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The Role of Interdisciplinary Scholarship and Research to Meet the Challenges Facing Agriculture in the 21st Century

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THE ROLE OF INTERDISCIPLINARY SCHOLARSHIP AND RESEARCH TO MEET THE CHALLENGES FACING AGRICULTURE IN THE 21ST CENTURY

by

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THE ROLE OF INTERDISCIPLINARY SCHOLARSHIP AND RESEARCH TO MEET THE CHALLENGES FACING AGRICULTURE IN THE 21ST CENTURY

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Throughout human history, scientific advancements have increased our understanding of the physical world. However, as our breadth of knowledge has increased, scholarship and research have become increasingly more specialized in order to add to the body of knowledge. University structures encourage this specialization through disciplinary learning and discovery. Although this model is necessary to continue growing the body of knowledge, the complex issues facing humanity, especially in regards to agriculture, require solutions that no single discipline can provide. These issues require an interdisciplinary approach to integrate the insights across multiple disciplines. Interdisciplinarity can be achieved through collaborative processes, but these efforts are often difficult because of epistemological differences among individuals from various disciplines. Another alternative model is the role of an interdisciplinary generalist that has a broader understanding across disciplines.

Agricultural interdisciplinary generalists are being trained to become professional plant practitioners at two universities in the United States, the Doctor of Plant Health program at the University of Nebraska – Lincoln and the Doctor of Plant Medicine program at the University of Florida. The objective of this paper is to provide further insight into the role of interdisciplinary scholarship and research as it pertains to

agriculture, and present the professional plant practitioner as a new profession to help meet the complex challenges currently facing agriculture.

Chapter 1 of this document focuses on the available literature associated with interdisciplinary scholarship. Chapter 2 presents the challenges facing agriculture and how interdisciplinary research is needed to address them. Finally, Chapter 3 describes the DPH and DPM programs and how interdisciplinarian plant practitioners fit into the challenge. Alumni from these programs and their employers were surveyed to evaluate the effectiveness of the degree programs. These programs are unique in their mission, and the graduates they are producing are filling roles in academia, industry, and government. Graduates reflect positively on their training and employers praise their abilities to perform in various positional roles. The biggest disservice to both programs is the overall lack of recognition by potential employers. To remedy this, graduates are gaining employment in high-level agricultural jobs and performing exceptionally. As the number of graduates continues to grow, the impact of professional-level agricultural interdisciplinary generalists will be realized in solving the challenges facing agriculture in the 21st century.

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PREFACE

I began my studies in the Doctor of Plant Health (DPH) program at the University of Nebraska – Lincoln with a different background than most graduate students entering an advanced degree program. It had been eight years since the last time I had been in college, during which time I had the opportunity to shape my understanding of the challenges facing agriculture by working directly with growers as a sales agronomist. Agriculture is a dynamic endeavor and I realized that to be an effective agronomist or any person who wished to make a significant impact on food production systems, I needed to elevate my knowledge in all of the disciplines that impact agriculture.

I entered the DPH program with great enthusiasm for the opportunity to continue my education, engage in scholarly activities that would challenge my thinking, get experience working in field research, and elevate my ability to communicate with growers through extension. That enthusiasm has not diminished in the past three years, but rather has grown with the realization that I am better equipped to contribute to the field of agriculture upon graduation because of the unique skill set I achieved through the DPH program.

Throughout my studies, I became interested in the transfer of knowledge. This is not just in the classroom from teacher to student, but in science policy from scientist to policy-maker, in extension from researcher to farmer, and in research settings among colleagues with different disciplinary specialties. I began to seek out opportunities to serve as a teaching assistant. I have now served as a teaching assistant for four courses in three disciplines, and eventually created my own course. I began to understand the challenges involved with engaging students and creating an environment that would help them transmit practical information gained beyond the classroom.

There are significant disciplinary boundaries between classes, and chances to engage in thought that bridges those disciplines happen, unfortunately, very infrequently. Having experienced the interdisciplinary nature of commercial agriculture and chosen to return to school to pursue an interdisciplinary degree, I became interested in learning about the pedagogy of interdisciplinary scholarship and how it might meet the challenges that we are facing in agriculture today. Chapter 1 of this document focuses on the available literature associated with interdisciplinary scholarship.

For my first DPH internship I had the opportunity to develop a website for summarizing current University of Nebraska research relating to soybeans so growers could access and benefit from the research results. This was another excellent opportunity to think about how information is transferred from the researcher to the end user. It was also an opportunity to engage in synthesis and communication of interdisciplinary research, involving plant pathology, entomology, weed science, soil science, genetics, and cropping systems.

A calendar format was created to best deliver this information to growers for their most effective implementation. Research reports were summarized, and much of the information currently housed in UNL's CropWatch was centralized so that growers could intuitively access university research in a timely manner to effect change in their own operations. I envisioned this as the essence of interdisciplinary scholarship – to conduct research studies, attain novel information, synthesize the information within an interdisciplinary context, communicate the outcome, and then expedite its **application** for positive change. Although it is often stated that the DPH program is not a research degree, I would argue that we have the ability to gain experience in numerous research projects, but also have the unique opportunity for independent synthesis to interpret how the research can be most effectively applied. This is critical as researchers in industry and academia confront the multi-faceted challenges facing agriculture today. Chapter 2 describes these challenges and how interdisciplinary research is needed to address them.

It is important to clarify that interdisciplinary research may not arise from the lab bench or greenhouse, but will often depend on field research conducted in unpredictable environments where diverse parameters interact. This concept was further supported by my opportunity to work on numerous extension projects during tenure at the university. There were opportunities to conduct herbicide screening, cover crop termination studies, and crop scout trainings and use small research and demonstration plots to transfer knowledge to growers; growers who ultimately would be able to affect change in agriculture. Such applied research should not be minimized as we turn toward solving some of the most daunting challenges ever to face agriculture.

I am certain that the need for interdisciplinarians is critical to advancing agriculture as we move further into the 21st century. To address this, Chapter 3 describes the DPH and Doctor of Plant Medicine (DPM) programs and how interdisciplinarian plant practitioners fit into the challenge. These programs are unique in their mission, and the graduates they are producing are filling roles in academia, industry, and government. Therefore, for each of the interdisciplinary programs, surveys of alumni and their employers were undertaken. Graduates reflect positively on their training and employers praise their abilities to perform in various positional roles.

The biggest disservice to both programs is the overall lack of recognition by potential employers. Additionally, although employers are pleased with their hires, the general public still does not know that the programs exist, let alone the capabilities of the graduates. Even those who hear about the program struggle with the concept because it breaks from the traditional academic path. To remedy this, graduates are gaining employment in high-level agricultural jobs and performing exceptionally. As the number of graduates continues to grow, the impact of professional-level agricultural interdisciplinary generalists will be realized in solving the challenges facing agriculture in the 21st century.

CHAPTER 1

Interdisciplinary Scholarship

Defining Interdisciplinarity

The concept of interdisciplinarity is not new. At its core, interdisciplinarity focuses on integration, synthesis and connection of ideas, an ideal that dates to ancient philosophy (J. T. Klein, 2005). However, the meaning of the term and the goals of interdisciplinary scholarship must continually be revisited. It is important to start with clear definitions of what interdisciplinarity and interdisciplinary studies are and why they are important in the current knowledge economy.

