation for the diaspora of critical theoretical texts that would emerge in the future, Horkheimer and Adorno set out to analyze what they perceived as a

regression in the capacity of the Enlightenment virtues as a motive force in society, in light of the catastrophic global events of the early and middle parts of the twentieth century that facilitated the rise of fascism (Zuidervaart, 2011). The central thesis of the text, that "myth is already enlightenment, and enlightenment reverts to mythology," alludes to a doubly critical perspective of both the loss of forms of knowledge that provided for the emergence of Enlightenment traditions, and the use of such traditions for engaging in wholesale destruction of humanity under an imposed ideological rubric of rationality (Horkheimer and Adorno, 2002; Zuidervaart, 2011). Their analysis would set the stage for critical theoretical practitioners throughout the fields of aesthetics, literary analysis, and philosophy of science (Zuidervaart, 2011). The expressed interest of the Frankfurt School practitioners in liberating knowledge from the cold, technical, and rationalist systems of modern hierarchies gave rise to confrontations with those who they viewed as purveyors of positivism (Frisby and Adey, 1976). The earliest of these confrontations was between Theodor Adorno and Karl Popper at a conference of the German Sociological Association in 1961 (Frisby and Adey, 1976). These disputes resulted in a series of texts from all parties directly and indirectly involved, firmly establishing the divergence in position between those who would come to be known as critical rationalists and the critical theorists (Frisby, 1972; Frisby and Adey, 1976; Ray, 1979). In fact, Herbert Marcuse and Karl Popper jointly published a succinct account of their divergences in their collaborative confrontation, *Revolution or Reform?: A Confrontation* (1985). In turn, Marcuse's confrontations with Popper against the supremacy of rationalism, positivist or otherwise, provided the basis for Jürgen Habermas to direct his attention to the subject of concern: the relationship between science and ideology.

Inspired by Marcuse's efforts to confront the hierarchical tendencies of the rationalist program of science, Jürgen Habermas, attempted to extrapolate the broader consequences of the

rationalist program of science in a collection of essays titled *Technology and Science as "Ideology"* (Technik und Wissenschaft als "Ideologie," 1968). Habermas sees science and technology as playing a distinct role in the reproduction of the capitalist system, and locates this role in the ideological functioning of the system, rather than simply improving the technical capacity of the system to extract surplus value from resources and labor (1968, pg. 100). Accordingly, he attributes science and technology a simultaneous characteristic of depoliticizing society and legitimizing extant political order:

Insofar as government action is directed toward the economic system's stability and growth, politics now takes on a peculiarly negative character. For it is oriented toward the elimination of dysfunctions and the avoidance of risks that threaten the system: not, in other words, toward the *realization of practical goals* but toward the *solution of technical problems*. (Habermas, 1968, pg. 103)

As such, Habermas envisions the encroachment of technocratic intentions into society that may outmaneuver democratic aspirations through the dismantling of ideology as symbolic interaction and its replacement as what is termed purposive-rational action, which is governed by technical rules, context free language, conditional imperatives, and the extension of technical control in the place of social norms, intersubjective but ordinary language, expectations of behavior, emancipation, and communication (Habermas, 1968; Kunneman, 1990). Habermas envisions this as a qualitative change in the order of society away from the Marxian paradigm of class struggle, in that the form of dominant ideology has moved away from bourgeois ideology of just exchange - which provides the justification for the expansion of democratic project initiated by the bourgeoisie - into the economic realm to ameliorate exploitation of the proletarian base of labor. Instead, the dominant ideology has shifted into the realm of technical control of society, such that the function of institutional power has been "designed to compensate for the

dysfunctions of free exchange” (Habermas, 1968, pg. 102). Therefore, according to Habermas, the tendency of capitalist society to engage in class struggle over control over the means of production has been consumed by advanced capitalist society’s tendency to mitigate, with the aim to annihilate, or solve, class struggle through expanding technical control over populations and resources (Habermas, 1968, pg. 108). This has dire consequences for any project, bourgeois or proletarian, concerned with the emancipation of humanity from systems that repress free exchange. As Habermas states succinctly:

Technocratic consciousness is, on the one hand, "less ideological" than all previous ideologies. For it does not have the opaque force of a delusion that only transfigures the implementation of interests. On the other hand today's dominant, rather glassy background ideology, which makes a fetish of science, is more irresistible and farther-reaching than ideologies of the old type. For with the veiling of practical problems it not only justifies a particular class's interest in domination and represses another class's partial need for emancipation, but affects the human race's emancipatory interest as such. (Habermas, 1968, pg. 111).

Concurrent with this repression of the emancipation of humanity is the distortion of communication through the obfuscation of frame of reference (class, gender, race, etc.) in language by the placement of positivism in “common thinking” (Habermas, 1968, pg. 112). As such, Habermas is sounding the knell that the dominant ideology of contemporary social order seeks the control of both humanity and the material world through systems of technical control, standardization, and quantitative measurement. Themes of standardization and quantitative measurement are central to the contemporary debates concerning the design of curriculum and administration of schooling at all levels of education (Hursh, 2000). However, the introduction of interdisciplinarity as a motive force for graduate education seems to run counter to the trending reform movements towards standardization and traditional forms of knowledge seen

other levels of education, which arguably conforms to Habermas's vision. In order to demarcate the interdisciplinary education reform movement from the standardized education reform movement, we will explore another important interrogation of the subject that is based in a more orthodox consideration of the nature of ideology, class struggle, and social reproduction.