The concept of integration was formally used to convey the relationship of subject matter in the mid-1800s, several decades before the term interdisciplinary was used. Klein (2005) mentions books of this time by Herbert Spencer (1855) and William James (1897) on the principles of psychology, as well as the theory of integrated instruction by Alexis Bertrand (1898) as early examples that discussed integration. These references focused on the learning process and the science of education. Regarded as the founder of pedagogy as a discipline, Johann Friedrich Herbart (1776-1841) also realized the importance of the connectedness of ideas. By acknowledging that ideas can either “fuse, combine, or repel one another” based on their similarity, Herbart noted that the order of the presentation of ideas is important to ensure “ideas combine to form the strongest possible unities” (Chambliss, 2013).

The first use of the term interdisciplinary is thought to have occurred in the mid-1920s. The US Social Science Research Council coined the term to characterize research that crossed multiple professional societies within the Council (J. T. Klein, 1996). It was later cited by *Webster’s Ninth New Collegiate Dictionary* and *A Supplement to the*

Oxford English Dictionary in reference to a 1937 issue of the *Journal of Educational Sociology* (Grigg, 1999).

Table 1.1: OECD definitions of terminology for cross-disciplinary scholarship and research, adapted from Apostel (1972).

Discipline	A specific body of teachable knowledge with its own background of education, training, procedures, methods and content areas.
Multidisciplinary	Juxtaposition of various disciplines, sometimes with no apparent connection between them, e.g.: music + mathematics + history.
Pluridisciplinary	Juxtaposition of disciplines assumed to be more or less related. e.g.: mathematics + physics, French + Latin + Greek.
Interdisciplinary	An adjective describing the *interaction* among two or more disciplines. This interaction may range from simple communication of ideas to the mutual integration of organizing concepts, methodology, procedures, epistemology, terminology, data and organization of research and education in a fairly large field.
Transdisciplinary	Establishing a common system of axioms for a set of disciplines (e.g. anthropology considered as "the science of man and his accomplishments").

In September 1970, the Organization for Economic Cooperation and Development (OECD) held the first international seminar on interdisciplinarity and put forth a landmark report titled *Interdisciplinarity: Problems of Teaching and Research in Universities* (Apostel, 1972). This report serves as a foundation for subsequent research and discussion about interdisciplinary scholarship and research. In the report, definitions were established to clarify terminology and concepts (Table 1.1).

Although these definitions were critical to coalesce educators and researchers around a common vernacular, there still remained confusion as interdisciplinary studies began to grow. Richard Meeth (1978) addressed the confusion surrounding definitions in regards to scholarship by describing an “interdisciplinary pyramid.” The base of the pyramid is disciplinary studies, followed by cross disciplinary, which is defined as viewing one discipline from the perspective of another. Implementing cross disciplinary programs is relatively easy because it does not require faculty to operate outside of their own disciplines. The next level of the pyramid is multidisciplinary, whereby several disciplines focus on a common problem. Although there are multiple disciplines working on the problem, there is no integration among disciplines. Interdisciplinary is the next level of the pyramid and differs from multidisciplinary in the integration of several disciplines to solve a problem. Integration in the context of interdisciplinary studies means “bringing interdependent parts of knowledge into harmonious relationship” (Meeth, 1978). Finally, transdisciplinary programs approach a problem irrespective of the disciplines involved. Only after the problem has been identified and the problem solving process has begun are the disciplines needed to solve the problem identified and investigated. This is the most difficult type of program to teach because it centers around problem solving, and faculty must be comfortable across a broad range of disciplines and theories (Meeth, 1978).

It is evident that even late into the 20th century there was still confusion about defining interdisciplinarity and how to structure interdisciplinary courses and programs in a university setting. Earl McGrath (1978) took great exception to the use of the term interdisciplinary in educational settings as he stated that integration was rarely provided. He reviews several programs that attempted interdisciplinarity for various reasons, not the least of which being a concession to pressures from prominent educational figures at the time. Although colleges were implementing interdisciplinary courses, he states that most, in fact, “involved no real merging of subject matter except in the catalog” and “represented no new consideration of the purposes of a college education in terms of the needs of today’s world” (McGrath, 1978).

With the ensuing conflict surrounding the establishment and development of interdisciplinary studies, the Association for Integrated Studies was founded in 1979 as a professional association devoted to interdisciplinary scholarship. The name was changed in 2013 to the Association for Interdisciplinary Studies (AIS) to more accurately reflect the mission of the association and the current understanding of interdisciplinarity, both within the United States and abroad. According to AIS, their mission is to “[promote] the interchange of ideas within a diverse community of scholars, teachers, administrators, and the public regarding interdisciplinarity and integration” (AIS, 2014). Initially, they were focused on defining interdisciplinary studies, and according to William Newell (2013), “[distancing] AIS from those who purported to engage in interdisciplinary teaching without integration.”

One of the key features of the association was the annual conferences they hosted at institutions with interdisciplinary programs. The conferences were an arena for participants to listen to other educators and interdisciplinarians and to collaboratively work through issues regarding interdisciplinary studies (AIS, 2014). Additionally, the association began sponsoring the publication of books devoted to interdisciplinary studies, including: *Interdisciplinary Undergraduate Programs: A Directory* (1986/1996); *Interdisciplinarity* (1990); *Interdisciplinary Studies Today* (1994); *Interdisciplinarity: Essays from the Literature* (1998); *Interdisciplinary General Education* and *Interdisciplinary Education: A Guide to Resources* (1999); *Innovations in Interdisciplinary Teaching* (2002); *Interdisciplinary Education in K-12 and College* (2002); *Becoming Interdisciplinary* (2005); *Interdisciplinary Research* (2008); and *Disciplining Interdisciplinarity* (2009) (AIS, 2014).

William Newell served as the first president of the association in 1980 and has served in the capacity of Executive Director (called the Secretary-Treasurer prior to 1993) since 1984 (AIS, 2014). With the help of William Green, they published the first article to present the seminal arguments that evolved from discussions within AIS. They stated that there were four issues that needed to be resolved before the field of interdisciplinary studies could "acquire the status" that supporters believed it deserved – define what interdisciplinary means, establish the objectives of interdisciplinary studies, establish canons of scholarship to judge excellence, and determine what the appropriate relationships are between interdisciplinary studies and academic disciplines (Newell & Green, 1982).

Even after the previous attempts to define interdisciplinarity, Newell and Green (1982) argued that the term interdisciplinary studies is used loosely and inconsistently; and, frequently used to label any course that does not align within a disciplinary department. This issue has not subsided as Manathunga et al. (2006) say that the term is at risk of becoming an empty buzzword because of its overuse. But they quote Klein et al.

(2001) to affirm that the term “interdisciplinary studies” is actually “saturated with meaning.”

In explaining the reason for the confusion regarding the definition of interdisciplinary studies, Newell and Green (1982) argue that disciplines themselves are often poorly defined. Disciplines may be defined based on their subject matter, method, perspective, or the questions they ask. They define a discipline as a “sociopolitical organization which concentrates on a historically linked set of problems.” It is telling that they perceive disciplines through the purview of an underlying problem or set of problems, as this is the typical mindset when addressing complex problems through interdisciplinarity. Rather than focus on advancing the knowledge within a discipline, disciplines are identified that are required to address the problem or challenge.

Newell and Green (1982) defined interdisciplinary studies as “inquiries which critically draw upon two or more disciplines and which lead to an integration of disciplinary insights.” Although Meeth (1978) had mentioned integration in his interdisciplinary pyramid four years earlier, he stated that integration merely meant bringing parts of knowledge from different disciplines together into a “harmonious relationship.” Newell and Green specify that the integration is not just of knowledge from different disciplines, but of the insights gained from the different disciplines. The goal of this distinction is to prevent the further misuse and overuse of the term.

Newell and Green (1982) enforce the importance of integration by discussing the significance of disciplinary insights. They deem that it is necessary to understand and appreciate the disciplines involved in answering a question to know whether the disciplinary insights are interdependent and “mutually enriching.” Only when the complexity of the relevant disciplines is fully realized and there is a "conciliation and integration of disciplinary insights…[can] the art of interdisciplinary inquiry…[be] fully realized."

Through the years, the definition of interdisciplinary studies has continued to be discussed and restated, but the underlying definition has persisted. Lattuca (2002) suggests that interdisciplinarity exists on a continuum, from informal communication between disciplines on one end to formal collaborations in research and teaching projects on the other. Ivanitskaya et al. (2002) emphasize the integration of knowledge from different disciplines across a "central program theme or focus." Even Newell (2001) restated his definition to conclude that "interdisciplinary study draws insights from relevant disciplines and integrates those insights into a more comprehensive understanding." Integration remains the ultimate characteristic of any definition relating to interdisciplinarity and must be the focus of interdisciplinary studies.

Why Interdisciplinarity

With the pains that have been endured to simply define interdisciplinary studies, is the pursuit worth it? Advocates for interdisciplinary studies certainly argue that it is, and a growing body of educators, researchers, philosophers, and policy-makers agree.

It is often argued that the challenges and problems that face society today require solutions drawn from multiple disciplinary insights (Newell & Green, 1982). However, it could be argued that throughout human history, mankind has continually been challenged to solve problems with broad scopes. Certainly great philosophers, inventors and scientists of the past like Plato, Leonardo da Vinci, and Albert Einstein, helped to solve far-reaching problems that faced society during their times. It is plausible, then, to concede that the problems facing society today are no broader than they have been in the past, so why is the focus on interdisciplinarity seemingly greater today than ever before?

A possible answer to this question is the vast quantity of knowledge that has been accumulated by mankind and the ability, or inability, to process and assimilate it. Before the 19th century, genuine scholars were considered individuals that were "familiar with the sum total of humanity's intellectual and artistic output" (Nissani, 1997). However, as the "sum total" knowledge of humanity continued to increase, it became impossible for individuals to retain a level of expertise across all knowledge arenas.

Focusing specifically on scientific knowledge, Simonton (2013) supports this argument in his provocatively-titled article, *Scientific Genius is Extinct*. Simonton is a psychology professor that studies scientific genius and claims that geniuses have influenced science in one of two ways – "they have founded new scientific disciplines" or they have "revolutionized established disciplines." He harkens notable scientists like Galileo who created telescopic astronomy and Charles Darwin who challenged Creationism with evolution.

However, with the breadth of understanding of the physical world, will contemporary scientists impact scientific disciplines in the same way? The knowledge created today is deeper within set disciplines with known basic tenets and principles, not novel doctrines. Simonton eloquently summarizes this based on his studies:

> "[In] my view, neither discipline creation nor revolution is available to contemporary scientists. Our theories and instruments now probe the earliest seconds and farthest reaches of the Universe, and we can investigate the tiniest of life forms and the shortest-lived subatomic

> particles. It is difficult to imagine that scientists have overlooked some phenomenon worthy of its own discipline alongside astronomy, physics, chemistry and biology. For more than a century, any new discipline has been a hybrid of one of these, such as astrophysics, biochemistry or astrobiology. Future advances are likely to build on what is already known rather than alter the foundations of knowledge" (Simonton, 2013).

With Simonton's perspective on scientific knowledge and the breadth of understanding of the physical world, it is difficult to accept that the problems facing humanity today are so great. If our basic understanding of the world is so deep, how can current problems require such great effort? Is John G. Kemeny wrong when he states that there is a need for "individuals who are capable of integrating the knowledge of many disciplines in a single mind" (Newell & Green, 1982)? What about Graham Riley's claim that "never more than at the present time has there been a need for citizens to be able to focus the insights of various disciplines on the problems and issues which beset our collective existence" (Newell & Green, 1982)?

Additionally, why was there a need to create the Association for Interdisciplinary Studies, or the emphasis placed on interdisciplinary scholarship through the establishment of the Integrative Graduate Education and Research Traineeships (IGERT) program by the National Science Foundation (NSF). The goal of this program is to "educate U.S. Ph.D. scientists and engineers with the interdisciplinary backgrounds, deep knowledge in chosen disciplines, and technical, professional, and personal skills to become, in their own careers, leaders and creative agents for change" (Carney, Chawla, Wiley, & Young, 2006).

Are the advocates for interdisciplinarity misguided? I submit that the answer is quite to the contrary. It is precisely the scenario that Simonton described that has created the need for interdisciplinary studies. Our level of understanding of the physical world is so deep, that scholars are required to focus on narrower and narrower competencies to be considered experts in the field. And as disciplinary understanding continues to grow, specialties within disciplines grow until scientists and scholars are no longer experts in a field, but rather experts of a singular specialty within a discipline.

University systems have flourished under this model of disciplinary segregation, but as a result, the fragmentation of knowledge has grown in the academic world (Brewer, 1999). Weick (1976) discusses the risks associated with this model of educational organization by describing it as a loosely coupled system. The networks and interdependencies can be reduced to the point where the loosely coupled system could become uncoupled (Kurland et al., 2010; Orton & Weick, 1990). In regards to addressing interdisciplinary problems, this level of compartmentalization is certain to make collaboration among disciplines very challenging.

These comments are not meant to be viewed as disparaging towards the academy, but rather to draw attention to potential shortcomings of, or gaps in, the current system. The current university structure has been critical for the growth of scientific knowledge, but the problems being faced by the "real world" do not always separate neatly into disciplines (Wolman, 1977). Likewise, the nature of complex systems in the natural world necessitate an academic pursuit that can adequately address the multiple facets associated with "real world" problems (Baker et al., 2009; Newell, 2001).

Gibbons et al. (1994) justify this need best by presenting new terminology in regards to knowledge production – Mode 1 and Mode 2. They state that "a new form of knowledge production is emerging alongside the traditional, familiar one…[and] affects not only what knowledge is produced but also how it is produced; the context in which it is pursued, the way it is organized, the reward systems it utilizes and the mechanisms that control the quality of what is produced." Differentiating these forms of knowledge production is important because we have moved into a new knowledge economy defined as "production and services based on knowledge-intensive activities…an accelerate pace of technical and scientific advance…[and] reliance on intellectual capabilities [rather] than on physical inputs on natural resources" (Powell & Snellman, 2004). Knowledge creation is based on "performative usefulness" rather than merely adhering to epistemological canons (Usher, 2002).

So what differentiates the traditional Mode 1 knowledge production from the new Mode 2 knowledge production? Mode 1 refers to "pure" research that is discipline-specific and pursued for the accumulation of knowledge. Mode 2, on the other hand, refers to research that is pursued because of applicability (Manathunga et al., 2006). Dissemination of the resulting knowledge differs as well. Mode 1 knowledge is typically disseminated through traditional means such as texts, refereed journals and conference papers, while Mode 2 is disseminated through more informal routes, such as summary reports and on-line postings. In Mode 2, there is less emphasis on distinguishing between the discovery and application, or between the discoverer and applier (Usher, 2002).

If we are in a new knowledge economy, then clearly there is a need to emphasize Mode 2 knowledge production and ensure that the constructs of the university system are equipped to promote these academic endeavors. Usher (2002) provides a table derived from Nicholls (2001) that illustrates how the understandings of academics are changing as demanded by the knowledge economy (Table 1.2).