Althusser on Ideology & Interdisciplinarity

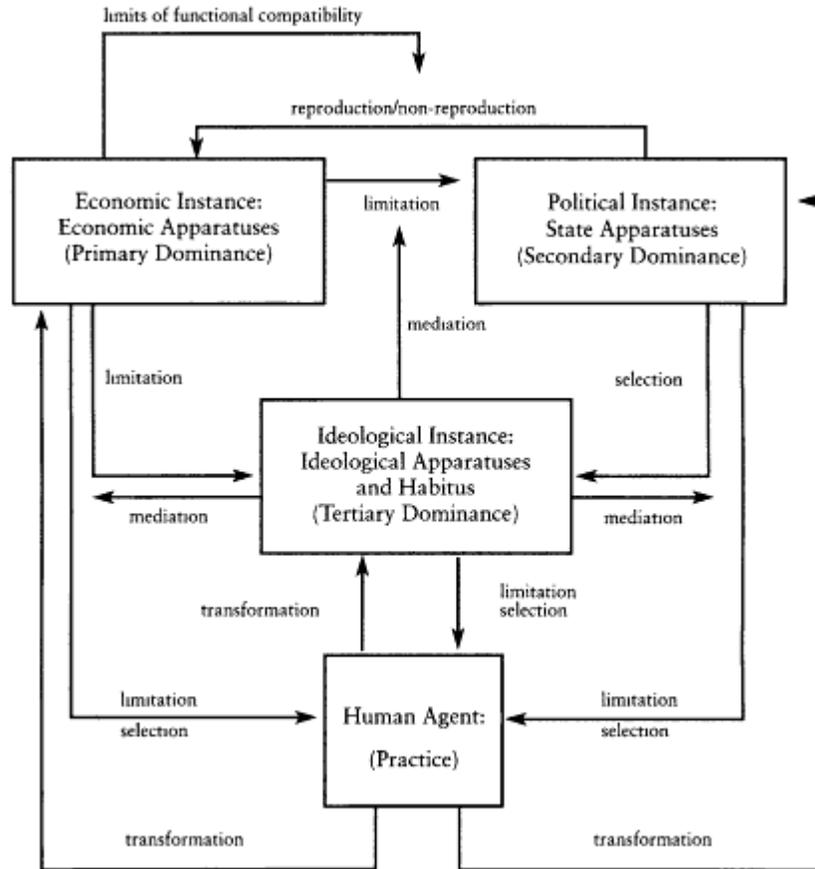
While the critical theorists provided a novel mobilization of Marx's dialectical methodology into the social context of science, other practitioners of Marx's method sought to understand the epistemology of scientific knowledge through the historical and materialist characteristics of Marx's dialectical thought. Louis Althusser offers an acute interrogation and useful theoretical model for investigating the subject of interdisciplinarity. In his classic essay, *Ideology and Ideological State Apparatuses* (1971), Althusser explores a question that emerges in the second volume of Marx's *Capital*, essentially the same question as Habermas - how are the productive forces of society reproduced, alongside the existing social relations that favor dominant ideologies? Unlike Habermas, Althusser locates the resolution to this problem in the orthodoxy of Marx's thought – class struggle. For Althusser, ideology is crucial to the reproduction of labor power, because laborers must be able to reproduce the technical knowledge required for the production of commodities, which in turn requires laborers to understand the practice of submitting to the technical information, like instructions for proceeding around the shop floor, or operating equipment (Althusser, 1971; Resch, 1992). As such, the state exists in part to ensure the reproduction of this knowledge, and uses a variety of apparatuses to enforce both the operation of productive forces and the social relations required for that reproduction (Althusser, 1971; Resch, 1992). These apparatuses appear quite clearly throughout history in the

form of what Althusser denotes as *repressive state apparatuses* (1971), when force is deployed to ensure the continued operation of productive forces and the viability of state structures, such as the use of police or military forces to break up a strike or to prevent the sabotage of productive forces or state facilities. Althusser's conception of the role of repressive apparatuses in the functioning of the state has been used as a foundational text for critical evaluations of a variety of educational systems and structures, particularly those emphasizing the repressive role of curricular and hierarchical structures within educational systems to promote general social reproduction (Carnoy, 1985; Dale 1989; Nozackj & Apple, 2002). Althusser reiterates his devotion to the primacy of class struggle when he declares that the, “whole of the political class struggle revolves around” state power, “the possession, i.e. the seizure and conservation of State power by a certain class or by an alliance between classes or class fractions” (Althusser, 1971). Importantly, the state, as Althusser understands it, is not limited to public or governmental entities, but instead is composed of the collective “ruling class...neither public nor private” that exerts controls productive forces (Althusser, 1971). From this, he differentiates another form of the *state apparatuses* from *repressive state apparatuses* - *Ideological state apparatus* are “a certain number of realities which present themselves to the immediate observer in the form of distinct and specialized institutions” that are imbued with distinctive characteristics based in their religious, educational, familial, legal, political, unionist, media, cultural, and otherwise forms (Althusser, 1971). From his model, he posits three theses about the function of ideology in the reproduction of productive forces and relations:

Thesis I: Ideology represents the imaginary relationship of individuals to their real conditions of existence.

Thesis II: Ideology has a material existence.

Thesis III: Ideology *interpellates* individuals as subjects (Althusser, 1971).



Modes of determination in contemporary capitalism (Resch, 1992)

According to these theses, the role of ideology in the reproduction of productive forces and relations is to stamp character role onto individuals which, at least in part, defines their position and function in society, based on the imagined relations to their real conditions of existence. That is to say, ideology imparts identity onto individuals (through their own choosing, or otherwise), making them subjects – the act of interpellation – and this subjective character differentiates individuals in society by virtue of their functioning as subjects. In essence, the material existence of ideology is based in the control of behavior, or practice, through the governing rituals that fulfill the conditions imagined relationship between an individual and their conditions of existence (Althusser, 1971; Resch, 1992). Importantly, the individual becomes an abstracted model of being within this philosophical framework, because individuals as subjects are defined

in terms of relations, to ideology or to other subjects. An individual can never come to understand itself as such, without approaching ideology to come to terms with the rituals that govern practice, or the relations between oneself and others. Therefore, Althusser (1971) posits that individuals are always-already subjects, and that as such, ideology is an eternal factor for the consideration of any subject.

The function of ideology in education systems has been a topic of interests to many critical education researchers and Althusser's insights about the material existence of ideology have been useful in critiquing modern conditions of education (Nozakj & Apple, 2002). However, there has been little exploration into Althusser's commentaries on a topic that is increasingly relevant to science education: interdisciplinarity. Specifically, how interdisciplinarity functions within the sciences as ideology, governing scientific practices and the relations between scientists. For the majority of his career, Althusser was employed as a professor of philosophy at Ècole Normale Supérieure in Paris, France (Lewis, 2009). In the autumn of 1967, he was asked to construct a course regarding the relationship between philosophy and science, which was then refined in the form of several written lectures (Althusser & Elliott, 2011; Resch, 1992). During the course of his lectures, after exploring several theses regarding the distinction of philosophy from science, he turns his attention to a tendency he observes amongst French scientists for “what can only be called the fashion for interdisciplinarity” (Althusser & Elliott, 2011, p. 78). Continuing his exploration of the subject, Althusser claims (2011) “behind the term interdisciplinarity, there may certainly be undeniably definite and important objective achievements...but behind the generality of the slogan of interdisciplinarity, there is also an ideological myth.” To clarify his position on the matter, he posits two important theses regarding the subject:

Thesis 9. An ideological proposition is a proposition that, while it is the symptom of a reality other than that of which it speaks, is a false proposition to the extent that it concerns the object of which it speaks.

Thesis 10. In the majority of cases, the slogan of interdisciplinarity is a slogan that today expresses an *ideological* proposition. (Althusser & Elliott, 2011, p. 79).

Recalling his consideration of ideology in the context of state apparatuses (1971), *Thesis 9* can be understood as a restatement of his claim that ideology is the imagined condition of real social relations. In *Thesis 10*, Althusser characterizes interdisciplinarity as an ideological mechanism. Hailing from his notion of ideological state apparatuses, interdisciplinarity will come to be understood as a governor of social relations between scientists.

Especially relevant to this research, he alludes to the emergent trend (fifty years ago in France) of framing scientific practice in terms of *global, social* objectives, such that the real conditions of scientific research are determined “not only [through] funding, but also relations with industry, with politics, etc.(Althusser & Elliott, 2011, p. 80).” Indeed, for Althusser (2011), reckoning with these emergent trends can only be undertaken from the point of view of the philosopher, who does not solve problems, but instead raises questions and posits theses that may allow for the development of a *correct* position regarding these problems. Orienting towards a correct position on these matters requires reflection on the historical circumstances that constitute any particular phase of development in the sciences. Indeed, at the core of historical and materialist inquiry is asking the questions - “where do we come from...where are we...where are we going...what is to be done (Althusser & Elliott, 2011, p. 81)?” Considering these questions entails the development of *practical ideologies*, which are complex constructions that

shape how people relate to their historical, social, and individual existence (Althusser & Elliott, 2011; Resch, 1992).