Table 1.2: Summary of the changing understandings of academics brought on by the knowledge economy, adapted from Usher (2002).

TRADITIONAL UNDERSTANDINGS OF ACADEMICS (Mode 1)	UNDERSTANDINGS DEMANDED BY THE KNOWLEDGE ECONOMY (Mode 2)
• Research is the central endeavor and focus of academic life	• Commercialization of research is the central endeavor and focus of academic life
• Quality maintained by peer review and professional autonomy	• Quality maintained by social accountability
• Knowledge pursued for its own sake	• Knowledge pursued for its performativity
• Task of the academic is the pursuit of cognitive truth	• Task of the academic is the pursuit of knowledge in the service of innovation
• Pursuit of knowledge best organized according to disciplines	• Pursuit of knowledge best organized in a trans-disciplinary way
• Reputations established through professional activities such as publication, conference attendance and research grants	• Reputations established through links with industry
• Rewards come to those who specialize in their discipline	• Rewards come to those who can best market their intellectual property

While the table is separated into two columns, it is unrealistic, and detrimental, to have universities operate strictly within one set of understandings or the other. There is a need for Mode 1 knowledge production to continue broadening and deepening our current understanding within disciplines. It is also important, however, to note that there is a demand by the knowledge economy for Mode 2 knowledge production. Manathunga et al. (2006) summarize this need by stating that in “the hyper-complex world of the twenty-first century, it certainly appears that both theoretical and applied interdisciplinary research will be necessary to solve the entwined issues of social, environmental and economic sustainability.”

Universities have traditionally been the primary creators of knowledge production and have focused on deepening our understandings of the natural world through disciplinary pursuits. However, as the quantity of knowledge has increased, researchers have focused more narrowly within disciplines to continue the production of new knowledge. Additionally, industry has taken a role alongside the university to create new knowledge that is based on performativity rather than the pursuit of knowledge for its own sake. The case has been made that there must be an emphasis on interdisciplinarity within the university so that scholars can “develop the skills of integration and synthesis so frequently demanded by the problems of a culture in the midst of profound transition” (Newell & Green, 1982).

Challenges for Interdisciplinary Studies

Although there has been great support for interdisciplinary scholarship today, especially in the humanities, there remains much resistance to its implementation and execution. Much of this conflict is inherent to the disciplinary segregation previously discussed. This manifests as both epistemological and structural barriers. Additionally, interdisciplinary endeavors are often viewed with hesitation because of the inherent risk under the current reward structures of universities.

To fully appreciate the epistemic barriers faced by interdisciplinary scholarship, it is helpful to review the analysis of Kuhn (1959) on “the essential tension between tradition and innovation." Kuhn commented on the differences between "normal science" and revolutions, and the role they have played in knowledge creation throughout history. The general argument is that knowledge creation is foundationally paradoxical. Normal science, as he calls it, is rooted in disciplinary consensus and is a highly convergent activity. Scientific revolution, on the other hand, is often a result of normal science requiring divergent thought from the disciplinary norms and is an innovative activity.

This paradoxical tension is viewed from the contemporary interdisciplinary perspective by Andersen (2013). Although collaborative science is common today, it is typically within disciplines and, therefore, epistemic differences are relatively minor among the collaborators. However, when collaborators are part of a larger interdisciplinary endeavor, epistemic differences tend to be greater. These differences can include what scholarship involves, how to evaluate evidence, the criterion for "good science," or even the basic concepts of truth (Bauer, 1990). Disciplines, in this regard, can be viewed more as unique cultures rather than simply concentrations on a specific knowledge set (Bradbeer, 1999).

Andersen (2013) argues that collaborators faced with these epistemic differences have two distinct options. The first is "to adhere to the ideals of intellectual independence and skepticism," which requires each collaborator to gain an adequate understanding of all disciplines involved so that "each individual [is] capable of making a rough assessment of the overall justification for the knowledge claims the group has produced and of judging each individual piece of it critically." Alternatively, the collaborators must relinquish "the ideals of intellectual independence and critical scrutiny and accept instead a profound epistemic dependence and the relations on trust on which it builds." Faced with these tensions, “intellectual independence and critical scrutiny” or “epistemic dependence and trust,” it is easy to see why interdisciplinary studies are met with such resistance.

In the classroom setting, interdisciplinary studies are often met with skepticism, suspicion, or even hostility from faculty and scholars (Newell & Green, 1982; Wolman, 1977). A common argument for this resistance is that students compromise depth of understanding for breadth (Benson, 1982). Interdisciplinary programs are thought to lack substance or simply duplicate current offerings from individual disciplines (Newell & Green, 1982). This again is related to the understanding of disciplines as a culture and realizing that differences in epistemological beliefs must be addressed. Different disciplines may have different values and epistemologies, so to truly succeed in interdisciplinary studies, “unconscious habits of thought” must be transcended (Bauer, 1990).

Turner et al. (2015) expand on Andersen’s description of epistemic tension to include two additional tensions, structural and affective. Structural tension is defined as stability versus flexibility in regards to institutional design. This is indicative of the previous discussion on the segregation of disciplines. The stable institutional design relegates disciplines into distinct “silos” where faculty are often limited to teach and conduct research within their disciplines (Baker et al., 2009). Taking the University of Nebraska – Lincoln as an example, there are 10 individual colleges within the university and approximately 146 different departments within these colleges.

The compartmentalization of disciplines is a growing concern and was the focus of a session at the Educause Mid-Atlantic Regional Conference in 2010. Participants of this session described the idea of a strong college model and noted that, while it does empower schools to attract talent and funds for individual colleges, it also “reinforce[s] insularity and make[s] it less likely that scholars from different colleges on the same campus will come together and tackle a subject from an interdisciplinary angle” (Kolowich, 2010).

Klein (2013) also compares the flexible and stable university structure with regards to interdisciplinary studies. The stable system does not challenge the existing structures and organizations of the university, whereas the flexible system is non-hierarchical (Table 1.3).

Table 1.3: Comparison of the features of a stable and flexible system for interdisciplinary studies in the university setting, adapted from Klein (2013).

FEATURES OF A STABLE SYSTEM	FEATURES OF A FLEXIBLE SYSTEM
• Free-standing institutions	• Learning communities of students and faculty
• Autonomous and cluster colleges	• Problem-focused research projects
• Centers and institutes	• Shared facilities, databases and instrumentation
• Interdisciplinary departments, majors, minors and concentrations	• Interdisciplinary approaches, schools of thought
• Mainstream and alternative general education programs	• Enhanced disciplinary curricula to accommodate new developments in scholarship and research
• Individual courses within disciplinary departments	• Subdisciplinary boundary crossing
• Tutorials	• Educational functions of centers and institutes
• Independent study and self-designed majors	• Training in collaborative modes and teamwork
• Travel-study, internships, and practicums	• Interinstitutional consortia and alliances

The final conflict described by Turner et al. (2015) was affective tension. This is described as the tension "between the security of working within cohesive research communities versus attraction to the creative challenges in new intellectual communities." Security in this definition can refer to a variety of things, but here we will focus on job security, both in regards to retention and advancement.

Wolman (1977) recognized the disciplinary segregation on campuses, but reasoned that it was primarily because of the reward structure that has been foundational to the success of universities. He focused on the role that promotion and tenure played in the scholarly activities that faculty pursue. It is true that the promotion and tenure process favors scholarly research and publication, and interdisciplinary research may limit the ability to produce the same number of publications. Professional societies are also situated around specific disciplines, or even subdisciplines, so research outside of one's own discipline may be less recognized by that individual's peers (Wolman, 1977).