Seeking to ground his understanding of ideology into a concrete example and to demonstrate the practice of philosophy as demarcating the scientific from the ideological, Althusser (2011) considers the subject of interdisciplinarity in the sciences. Foreshadowing the conditions of rising interest in interdisciplinary sciences described by Rhoten (2004), Althusser declares that in France during the late 1960s, interdisciplinarity was “a widely diffused slogan, which is expected to provide the solution to all sorts of difficult problems in the [physical] sciences, the human sciences, and other practices (2011, p. 84).” In spite of this characterization, Althusser (2011) remains perceptive of need to assemble a multitude of specialists to fulfill specific tasks related to solving a scientific problem or conducting research to make an informed decision. But what is in question is the invocation of interdisciplinarity as a positive modifier of scientific practice, and the degree to which this practice already entails cooperation between scientists with different specialties. In order to better understand this invocation of interdisciplinarity, an examination of the existing relations between scientific disciplines is required. To differentiate the relations between sciences, he defines *relations of application* and *relations of constitution* as categories of relations (Althusser & Elliott, 2011). The former denotes relations between disciplines that involve the application of one set of disciplinary knowledge as an instrument for solving a problem in another discipline, e.g. applied physics (Althusser & Elliott, 2011). On the other hand, *relations of constitution* are defined by an interpellation of multiple disciplines as a definitive structure in their own accord, e.g. biochemistry (Althusser & Elliott, 2011). Contrasting *relations of constitution* with the ideology of interdisciplinary sciences, these *relations of constitution* correspond to the development of new branches of

existing disciplines, or new sciences altogether (Althusser & Elliott, 2011). Defining these *relations of constitution* as such, Althusser unknowingly echoes Kuhn's (2012) consideration of the structure of scientific revolutions, in that paradigm shifts, or ruptures from the existing epistemological structures of the sciences, guide the development of new sciences (Resch, 1992; Baltas, 1993). Equally resonant with the thought of his contemporary Gaston Bachelard, a French rationalist philosopher of science, the relations between sciences allow for the development of new sciences at the edges of established disciplines, based on these epistemological ruptures (Resch, 1992; Baltas, 1993; Althusser & Elliott, 2011).

Essentially, Althusser's philosophical investigation into these matters hopes to accomplish two critical tasks. The first task is to draw “a line of demarcation between the ideological pretensions of interdisciplinarity and the realities of which it is the symptom (Althusser & Elliott, 2011, p. 84).” That is to say, philosophy can differentiate science from ideology, and the ideology of interdisciplinarity emerges from a historical material reality, but this ideology is not in correct alignment with the reality of scientific practice, and thus comes from realities of nonscientific (e.g. religious, moral, etc.) practice. Accordingly, his second task becomes to understand how an ideology in correct alignment with scientific reality can be characterized. Pondering this relation, Althusser develops his conception of the scientific ideology as inseparable from scientific practice, in that it develops “spontaneously” alongside scientific practice, unlike religious and moral ideologies, which emerge from considerations of the “origins” and “ultimate ends” of all of everything (Althusser & Elliott, 2011, p. 82). Consistent with the understanding that the ideology of interdisciplinarity emerges from nonscientific practices, the invocation of interdisciplinarity into conditions of scientific practice represents a contradiction. This contradiction is a symptom of theoretical immaturity grounded in a failure to adequately identify

the object of study, rather than a problem of constitutive relations between scientific disciplines – the problem which interdisciplinary arrangements falsely promise to solve (Althusser & Elliott, 2011). This ideological practice is prevalent in the human sciences, where mathematical findings are produced as justification of their scientific merit, rather than as a method to build adequate theoretical models of their object of study (Althusser & Elliott, 2011). Indeed, there is a practical component to this philosophical exercise in that through grounding the understanding of scientific practice as the adequate approach of the object of study for the development of theory, ideological collaborations are minimized, and more capable scientific arrangements might emerge. Toward the end of his discussion of interdisciplinarity, he characterizes these ideological arrangements as oscillating “between a vague spiritualism and technocratic positivism” (Althusser & Elliott, 2011, p. 97). The spiritualist and technocratic impulse of the interdisciplinary collaborations is openly mocked by Althusser (2011), who declares, “the practice of 'round tables' is necessarily accompanied by an ideology of the virtues of interdisciplinarity... ideology is contained in a formula: when one does not know what the world does not know, it suffices to assemble all the ignorant: science will emerge from an assembly of the ignorant.”

The contributions of Althusser from his lectures on the *Spontaneous Philosophy of the Scientists* open the door for inquiry into ideological mechanisms that drive education reform; his critique of interdisciplinary science is rich with potential for inquiry into the reforms that have pushed for developing interdisciplinary science graduate education. Quite certainly, he declares that:

“all science teaching, whether it wants to or not, conveys an ideology of science and of its findings – that is, a certain knowing-how-to-act-in-relation-to-science and its findings, based on a certain idea of the place of science in society, and on a

certain idea of the role of intellectuals who specialize in scientific knowledge and therefor of the division between manual and intellectual labor” (Althusser & Elliott, 2011, p. 95)

To consider how ideology directs education reform, the relationship between political and economic institutions, which are inherently ideological, and systems of education must be analyzed (Nozakj & Apple, 2002). Similarly, periods of political and economic crises often define the real conditions from which new ideologies are imagined, and these shifting dominant ideologies of political and economic order drive the development educational reforms (Althusser & Elliott, 2011). Once again, the focus of this investigation turns to demarcation of the ideological from the scientific; the former relates to practice and society, and the latter relates to knowledge and the sciences (Althusser & Elliott, 2011). Especially within the context of training professional scientists, interdisciplinary education reform implies shifting conditions of the division of specialized scientific labor - intellectual, academic, research, or otherwise (Althusser & Elliott, 2011, pg 97). Within the context of graduate education, these reforms are particularly intriguing, because terminal degrees confer specialization within academic or research professions. It is important to consider shifts in the conditions of labor for scientists in relation to these graduate education reforms. In line with the conclusions of Althusser (2011), these shifting conditions are fundamentally social and practical, and must relate shifts in dominant ideologies.

IV. Methods

The crux of this research is the construction of critical and historical analysis of the development of interdisciplinary science graduate education programs. In order to accomplish this, a mixed methods textual analysis was conducted on the data and documents relevant to the historical discussion of the NSF IGERT program. Of primary interest are sources of federal data concerning interdisciplinary science graduate education programs. The first phase of this analysis is concerned with understanding the overall makeup of educational content of NSF IGERT grants awarded from the inception of the program in 1998 to its closure in 2013. Establishing the themes of the interdisciplinary educational content in each NSF IGERT center allows for the construction of a comprehensive overview of what subject matters were the focus of the program. Information about the thematic content of each NSF IGERT center had been partially compiled by the communications managers for the IGERT program, but this dataset was incomplete, as many of the programs listed on the IGERT.org (2014) have no assigned themes. For these incomplete datasets, grounded theoretical methods were used to establish themes based on coding the abstracts of each awarded center, and matching the codes to the appropriate themes (Glesne & Peshkin, 1992). Additionally, award information from IGERT.org (2014) was combined with chronological information about the each award start date from NSF.gov (2014), based on the initial amendment date for each awarded center. This will allow for a better understanding of the interdisciplinary educational content offered through centers awarded through the NSF IGERT program.

The second phase of this analysis is concerned with characterizing the role of ideology in the movement for interdisciplinary science graduate education reform, using critical and historical perspectives to analyze the discourse of these programs embedded within the text

reform policy documents (Fairclough, 1992; van Dijk, T. A. 1993). The principles derived from Althusser's philosophical inquiry into science, ideology, and interdisciplinarity will inform this investigation into the development of interdisciplinary programs in the United States. In particular, the NSF IGERT program makes for a good example for analyzing the relation between dominant ideologies and educational reform. As a federally funded education program, it is directly related to political and economic institutions, which have well-documented perspectives on the necessity of these interdisciplinary science graduate education reforms from representatives of dominant political, economic, and educational institutions. The case of NSF IGERT is particularly relevant to understanding how shifts in dominant socioeconomic ideology effect education reform, especially since the decision was recently made to defund the program after 15 years of operation. As such, comparing and contrasting the socioeconomic ideological discourse embedded within various documents that have influenced the development of interdisciplinary science graduate education reform will inform a better understanding of how ideology relates to forces of educational reform, and critique of education reform as a whole from the historical and materialist perspectives.

The policy literature from the National Academies and the assessment literature from National Science Foundation concerning interdisciplinary science graduate education programs will be used as the substrate for this analysis. From the National Academies, *Reshaping the Graduate Education of Scientists and Engineers* (1995) will be analyzed as the foundational reform document that lead to the creation of NSF IGERT. Similarly, *Facilitating Interdisciplinary Research* (2004) acts as a supporting document that focuses on implementing interdisciplinary science graduate education reforms in universities. On the other hand, the report *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic*

Future (2005) and its sequel – *Rapidly Approaching Category 5* (2010) – are policy documents that assess the state of science and technology in the United States, while making recommendations for reforming graduate education in the sciences based on these assessments. Examining how the National Academies leadership has defined the role of graduate education for scientists and has made recommendations for reform in light of shifting socioeconomic contexts will facilitate a better understanding of the ideological characteristics of these reforms. Of particular concern is how their vision, or imagination, of the relations between scientific labor and broader socioeconomic phenomena, informs their recommendations for reforming the education and training of future scientists. Similarly important is coming to understand how the relations between scientists are to be constructed or reconfigured through these reforms. As such, the critical, historical, and materialist contributions of Althusser on the relationship of ideology and science will guide the analysis of the key findings in these reform documents.

V. Findings and Analysis

In order to understand how socioeconomic ideology guides the development of education reform, one must trace the historical development of educational practice. The beginnings of interdisciplinary science graduate education as a program of national interest can be traced to the publication of a report titled *Science, Technology, and the Federal Government: National Goals for a New Era* by the Committee on Science, Engineering, and Public Policy (COSEPUP, 1995), an assembly of National Academies experts that report to the science advisor for the U.S. President. Originally published in 1993, the report recommended and modeled a framework for federal policy to support science and technology research and development, which included initiatives to enhance graduate education in science and engineering (COSEPUP, 1995). As a follow up to the desired educational initiatives, the U.S. National Academy of Sciences, the National Academy of Engineering & Institute of Medicine authored a report titled *Reshaping the Graduate Education of Scientists and Engineers*, which provided in part a justification for the creation of interdisciplinary graduate training programs to prepare U.S. graduate students in science and engineering for what was considered to be a changing career landscape in the context of globalization (COSEPUP, 1995). Importantly, the document emphasizes the impact that graduate education has on the “broader national goals of technological, economic, and cultural development” within the United States, and that graduate students in science and engineering will play a major role in navigating the economic and environmental challenges of the twenty-first century as they transition into their professional life (COSEPUP, 1995, p. 1). Providing security for the careers and professional lives of future scientists in light of changing social and economic circumstances is a major focus of the content in this publication.

Another point of emphasis in the document is that the purpose of graduate education in science and engineering has remained undefined, and the nature of the education is typically a secondary factor of how money is allocated through larger research and development funding initiatives. Interestingly, the report also lends itself to criticizing the overemphasis of graduate education on preparing students for careers in academic settings, since at the time of publication more than half of doctoral graduates ended up working outside of the academic research setting (COSEPUP, 1995, p. 22-23). Indeed, study considers it a major finding that “PhDs are increasingly finding employment outside universities and more and more are in types of positions that they had not expected to occupy (COSEPUP, 1995, p. 23).” Similarly, the report addresses the concerns of an oversupply of science and engineering doctorate earners relative to positions that require a Ph.D. as a symptom of shifting employment to contexts outside of the academic environment (COSEPUP, 1995, p. 65-67). Based on a survey of the conditions of graduate education in the up to the mid-1990s, the authors of the report made recommendations to broaden to options and curriculum for graduate education to allow students to gain a more diverse set of skills, to provide more and better information to graduate students about careers and developments in their field, and to develop a national policy for human resources of graduate students, including national objectives and outcomes for graduate education of scientists (COSEPUP, 1995, p. 4-8). According to the report, the common theme among its recommendations is that:

many of the job opportunities of the future will favor students with greater breadth of academic and career skills, so the universities and their partners in the graduate-education enterprise should therefore cooperate to broaden curricular options for graduate students (COSEPUP, 1995, p. vi).

Overall, the report aligns itself with the idea that graduate education ought to be more compatible with the interests of centers for research and development that are extraneous to academic settings, including industry, research institutes, and national laboratories. This is important to consider in light of Althusser's (2011) contributions on the role of *practical ideologies* as the governor of the practices and rituals that define the relations of individuals in social order, especially when subject to market forces within the capitalist system. Likewise, the perception of new economic realities, in terms of shifts in the market for scientific labor, fuels the imagination of an ideal arrangement of training for new professional scientists, in the hopes that such an arrangement will fall in correct alignment with the nature of this economic reality, thus promoting the social reproduction of these professionals in changing systemic circumstance.

Emphasis on broadening education in order to mold its compatibility with industrial pursuits is characterized throughout the report as a key function of interdisciplinary graduate education. Addressing concerns about economic symptoms of falling demand for scientists with doctoral degrees in academic settings, which was beginning to accelerate in the 1990s in relation to rising supply of doctoral graduates, led the authors of the report to induce skepticism about the efficacy of supply-demand models for understanding the conditions of employment for these highly-trained professionals (COSEPUP, 1995, p. 66-67). The authors appear to be addressing the perception that reduced ability for productive forces to absorb new scientific labor will have negative consequences on federal funding of existing and future research projects, which contribute a significant portion of funding for both professional scientists and graduate students. Continuing to urge caution in decision-making about funding for research based on conditions of employment, the authors cite large shifts in employment that occurred as a result of global political events surrounding the end of the Cold War, which induced increased immigration of

scientists into the United States, placing them into competition with the large volume of scientists whose careers emerged as a consequence of increase defense spending on research:

As an example of unanticipated external events affecting science and engineering employment, the buildup of physical scientists and engineers in the late 1980s stimulated by increased defense spending earlier in the decade was followed by the end of the Cold War, which reduced demand for scientists and engineers; similarly, no one could predict the immigration of experienced scientists and engineers from the former Soviet Union and eastern Europe. The intensified pressures of international economic competition have also had unexpected effects, which have led some large high-technology companies to reduce their research staffs and redirect those who remain toward more-applied research with near-term payoffs. (COSEPUP, 1995, p. 68)

Indeed, the situation characterized here resembles one that informed Althusser's critique, as problems of scientific practice have become “posed in global terms from the social point of view...problems of the material and financial conditions” that inform strategies for conducting scientific research (Althusser & Elliott, 2011, pg. 79-80). Political and economic conditions seem to be the operating framework for structuring reforms in the education of scientific professionals. Aligning the education of scientists with the considerations that define their division of labor in the workforce as a whole is a major consideration of efforts to implement interdisciplinary science graduate education.