Additionally, it is important for individuals to establish an identity for themselves. While interviewing program directors of interdisciplinary research centers, Turner et al. (2015) noted there is an inherent resistance to interdisciplinary scholarship and research because scholars will find that they are cast with multiple academic titles. The argument for tenure was also noted as a challenge for interdisciplinarians as one respondent noted, "If you are working in an area where there's nobody out there who knows what you are doing, you won't get tenure." Whether real or imagined, the current promotion and tenure process is viewed to favor specialists from single disciplines that are able to create a clear academic identity.

Outcomes of Interdisciplinary Programs

Interdisciplinary studies are prevalent in universities across the globe and range from undergraduate programs to doctoral level programs. However, most of the literature for studying interdisciplinary comes from the humanities. This review will focus on advanced graduate degree programs, primarily doctoral and professional doctorate degrees, in the United States, United Kingdom, Canada and Australia. It is important to uncover what is needed to create a successful interdisciplinary program and the observed outcomes.

If one is to look at the evolution of our modern educational system, especially in regards to doctoral programs, contemporary universities are nearly unrecognizable to those of ancient times, or even to those of the early nineteenth century. Through the Middle Ages, scholarship involved the study of the trivium and quadrivium (Kockelmans, 1986). The trivium – grammar, rhetoric and dialect, and the quadrivium – arithmetic, geometry, astronomy and music, were intended to provide “free men” an education that “included all the knowledge and skills needed to exercise their social roles” (Frodeman & Mitcham, 2007). The liberal arts curriculum was intended to be approached holistically; disciplinary specialization resulting in knowledge of one component of the liberal arts without all would be, in the words of Frodeman and Mitcham (2007), viewed as a “deformation of the mind.”

Universities were first established after the turn of the millennium in Bologna (1088) and Paris (1218) (Frodeman & Mitcham, 2007). After the twelfth century, doctoral education began to spread to other countries across Europe and eventually to countries around the world. However, the educational objective was different than that of modern doctoral programs. Kot and Hendel (2012) quote Buchanan and Hérubel in stating that the orientation of the early doctoral degree was the “qualification which permitted a scholar to become a full participating member of a guild.”

Early in the nineteenth century, the research university and doctoral degree began to take on its modern form under the direction of Wilhelm von Humboldt. The first modern Doctor of Philosophy (PhD) degree was soon established at Berlin University and became an attraction to scholars from around the world. Eventually, the PhD was established in other countries, including the United States (Yale in 1861), Canada (Toronto in 1897), the United Kingdom (Oxford in 1917), and Australia (Melbourne in 1945) (Kot & Hendel, 2012).

It is safe to say that for most of human history, the educational system was designed to provide the learner with a holistic understanding of the relevant knowledge of the time. Not until the late nineteenth and early twentieth centuries did the quest for scientific advancement replace advanced general education with disciplinary specialization. However, once knowledge accumulation began to increase, specialization continued to grow. With this understanding, it can be claimed that it took less than a century for scientific researchers to realize that there was a need to integrate the knowledge from these new disciplines, in spite of the rapid increase in specialization.

Frodeman and Mitcham (2007) discuss the rise of the “unity-of-science” movement that started in the 1930s to address projects like radar, the atomic bomb, and other military projects that were not possible to approach with any single discipline. The atomic bomb is actually commonly cited as an interdisciplinary success, although Bauer (1990) argues that this was actually a multidisciplinary endeavor because the physicists, engineers, and soldiers all continued to work in their own styles and methodologies. Later in the twentieth century, there was an even greater focus on interdisciplinarity to address complex social problems like poverty, war, hunger, overpopulation, and environmental degradation (Frodeman & Mitcham, 2007).

With the acknowledgement from the scientific community that interdisciplinarity is needed to address the complex issues that face society, the process for interdisciplinary education becomes central. Vincent Kavaloski identifies three objectives for interdisciplinary education, "'integration of knowledge' – the awareness of the interconnectedness of the world, the ability to see the larger context; 'freedom of inquiry' – the opportunity to follow an issue without regard to artificial disciplinary barriers; and 'innovation' – the chance for unconventional thinking and original insights" (Newell & Green, 1982).

Using Kavaloski's objectives for interdisciplinary education as a base, we can move into defining a model for interdisciplinary learning. Biggs and Collis' (1982) structure of the observed learning outcome (SOLO) taxonomy was developed to evaluate learning quality across diverse educational settings and subject matters. It highlighted five structural levels that a learner passes through – prestructural, unistructural, multistructural, relational, and extended abstract. Ivanitskaya et al. (2002) adapted this structural model to evaluate interdisciplinary programs (Table 1.4). They modified the taxonomy to exclude the prestructural level of learning and included a description of how the structural level operates within the context of interdisciplinary learning. Not until the learner passes through the relational or extended abstract level are they actually engaged in interdisciplinary learning.

Table 1.4: Adaptation of Biggs & Collis (1982) structural model to interdisciplinary learning ,adapted from Ivanitskaya et al. (2002).

Structural Level	Description within a context of interdisciplinary learning	Outcomes
Uni-structural (uni-disciplinary)	Learner focuses on a relevant discipline	Declarative and procedural knowledge in one discipline
Multi-structural (multi-disciplinary)	The learner acquires knowledge in several disciplines but does not integrate them	Declarative and procedural knowledge in several disciplines that are related to a central theme; multidisciplinary thinking
Relational (interdisciplinary, limited to one central theme or problem	The learner integrates knowledge from several disciplines around a central theme. Critical thinking skills are being developed as the learner becomes aware of the strengths and limitations of the perspectives offered by each discipline	Interdisciplinary content thinking (declarative and procedural knowledge); critical thinking skills; some metacognitive skills; advanced epistemological beliefs
Extended abstract (interdisciplinary, extended to other themes or problems	The learner acquires a knowledge structure that integrates interpretive tools (methodologies, theories, paradigms, concepts, etc.) from multiple disciplines. The learner uses metacognitive skills to monitor and evaluate his or her own thinking processes. The learner applies an interdisciplinary knowledge structure to new interdisciplinary problems or themes.	A well-developed interdisciplinary knowledge structure; interdisciplinary content thinking; critical thinking skills; metacognitive skills; highly advanced epistemological beliefs; transfer of interdisciplinary knowledge

If there are structural levels that a learner must pass through, there must also be an established process to direct an interdisciplinary program. Although there is discrepancy concerning whether the process is linear and sequential or looped and flexible, there is general agreement on the steps involved in the process. Newell (2001) provides two versions that attempt to specify the steps involved in the interdisciplinary process. The first was proposed by Klein (1990) and blended theory with practice:

- *Defining* the problem [question, topic, issue]
- *Determining* all knowledge needs, including appropriate disciplinary representatives and consultants, as well as relevant models, traditions, and literatures
- *Developing* an integrative framework and appropriate questions to be investigated
- *Specifying* particular studies to be undertaken
- *Engaging* in “role negotiation” (in teamwork)
- *Gathering* all current knowledge and *searching* for new information
- *Resolving* disciplinary conflicts by working toward a common vocabulary (and focusing on reciprocal learning in teamwork)
- *Building* and *maintaining* communication through integrative techniques
- *Collating* all contributions and *evaluating* their adequacy, relevancy, and adaptability
- *Integrating* the individual pieces to determine a pattern of mutual relatedness and relevancy
- *Confirming* or *disconfirming* the proposed solution [answer]

- *Deciding* about future management or disposition of the task/project/patient/curriculum.