National policy for developing interdisciplinary programs for training the next generation of scientists has been informed by the perspective that people who receive this form of training will be able to adapt to changes in the global scientific labor market. As such, many recommendations have been made throughout the past two decades by the National Academies to funding agencies to create and support the development of programs that expose students a

breadth of curriculum and training opportunities. However, it is less certain that this conception of increasing the supply of skilled scientific labor as a means to spur economic growth and innovation is grounded in the realities of the scientific labor market. First of all, the volume of U.S. scientific labor that can be absorbed by global market forces varies significantly depending on institutional capacities for hiring new scientists, the rate of production of doctorally trained scientists from outside of the United States, and the relative demand for specific technical and research capabilities of available scientific labor (Freeman, 2006; Charette, 2013). Likewise, while it can be said that a variety of occupations and industries value the competencies of scientifically trained labor, occupations in science only make up about six percent of the total U.S. labor market, and the majority of workers trained in science divert to other occupations (Carney et.al., 2011; Charette, 2013). Equally distressing, nearly sixty percent of people earning a degree in sciences, technology, engineering, or mathematics switch to careers in a different field after ten years from having earned a degree in such subjects (Charette, 2013)! Similarly, recent occupational surveys indicate that the vast majority of scientists feel that diminishing federal expenditures on scientific research has negatively affected the global competitiveness of the U.S. research enterprise, and that as a result some scientists are seeking to continue their career outside of the United States with the hopes of securing better funding opportunities (ASBMB, 2013). As such, it is difficult to understand how efforts to increase the supply of scientific labor will positively impact the competitiveness of each U.S. scientists, when the current conditions of the scientific labor market are not understood to be capable of supporting these scientists in such a way that they can engage in innovative research. Again the caveat to this assertion is that this excess scientific labor is becoming absorbed by other sectors of industry, shifting scientific labor away from research settings in general, and academic

environments in particular. There seems to be quite a disconnect between the vision of educational reformers and the conditions that a scientist searching for employment may face after earning a doctoral degree – another point for reflection on the relation of ideas to practice.

Of course, restructuring scientific labor on the basis of economic considerations holds a potentially threatening possibility that, for some policymakers, the inability to place graduate educated scientists into positions of employment could become a pretext for defunding of research that provides support for graduate students. Readers of the COSEPUP (1995) report are encouraged to consider that because there are no reliable measures of long term employment conditions for such professionals, there is no evidence that a reduction of this workforce should be induced, though mechanisms like diminished federal funding for research, in order to match misconceptions that conditions of full employment of these professionals can be created (COSEPUP, 1995, p. 68). But, despite coming to understand the difficulties of policymaking based on predictive labor calculations, a major conclusion of the report is that the lack of a definite national human-resources policy regarding the training of scientists at the graduate level has contributed to the conditions wherein graduate education is simply a byproduct of research support, and that interventions are necessary to fill this gap in structure (COSEPUP, 1995, p. 75). But, it is important to note that this intervention is explicit in its intention to divert those human resources outside of the academic environment:

In effect, human resources have been taken for granted as a byproduct of our policies for the support of research. The simplifying assumption—both inside and outside the university community—has been that *the dominant function of graduate programs is to produce the next generation of academic researchers*. It is time for a fuller recognition, by academics and policy officials alike, of the changing way that graduate education in science and engineering contributes to the wide array of *national needs*. For many of these needs, it is a career in

professional service, applied research, development, or consulting that graduates will find open to them (COSEPUP, 1995, p. 75).

Interestingly, the executive summary of the report declares that, “a world of work that has become more interdisciplinary, collaborative, and global requires that we produce young people who are adaptable and flexible, as well as technically proficient (COSEPUP, 1995, p. 2).” That the authors of the report characterize young people as a product, presumably modeled in the productive structure of education systems, to fit the needs of industry, seems to indicate that political institutions understand the function of ideological apparatuses in social reproduction. Indeed, a key driver of this to align scientific skills with the needs of the marketplace is the perception that graduate students in the sciences are becoming “too specialized (COSEPUP, 1995, p. 75).” Similarly, the discussion of modeling the management of graduate studies within the framework of human-resources indicates an intention to intervene and restructure the division of labor among these professional scientists. The critical power of the Althusserian perspective emerges once again, as the philosopher observed, “interdisciplinarity therefore remains a magical practice, in the service of an ideology, in which scientists formulate an imaginary idea of the division of scientific labour...to give them an impression of grasping an object which escapes them (Althusser & Elliott, 2011, p. 97).” In this way, these interdisciplinary science graduate education reforms seek to service an economic ideology, which permits scientific labor to be transposed between the academy, industry, research institutes, and national laboratories, according to the dictation of market forces of society under capitalism.

In 1998, as a response to the recommendations of this report, the National Science Foundation developed its Integrative Graduate Education and Research Traineeship (NSF IGERT) program to provide funding to universities seeking to form interdisciplinary science and engineering graduate programs (IGERT.org, 2014; Carney, J, et. al., 2011). Over the course of 15

years of operation, IGERT came to be described as “America’s hallmark grant program for interdisciplinary graduate training (Gamse, Espinosa, & Roy, 2013).” Since its inception, some 303 programs have been funded, with an average award size of around three million dollars, which mostly go to providing healthy stipend of around \$30,000 a year for graduate students enrolled in these programs (IGERT.org, 2014; Gamse, Espinosa, & Roy, 2013; Carney, J. et. al., 2011). As of fall 2012, NSF IGERT had provided support for about 6,700 trainees at 125 institutions (Gamse, Espinosa, & Roy, 2013).” In total, fifteen cross-cutting themes were represented in the education and research content for each NSF IGERT center: bioinformatics, biological evolution, civil infrastructure, climate change, computational science and engineering, device development, energy, entrepreneurialism, human and social dimensions of science and technology, materials science and engineering, nanoscience, neuroscience, sensing-signaling-imaging, sustainability, and water (IGERT.org, 2014). Most programs had multiple themes present in the language of their abstracts. In total, 790 themes were present in the 303 NSF IGERT programs funded between 1998 and 2013. On average, any given IGERT program abstract represented between two and three (avg = 2.6) of the fifteen possible interdisciplinary themes. Interestingly, the IGERT program with the highest number (n=9) of themes was the Natural-Human Systems in the Urbanizing Tropics hosted at the University of Puerto Rico at Rio Piedras. More importantly, the most dominant themes overall were computational science and engineering, human and social dimensions of science and technology, and sustainability. The fusion of computational science and engineering with training in a variety of other scientific subjects raises additional questions about the desired impact of these programs on the whole of the science labor market, as the development of automation in research does not necessarily bode well for the employment of specialists.

Thematic Presence in NSF IGERT (1998-2013; n=790)

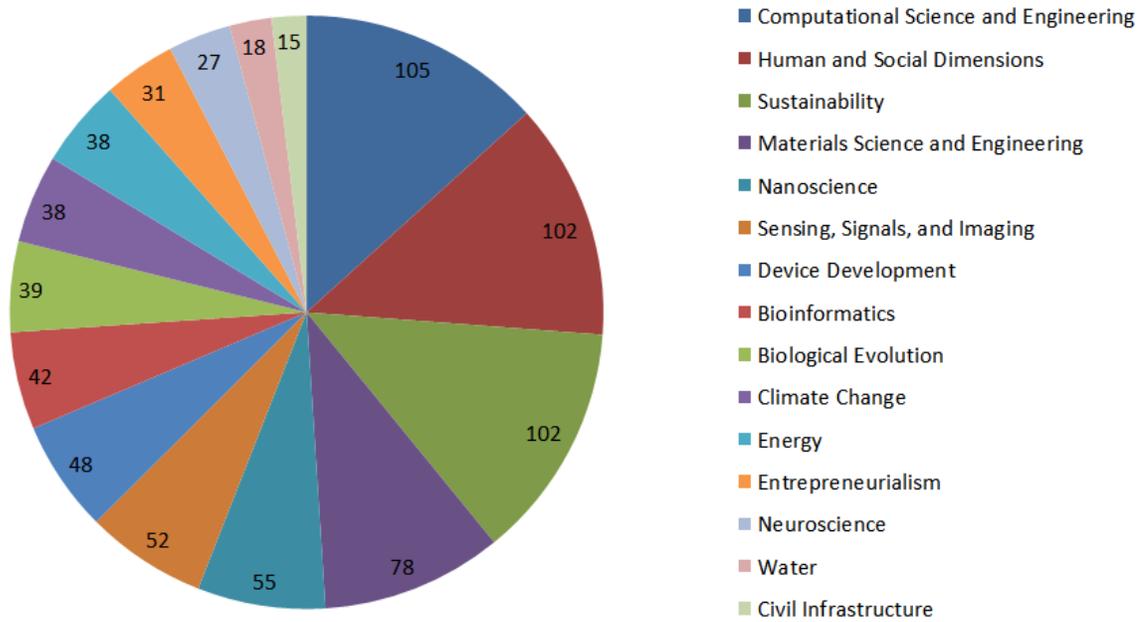


Fig 1. Thematic Presence in NSF IGERT (1998-2013)

Number of IGERT Awards per Year (1998-2013; n=303)

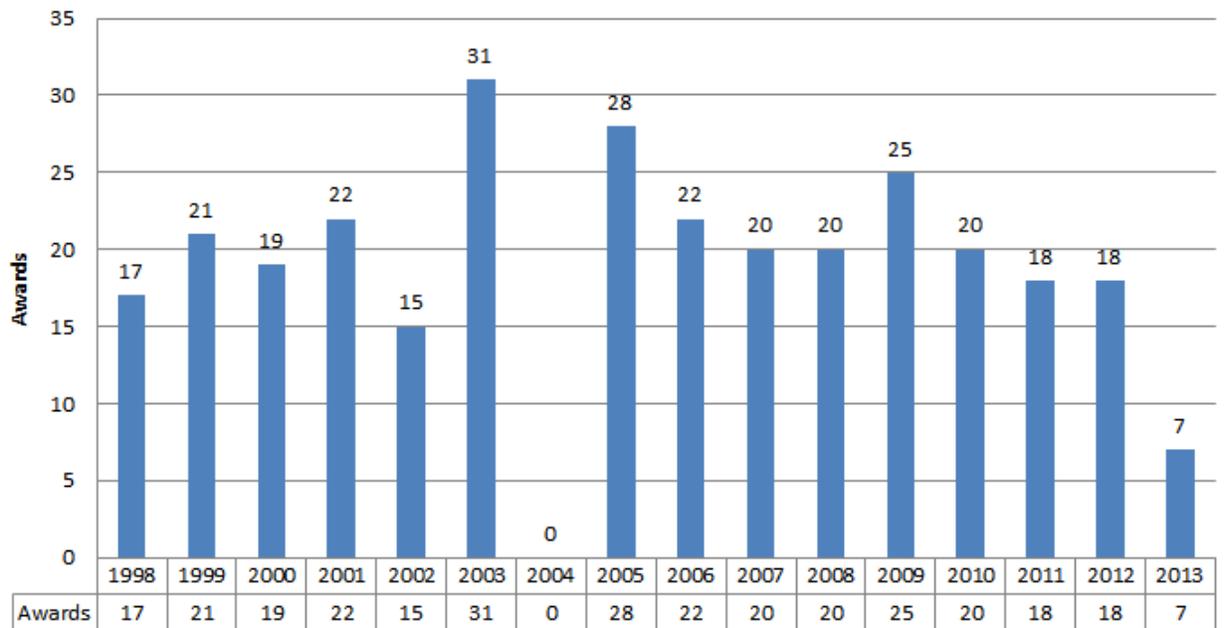


Fig 2. Number of IGERT Awards per Year (1998-2013)

To consider how the programming of NSF IGERT relates to the broader issues concerning scientific labor, it is important to understand the nature of the training received by participants in this program. An interesting effect of the structure of the NSF IGERT funded graduate programs is that the students are reported to graduate more quickly than students in traditional doctoral programs, but only by one semester (Carney, J, et. al., 2011). As the financial support is much greater than typical doctoral programs, and is closer to the equivalent of an entry-level full-time job, students in IGERT interdisciplinary programs have reported that it had the greatest impact on their abilities to complete their degrees, when compared to other factors like increased time to engage in research and access to technology (Carney, J, et. al., 2011). Students employed by an IGERT program were likely to be employed primarily research assistantship positions, thus giving them more time to engage in research (Gamse, Espinosa, & Roy, 2013). Some 82 percent of IGERT graduate students were employed in research capacities, with 35 percent of these students reported to be involved in research only (Carney, J, et. al., 2011). Also, nearly all of the students that passed through an IGERT sponsored doctoral program reported that they felt prepared to navigate the challenges of working in an environment that fostered collaboration and integration between multiple disciplines (Carney, J, et. al., 2011). Another boon to NSF IGERTs success from a purely economic perspective is that the majority of graduates from the program found employment after their doctoral work, and less than a third went on to postdoctoral programs; of those that became employed, about half found themselves working in the academy and the other half worked for industry or the government (Carney, J, et. al., 2011). Indeed, these findings indicates that the IGERT program has been quite effective in fulfilling many of the recommendations set forth by the 1995 COSEPUP document, especially in terms of shifting the location of highly trained scientific labor outside of academic settings. Once

again, this analysis conforms well to Althusser's (2011) understanding that interdisciplinarity functions as an ideological regulatory mechanism for both maintaining fluidity in the scientific labor market and achieving objectives of national economic security through inducing changes in science education practice.