The second version is proposed by Newell himself, and he categorizes his steps according to the definition of interdisciplinarity derived by Klein and Newell (1997):

A. Drawing on disciplinary perspectives:
    - *Defining* the problem (question, topic, issue)
    - *Determining* relevant disciplines (interdisciplines, schools of thought)
    - *Developing* working command of relevant concepts, theories, methods of each discipline
    - *Gathering* all current disciplinary knowledge and *searching* for new information
    - *Studying* the problem from the perspective of each discipline
    - *Generating* disciplinary insights into the problem

B. Integrating their insights through construction of a more comprehensive perspective:
    - *Identifying* conflicts in insights by using disciplines to illuminate each other's assumptions, or by looking for different terms with common meanings, or terms with different meanings
    - *Evaluating* assumptions and terminology in the context of the specific problem
    - *Resolving* conflicts by working towards a common vocabulary and set of assumptions
    - *Creating* common ground

- *Constructing* a new understanding of the problem
- *Producing* a model (metaphor, theme) that captures the new understanding
- *Testing* the understanding by attempting to solve the problem

Newell states that the two versions of the interdisciplinary process that he provides are both valid lists and would be accepted by most interdisciplinarians. He does state, however, that both lists were developed through observation and not based on theoretical rationale.

Although the steps in the interdisciplinary process have been specified, there remains debate on the development of curricula for interdisciplinary programs. It is often contended that the lack of a standardized curricula is a disadvantage because it is difficult to assess the interdisciplinary education. However, this argument is perceived through the lens of typical disciplinary structures, and Field, Lee and Field (1994) suggest that it may in fact be an advantage. “The development of the intellectual capability in the student rather than on a fixed body of information” is the focus of educational assessment.

There are countless publications that address the perceived and realized benefits and outcomes of an interdisciplinary program, but there are general outcomes that are commonly discussed. Ultimately, Ivanitskaya et al. (2002) state that “as learners attain mastery in interdisciplinary studies, they use interpretive tools to combine and integrate information into a complex interdisciplinary knowledge structure focused on the program’s theme.” Table 1.5 provides a comprehensive list of the expected outcomes of interdisciplinary programs modified from Ivanitskaya et al. (2002). The list further perpetuates the expectations that interdisciplinary programs elevate the student’s ability to think critically, remain flexible, adapt to learning situations, and address complex issues in a critical and thoughtful way.

Table 1.5: Predicted outcomes of interdisciplinary programs, modified list from Ivanitskaya et al. (2002).

Author	Outcome
D. B. Ackerman (1989)	Flexible thinking Ability to generate metaphors Understanding of the strengths and limitations of disciplines Ability to assess value to knowledge gained
D. Ackerman and Perkins (1989)	Enhanced thinking and learning skills Improved higher-order cognitive skills Improved content retention Capacity for proactive and autonomous thinking skills Ability to devise connections between seemingly dissimilar contexts
Bradbeer (1999)	Enhancing epistemological understandings of the student's original discipline and how this knowledge relates to and sometimes conflicts with that of other disciplines
Field et al. (1994)	Ability to tolerate ambiguity or paradox Sensitivity to the ethical dimensions of issues Enlarged perspectives and horizons Ability to synthesize or integrate Enhanced creativity, original insights or unconventional thinking Enhanced critical thinking Capacity to perceive a balance between subjective and objective thinking Humility, sensitivity to bias, and empowerment Ability to demythologize experts
Ivanitskaya et al. (2002)	Shift from memorizing facts to applying knowledge to a central theme Develop advanced epistemological beliefs Enhance critical thinking Enhance metacognitive skills Understand how different disciplines are related Internally organize knowledge Expert problem solvers
J. T. Klein et al. (2001)	Enhancing higher order thinking and metacognitive skills
Lattuca (2002)	Relational, mediated, transformative and situated learning experiences

Conclusion

This review of interdisciplinary scholarship should serve as a foundation for the argument that interdisciplinary programs are essential to prepare graduates to meet the challenges of a complex society. It is important to have a basic understanding of how interdisciplinarity and interdisciplinary studies are defined and how they have evolved within the current constructs of the university system. There are of course challenges associated with interdisciplinarity, as was described by the essential tensions. However, it is clear that the outcomes of interdisciplinary programs are critical to address the needs of the current knowledge economy.

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CHAPTER 2

Agriculture and Interdisciplinarity

Introduction

The global food production system faces immense challenges as we move further into the 21st century. It is widely repeated that current food production will need to more than double by the year 2050 to feed the estimated 9 billion people that will inhabit the planet. At the same time, less land is available for agricultural production so systems need to become more efficient as well. This must all be accomplished while reducing the environmental impact of agricultural production with growing threats of climate change. Clearly, such a complex challenge requires unique solutions that are not possible through the theories and methodologies of any single discipline. This challenge will involve the collaborative work of experts in soil science, agronomy, genetics, entomology, plant pathology, food nutrition, ecology, and economics to name a few. Not only will this work need to be collaborative, it must be integrated in a way that pulls together insights and perspectives from different disciplines to approach the challenge. This integration is the essence of interdisciplinarity and is required to continue to sustainably feed the growing population.

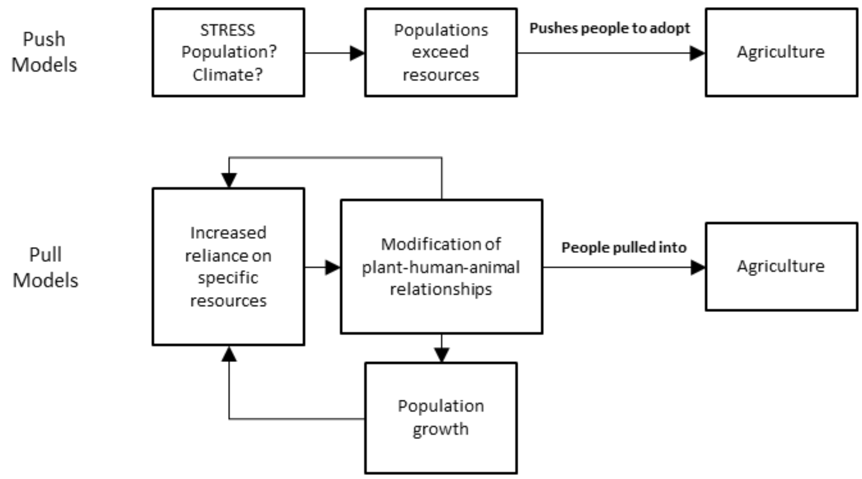
Origins of Agriculture and Food Production Systems

Agriculture is defined by Merriam-Webster's dictionary as the "science, art, or practice of cultivating the soil, producing crops, and raising livestock and in varying degrees the preparation and marketing of the resulting products" ("Agriculture," n.d.). Describing this term as a science, art or practice indicates that there are many nuances involved with agriculture that do not fit neatly into disciplinary canons. Additionally, the notion that agriculture involves soil, plants, and livestock, the act of cultivating, producing and raising, and ultimately marketing an end-product, makes it clear that agriculture is innately multidisciplinary and more often inter- and transdisciplinary. By investigating the origin and advancement of agriculture from the earliest agrarian societies to modern times, the multiple disciplines, theories, and practices important in modern agriculture are revealed.

Agriculture dates its origin to roughly 12,000 B.C. when humans began to transition from nomadic hunter-gatherer societies to more sedentary societies. The transition was slow, and the first agrarian societies are thought to have arisen in three distinct regions – the Near East, northern China, and Mesoamerica (Bogucki, 1999). Bogucki (1999) states that the "establishment of communities that were specifically adapted to the maintenance of an agro-ecosystem" took place slowly over 2,000 years. The reasons that humans transitioned to agriculture are speculative, but Bogucki presents potential models that represent this transition, including the 'push' and 'pull' models (Figure 2.1).

The push model states that humans were forced into agriculture because of some stress, such as climatic changes or population pressure, whereas the pull model describes the growing dependence upon a resource after its initial domestication or exploitation (Barker, 2009). One theory that supports the push model is that the prolonged cold and dry period during the glacial advance of the Pleistocene period resulted in a reduction of wild food crop species essential to the hunter-gatherer societies (Flannery, 1973). There is evidence that wild-type food crops were used in diets, but additional plant species were being domesticated – emmer and einkhorn wheat, barley, peas, and lentils in the Near East, millet and rice in northern China, and beans, chilies, maize, and gourds in Mesoamerica (Bogucki, 1999).

Figure 2.1: Schematic representation of the general arguments underlying 'push' and 'pull' models of the transition to agriculture, adapted from Bogucki (1999).



In the Near East, the first agrarian societies are believed to have arisen between 10,500 and 10,100 B.C. either simultaneously in the Levant and northern Fertile Crescent, or in a single location somewhere in the Fertile Crescent, such as modern-day southeast Turkey (Zohary, Hopf, & Weiss, 2012). Food crop domestication began with eight "founder crops"; three cereals (emmer wheat, einkhorn wheat, and barley), four legumes (lentils, peas, bitter vetch, and chickpea), and flax. Wheat and barley were always present and one or more of the remaining founder crops were planted in some combination in early agrarian societies (Zohary et al., 2012).

Agriculture began to spread and soon covered the whole Fertile Crescent by 9,500 to 9,000 B.C, Crete and Greece by 9,000 to 8,500 B.C., and Bosnia-Herzegovina, Turkmenia, Moldavia, and Sicily by the end of the ninth millennium (Zohary et al., 2012). Agriculture expanded into Europe by the second half of the eighth millennium across the loess soils of central Europe, including Poland, France, and Germany, and simultaneously into Spain, the Nile Valley, and Caucasia (Zohary et al., 2012).

The first fruit crops appeared between 6,800 to 6,300 B.C. and included olive, grape, fig, and date palm. Apple, pear, plum, and cherry did not arrive until much later into the first millennium B.C. as these required vegetative propagation through grafting, a more sophisticated technique (Zohary et al., 2012). Horticulture, defined here as vegetable production, was also developed during the Bronze Age (3300-1200 B.C.). Zohary et al. (2012) state that this was probably out of necessity because population centers were expanding in arid environments. Without an abundance of green plants in these environments, horticulture provided adequate food production using the limited irrigation that was available.

As population centers grew, food needed to be provided in greater quantities. To this point, a dichotomy arises to explain the relationship between population growth and food production. Boserup (1965) describes the theory presented by Thomas Malthus that states “the supply of food for the human race is inherently inelastic, and that this lack of inelasticity is the main factor governing the rate of population growth.” She posits that the relationship, however, is actually in the opposite direction and “population growth is…regarded as the independent variable which in its turn is a major factor determining agricultural developments” (Boserup, 1965). To state it another way, Lele and Stone (1989) define the Boserup hypothesis as a phenomenon where market forces associated with increasing populations result in increased agricultural production and more intensive land use.

The “market forces” that led to greater agricultural production were also likely responsible for the establishment of stratified, or hierarchical, societies and interregional trade. In Mesoamerica, the process of stratification began in the second millennium B.C. due to emerging economic systems and exchange networks to move local goods throughout geographic regions (Hirth, 1978). Maize was the primary crop produced in these regions and the unpredictability associated with yields was likely a catalyst for trade. As trade grew and stratification became more complex, interregional trade is thought to have evolved and further solidified societal rank within regions (Hirth, 1978).

It is important to identify the transition to and expansion of agriculture in early societies because it reveals the evolving relationship between humans and plant species as food sources. Climate is likely to have played a factor in the domestication of plant species. Early agrarians were also beginning to select for crops that were best suited for the needs of society. Management practices, like irrigation, were implemented and sophisticated techniques, like grafting, were being developed as humans gained a better understanding of crop production. Stratified societies were also emerging as food became an important resource to establish societal ranking. Food resources also allowed for trade to be established within and between regions. Much of what the early agrarian societies were encountering runs parallel to the current challenges facing agriculture. Potential climate change, genetic gain through conventional and molecular breeding, resource management, and food security are all current issues that the global agricultural society is facing today.

Current Challenges Facing Agriculture

Significant challenges face agriculture today; however, if we are to solve these challenges, as we must, it is important to identify and critique the challenges, but also determine what they are not. It is my concern that the current challenges have been reduced to a boilerplate message that has resulted in the loss of the true complexity of the situation. Clearly, the goal of this paper is not to solve the challenges facing global agriculture, but it is important to challenge the common, and sometimes overused, statements that attempt to define the challenges.

The challenge to global agriculture is usually summed up in three key points: 1) food production needs to increase substantially to meet the projected population of the year 2050 (sometimes specifying the need to address food security of the malnourished peoples of the world), 2) available land is not increasing, so production must be intensified on existing land while reducing environmental impacts, and 3) agriculture is a primary driver of increased greenhouse gas (GHG) emissions and must become sustainable to help mitigate climate change. It is common for these points to be included in abstracts and introductions of any paper that addresses agricultural systems (Dyson, 1999; Godfray et al., 2010; Jaggard, Qi, & Ober, 2010; Ray, Mueller, West, & Foley, 2013; Tilman, Balzer, Hill, & Befort, 2011). All of these points are valid, but unless each point is sufficiently deconstructed to reveal the complexity involved with each one, it will be very challenging to adequately address the challenges in a meaningful way.

The challenges facing agriculture today are often discussed and presented in such a way that they are at risk of becoming empty sentiments rather than critical challenges that must be addressed with great contemplation. Pretty et al. (2010) break down the challenges at hand in a meaningful way. They too start with this boilerplate message in the abstract and introduction, "…one of the most important challenges facing society today is how to feed an expected population of some nine billion people by the middle of the 20th century"; however, the authors shift the message towards where solutions must come from and why meeting these challenges is difficult.

Pretty et al. (2010) note that the complexity of the challenges makes them difficult to address, but also highlight ineffective communication between scientists, policy makers, and practitioners as an additional hindrance to solving the challenges. They hope to identify questions that will not only impact global agricultural practices, but also improve the relationship between research, policy, and practice (Pretty et al., 2010).

Identifying priorities for research and policy is essential when approaching large, interdisciplinary problems. Several examples exist in relation to agriculture, conservation, climate change, and other large scale challenges (Morton et al., 2009; Rudd et al., 2011; Sutherland et al., 2009). It is also important to establish conditions that the priorities must meet. In regards to Pretty et al. (2010), they identified six criteria, including such characteristics as being answerable and capable of research design, not based on value judgements, novel ideas, be measureable, require more than a yes/no answer, and be on an appropriate scale.

These criteria help to deconstruct the generalized sentiments regarding the current challenges facing agriculture. Requiring answerable questions prevents the generalization that we must produce more food by the year 2050 from being an issue. Rather, questions must be asked that can inquire about where calorie deficits are going to be most prevalent, or what cropping systems will be most beneficial for regions where malnourishment is a primary issue. The final criterion that questions should be on an appropriate scale also requires the broad generalities to be broken down into manageable problems. Instead of asking the question of how agriculture will reduce its impact on climate change, which is not on a scale that can be answered, questions should focus on areas such as, how can carbon-sinks be created on individual farms in the U.S. Midwest?