In order to better develop the practice of interdisciplinary science in different research institutions, many efforts were dedicated to studying how to make just about everything in research institutions more interdisciplinary. In 2004, the National Academies' COSEPUP published another tome of a report titled *Facilitating Interdisciplinary Research* that made recommendations for best practices for conducting interdisciplinary research for universities, funding organizations, and professional societies. Funding for this report came from the W. M. Keck Foundation Futures Initiative, which was created to "stimulate new modes of inquiry and break down the conceptual and institutional barriers to interdisciplinary research that could yield significant benefits to science and society (COSEPUP, 2004)." This report included proposed models on how to best administer interdisciplinary research in a variety of settings in terms of organizing research and education structures and how to evaluate these models based on the recommendations of experts in interdisciplinary theory and the experiences of scientists at the top of research hierarchies (COSEPUP, 2004). Likewise, many of the management models that the report bases its recommendation on come from outside the university, notably from corporate and industrial research institutions (COSEPUP, 2004). Overall, these recommendations are informed by a top down perspective that is useful to administrators and executives who are looking to intervene into research practices of their institution with an aim to induce conditions of greater productivity. Wealth creation and national security ultimately inform the rationale for inducing these reforms, and the advancement of scientific knowledge for any other purpose plays

only a weak balancing role against the overwhelming economism within these political reform documents. Succinctly:

Strengthening [interdisciplinary research] is not merely a concept that is philosophically attractive or that serves the special interests of a few neglected fields. It has been vital since the creation of our great research universities—and critical during times of national emergency. It has led to major *new industries* and opened up the world to the *creation of wealth*, to international collaboration, and to enhanced technology and scientific exchange (COSEPUP, 2004, p. 22).

An entirely impotent understanding of philosophy or history of science reigns high in these reform documents as well, given the incoherent explanations given for seemingly major ruptures in the constitution of certain sciences. For instance, the authors of the document declare that “biochemistry was long ago considered an interdisciplinary activity; today it has departmental, program, or similar structural status in most major universities” with no other account for this epistemological shift, other than through the magical mechanism of interdisciplinarity (COSEPUP, 2004, p. 33). This tautological statement might as well have been refined to state “history has happened” and left the matter alone.

Despite the success of the NSF IGERT program in training graduate students for careers across private, public, and academic sectors, continuing shifts in global political and economic conditions since the beginning of the twenty-first century have changed the dynamics of public expenditures into science research, and thus science graduate education. Indeed, despite the alarms of economic urgency sounded by national institutions for the better part of two decades alongside recommendations for navigating these conditions, heightened concerns about the state of affairs for science and technology in the United States abounded. In 2007 members of the National Academies COSEPUP reconvened as the Committee on Prospering in the Global

Economy of the 21st Century to author a report titled *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, in order to make further policy recommendations based on heightened concerns that conditions of weakened “science and technology in the United States would inevitably degrade its social and economic conditions and in particular erode the ability of its citizens to compete for high-quality jobs (CPGE21, 2007, p. vii).” Foreshadowing the nationalistic ideological narratives contained within the document, the cover is illustrated with a United States flag positioned underneath a dark brewing storm. Confirming that ideology indeed informs recommendations for reform, the report begins with a lengthy discussion of the state of global political and economic conditions described by the popular, supposedly nonfiction, book, *The World Is Flat*, by New York Times writer Thomas Friedman (CPGE21, 2007). To open the chapter titled “A Disturbing Mosaic,” the CPGE21 committee hails Friedman’s vision of global society based on fierce economic competition between nations:

[D]espite the dangers [of globalization], a flat world is on balance a good thing—economically and geopolitically. Lower costs benefit consumers and shareholders in developed countries...[whose] rising middle class will have a stake in the “frictionless” flow of international commerce—and hence in stability, peace, and the rule of law. Such a desirable state... will not be achieved without problems, and whether global flatness is good for a particular country depends on whether that country is prepared to compete on the global playing field, which is as rough and tumble as it is level. (CPGE21, 2007, p. 1-1).

The contradictions – a simultaneously dangerous and peaceful world, global competition in which all ultimately win, the stability of dynamics – are staggering, if not entirely frightening that any scientist, much less a body of scientists, would give even an iota of consideration to any argument premised upon the flatness of the globe. Equally disconcerting, the committee flatly

declares that any expectation of having a high quality of life in the United States is characterized as “circl[ing] the wagons to defend [a sense of] entitlement,” and this vision is not compatible with the need for reforming education to produce a competitive national workforce (CPGE21, 2007)! Equally peculiar, diminished funding for public education is characterized in this report as something based changing views of all of the whole nation towards favoring higher education as a private good, rather than as the result of specific actions taken by powerful political and economic agents (CPGE21, 2007). Similar to the other National Academies documents reviewed in this research, science is characterized not as an enterprise for constructing knowledge, but as “a principal means to creating new jobs for our citizenry as a whole in this global marketplace of the 21st century (CPGE21, 2007, p. 1-16).” The report emphasizes that, amongst other issues, without major improvements into graduate research and education curricula, there will be a shortage of professionals with the technical knowledge required to operate and expand the U.S. economy in the wake of an economic recession (CPGE21, 2007). Based on such conclusions, the committee made recommendations for providing expanded funding to research institutions in order to address these concerns of maintaining national security and stability in the wake of global socioeconomic and political changes (CPGE21, 2007). Additionally, recommendations are made for funding graduate students to pursue education and research in fields of science and technology related to these national interests (CPGE21, 2007, 7-5). The shift in focus from developing career fluidity for new professional scientists in a changing global economy, to working for national interests in a in a changing global economy, reflects shifts in the socioeconomic ideology driving graduate science education reform.

Three years later, members of the original committee met again to author a follow up report to the initial *Rising Above the Gathering Storm* document titled *Rising Above the*

Gathering Storm Revisited: Rapidly Approaching Category 5 (explored the conditions of the continuing global and national economic slump in terms of federal investments into science and engineering research. The report concluded that, despite the short term improvement in the economy provided by the American Recovery and Reinvestment Act and the America COMPETES act, the U.S. economy still faced serious challenges to a full recovery, in part because of the failure of the federal government to fully invest in the recommendations pushed in the original assessment (Rising Above the Gathering Storm Committee, 2010). In terms of the initial recommendations regarding the expansion of graduate education programs to fund 5,000 new graduate fellowships, the follow up report concluded that the only progress on this initiative was the continued funding of the NSF IGERT program up to that point (Rising Above the Gathering Storm Committee, 2010). No other initiatives were listed for fulfilling recommendations to increase the total number of graduate students with advanced science and engineering backgrounds (Rising Above the Gathering Storm Committee, 2010). Since then, the Committee of Science, Technology, Engineering, and Math Education (CoSTEM), part of the National Science and Technology Council to the executive branch was formed by the America COMPETES Reauthorization act of 2010 in order to undertake further initiatives to reform STEM education from K-12 to the collegiate level with the hopes of improving the economy (CoSTEM, 2013). Regarding graduate education, CoSTEM is charged with determining national goals of federal agencies to correspond with the mission of “graduate-trained STEM professionals with basic and applied research expertise, options to acquire specialized skills in areas of national importance, mission-critical workforce needs for the CoSTEM agencies, and ancillary skills needed for success in a broad range of careers (CoSTEM, 2013).”

The effects of the recommendations from executive branch committees and other

stakeholders in scientific enterprises that the federal government fund more graduate fellowships for research on items of national interest are starting to emerge. Despite expectations from many those embedded in the IGERT program that the program would continue to be funded (IGERT.org, 2014), as of early 2014, the National Science Foundation has discontinued accepting applications for funding IGERT programs (NSF, 2014). In its place, the NSF has announced in 2014 will fund NSF Research Traineeships (NRT), designed to “ensure that graduate students develop the skills, knowledge, and competencies needed to pursue a range of STEM careers (NSF, 2014).” Echoing the ideological discourses on the effects of globalization on scientific labor and the urgency of developing national competitiveness in light of these changes, this funding solicitation is meant to address:

[T]he accelerating pace of science discovery and technological innovation, *national STEM workforce trends*, the growing *internationalization of science*, and the unrealized potential to align graduate education practices and models with increasing understanding of how people learn. The increasing calls for new approaches to STEM graduate education, which are from *all sectors and stakeholders*, also represent an extraordinary opportunity. Accordingly, this solicitation encourages proposals to develop, implement, and scale-up innovative and effective STEM graduate training models and practices, while fostering fundamental research advances *in support of national priorities*. (NSF, 2014).

Equally intriguing, a distinguishing feature of the NRT program is that it will supposedly rotate along different themes every two or three years, unlike IGERT which accepted proposals from a variety of themes simultaneously (NSF, 2014). Unsurprisingly, considering that computational science and engineering was the most dominant theme in the IGERT program, the initial thematic interest of the NRT program is Data-Enabled Science and Engineering, also other interdisciplinary proposals will be considered (NSF, 2014). Conforming to the desired material

effects of evoking interdisciplinary ideology as expressed in the multitude of political documents that preceded the development of NRT:

Strategic collaborations with the *private sector, non-governmental organizations (NGOs), government agencies, museums,* and academic partners that enhance research quality and impacts and that facilitate development of technical and transferrable professional skills are encouraged (NSF, 2014).

Once again, the displacement of scientific labor into environments outside of the academy in order to support national socioeconomic interests remains a major thrust behind interdisciplinary programming. Likewise, the change in discourse within NSF graduate education funding solicitations from concerns about the general employment of individual scientists within shifting national workforce needs, to the broader consideration of how the employment of these individual scientists within the nation effects the overall position of the United States in the globalized world, reflects the need of state support structures to align their discourse with dominant socioeconomic ideology expressed in national political literature in order to avoid defunding or termination.

VI. Conclusions

This critical inquiry into the recent history of interdisciplinary graduate science education in the United States has revealed much about the character of socioeconomic ideology present in the discourse of reform policy documents associated with the development of national programs to provide this training. While the development of the National Science Foundation's Integrative Graduate Education and Research Traineeship represents a highly visible instance of graduate education reform informed by an attempt to reconcile institutional and the economic realities, inquiry into the history of the program has revealed that ideology and graduate science education reform are mutually constitutive. Propositions for these reforms are based in socioeconomic ideological discourse, with special concern paid to the changing conditions of the global scientific labor market, in order to better serve the needs capitalist market order with the nation. The guiding presumption in these reforms is that the structure of graduate science education should conform to the skills needs of the scientific labor market, which is to say that education exists to serve the interests of the capitalist market economy. The major finding of this study is that the political documents associated with the promotion of interdisciplinary science graduate education reforms make explicit the perceived need to shift the location of scientific labor to locations outside of the academy - specifically into both private research entities, like corporations and industry, and governmental research institutions like national laboratories. As such, a key function of interdisciplinary science graduate education reform is to intervene into the division of scientific labor, in order to make it more compatible with the socioeconomic ideology of experts and policymakers who are tasked with securing national interests. Similarly, it is unsurprising that so much research into interdisciplinary graduate programs has made effective administration and scientific management of students and faculty a top priority, with

aim to develop a human resources approach to education. Such a focus on developing best practices for facilitating the achievement of programmatic outcomes, likely a side effect of competitive efforts to secure funding, has led to a lack of critical inquiry into the development of interdisciplinary science graduate education.

Considering the changes in interdisciplinary science graduate education as a factor of shifting national interests is particularly interesting, because it seems that both the socioeconomic and interdisciplinary ideology expressed in the reform documents associated with the development of NSF IGERT remained constant through its termination and the development of the new NRT program. This is especially intriguing considering that the full-scale assessment reports that the National Science Foundation contracted external research agencies to conduct on IGERT seem to indicate that it was fairly successful in fulfilling many of its goals. Indeed, providing a breadth of training content, like fusing technical content knowledge in computational or materials science and engineering with other disciplines, or through exposure to issues of science and society or communications, seemed to fair well for the careers of students who matriculated through NSF IGERT programs. This is especially true for the substantial number of these trainees that were not limited to finding careers in academic settings after earning their doctorates. Indeed, harkening back to Althusser (2011), the real restructuring that has taken place through the implementation of these reforms can be located in the division of labor among scientists, in terms of moving scientific research labor outside the university. So, while the socioeconomic ideology politicians and reformers had expanded to the level of national interests in a globalized society, interdisciplinarity remained the primary ideological driver for intervening into the structure of scientific enterprise by reconfiguring the division of scientific labor to better serve these interests.

In addition to developing a critical and historical perspective on the rise and fall of NSF IGERT, a major goal of this research was to explore the relations between ideology and science in order to inform a deeper critique of interdisciplinary science education reform. The recently translated contributions of Louis Althusser on the philosophy of science and ideology of interdisciplinarity, in addition to his classically referenced texts on ideology, have proven indispensable to examining this issue. Indeed, these works ought to be integrated into surveys of critical educational studies, as the theoretical maturity and sharpness of critique present in his lectures is in total contrast with the superficial and administrative concerns of much of the literature on interdisciplinary science education reform. In coming to terms with the real relations of science to ideology, Althusser's theoretical model, which was based in part through interpreting similar historical events surrounding interdisciplinary science education in France, corresponds well with what has been observed in the historical development and replacement of NSF IGERT. The revelations that ideological and scientific processes are demarcated in character, that ideology informs practical and ritual affairs in social order, and that ideology can be located in moments of intervention into social structures, such as the division of labor, are all crucial contributions in how critically interpreting how ideology drive education reform. This is very much a rebuke of how Habermas in particular came to conflate science and technology as depoliticized, entirely rationalist ideology, which superseded conflicts over labor and resources as the dominant ideological organizer of society, through devising technical solutions to problems of class struggle. In separating ideology from science, and relocating the former within the realm of the division of labor as the defining structure of social relations under capitalist market order, Althusser demonstrates the real fortitude of historical and materialist inquiry as a means for interrogating ideology. Just as his intellectual forefather Karl Marx is claimed to have

placed Hegel back onto his feet by demonstrating that material forces drove the development of history, philosophy, and science, Althusser corrects the post-Marxist critical theorists counterparts by deriving a historical and materialist conception of ideology and science. Only through keeping this orientation in perspective can scientists, science educators, and critical educators come to understand how our existence is shaped by larger social forces, such as education reform movements and shifts in dominant ideologies in the wake of globalization.

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