Disciplines Required to Meet Those Challenges

The 100 questions from Pretty et al. (2010) were organized into four categories, (i) natural resource inputs; (ii) agronomic inputs; (iii) agricultural development; and (iv) markets and consumption. This list is indicative of the interdisciplinary nature of the challenges facing agriculture and represents the need for interdisciplinary research to meet those challenges. Table 2.1 provides a selection of four questions, one from each section, that represent the need for interdisciplinary research.

Table 2.1: A selection of questions from each of four categories presented by Pretty et al. (2010).

Category	**Question**
Natural resource inputs	What is the relationship between productivity and biodiversity (and/or other ecosystem services) and how does this vary between agricultural systems and as a function of the spatial scale at which land is devoted mostly to food production?
Agronomic practice	What practical measures are needed to lower the ideological barriers between organic and [genetic modification] GM, and thus fully exploit the combined potential of both GM crops and organic modes of production in order to achieve agroecological management practices compatible with the sustainable intensification of food production?
Agricultural development	Under what environmental and institutional conditions will increasing agrobiodiversity at farm and landscape scales result in increased livelihood opportunities and income?
Markets and consumption	Where is food waste greatest in food chains in industrialized and developing countries and what measures can be taken significantly to reduce these levels of food waste?

Each of the questions presented can be broken down to illustrate the need for interdisciplinary thought and insight. The “Natural resource inputs” question deals with the compatibility between productivity and biodiversity. Clearly no single discipline is equipped to deal with such a complex problem. Crop production alone requires knowledge of cropping systems, pest management, whether phytopathological or entomological, nutrient management, genetics, and many more. Biodiversity refers to a plethora of flora and fauna, both at the micro and macro scales. Soil microbiologists are needed to understand the diversity of soil organisms, from fungi to bacteria to nematodes, while entomologists are needed to ensure that pollinators and other beneficial insects are accounted for when weighing the impact of production systems on biodiversity. These are critical factors that must be considered, as farming is one of the leading causes for the decline of taxa, ranging from birds to insects to plant species (Green, Cornell, Scharlemann, & Balmford, 2005; Robinson & Sutherland, 2002).

The second question highlighted deals more with the issue of science literacy and the divisiveness that has arisen between proponents of different farming practices that, at face value, seem to be at odds with one another. While this issue still requires attention from individuals with knowledge rooted in multiple disciplines, it also requires an understanding of the barriers that have been constructed and an understanding of how to effectively communicate scientific knowledge to the general public.

The role of transgenic crops and organic agriculture are often framed as being exclusive from one another, requiring individuals to pick a side. Journal article titles like, *Selling suicide: farming, false promises and genetic engineering in developing countries* (Simms, 1999) and *The second Silent Spring?* (Krebs, Wilson, Bradbury, & Siriwardena, 1999), are certainly polarizing with their emotional connotations. Proponents of transgenic crops may not be as creative with their descriptive titles, but they are just as vocal about the benefits and necessity of the technology (Carpenter, 2010; Dale, 1999). To bridge this divide, we must actually address the ethical issues and perceptions concerning all arguments and not simply concede to a “binary categorization” of good or bad when discussing such topics (Reiss, 2001).

Addressing the third and fourth questions referenced in Figure 2.2 requires even more disciplines. Economics, human nutrition, animal husbandry, ecology, climatology, gender studies, sociology, and numerous other disciplines are all implicated as we begin to unravel the complex questions that must be answered to address global agriculture in the future.

Another measured analysis of the multitude of issues facing society today in regards to food production and environmental factors is given by Tilman, Cassman, Matson, Naylor, and Polasky (2002). Beyond providing the boilerplate message about the issues at hand, the authors describe the inherent challenges with addressing those issues. They begin by acknowledging the accomplishment of doubling cereal production between the years 1960 and 2000 due to technologies involved in the ‘Green Revolution.’” However, they also state that doubling production again presents significant “scientific and policy challenges that must be met to sustain and increase the net societal benefits of intensive agricultural production” (Tilman et al., 2002).

Tilman et al. (2002) present potential outcomes associated with increasing food production systems to meet the demand of a growing population. They do not necessarily present the challenge of reaching the goal, but what the consequences will be if and when we actually do. “Ecosystem services,” for example, defined as the ability of an ecosystem to provide food, feed, fiber, and fuel production, carbon, nutrient, and water cycling, and improvements in soil, water, and air quality (Blanco-Canqui et al., 2015), presents possible consequences of the agronomic practices, like continued increases of fertilizers and pesticides, that could be required to continue yield gains in cereal production. Therefore, increased fertilizers could result in increased nutrients in the ground water, potentially contributing to the degradation of aquatic habitats by eutrophication (Tilman et al., 2002). This is yet another example of the complexity of the challenges that face us today and the need for interdisciplinary approaches.

Interdisciplinary Research

The previous section argued that meeting the challenges facing agriculture will take an interdisciplinary approach. Chapter one of this document focused on interdisciplinary scholarship. Since most of the research and literature available on interdisciplinarity is from the humanities, much of the information presented on interdisciplinary scholarship was taken from humanities-based research. However, this section will bridge the theories and definitions derived from humanities-based literature with current programs, projects and trends in the experimental sciences. Research is a critical component of scientific discovery, but it must be considered in the context of application as well as discovery.

Just as definitions for interdisciplinary studies were complex and evolving, the definition of interdisciplinary research remains fluid. Barković (2010) defines the term as “a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice."

It is important to note that interdisciplinary research in this definition can be accomplished by "teams or individuals". This is a distinction that often arises between humanities- and experimental science-based research. From the perspective of humanities researchers, interdisciplinary research has tended to focus more on the "individual intellectual processes of synthesizing perspectives, theories, and methods from multiple disciplines" (Borrego & Newswander, 2010). One explanation for this difference is likely due to the level of consensus and defined terminology within or across particular disciplines. Researchers in fields like sociology and political science must work on simply agreeing on methods or interpretations of data, resulting in less frequent collaboration (Lodahl & Gordon, 1972). Alternatively, researchers in fields like physics or chemistry, where there is already well-defined terminology and high consensus, are likely to collaborate more frequently, even if it is merely due to division of labor (Hagstrom, 1964; Lodahl & Gordon, 1972). It is from this perspective that interdisciplinary research will be discussed further.

While several of the definitions refer to individuals with disciplinary specialties (Bruhn, 2000; Rhoten & Pfirman, 2007), Repko (2008) refers to an interdisciplinarian as part of the collaborative process. This is an important point to make as collaborative research in the experimental sciences can often rely simply on the division of labor and miss the full benefit of true interdisciplinarity (Borrego & Newswander, 2010). The interdisciplinarian offers the unique ability to not only enhance the collaborative research process, but also translate the knowledge into application.

Müller-Merbach (2009) enforces this idea with a profile of an interdisciplinary generalist. He identifies three criteria for this individual – a familiarity with contents of the individual disciplines, the ability to apply his or knowledge, and a passion for the disciplines. He describes an interdisciplinary generalist of science as having "knowledge of the static states and the dynamic processes of the living and the inanimate nature; the ability and the will to apply this knowledge to technical realizations; respect for creation, administration of nature in its eternal harmony."

Szostak (2013) presents an authoritative look at interdisciplinary research by providing best practices that he believes to be, at least in some part, a definition for the term interdisciplinary research. He first includes two "attitudes" that are useful in defining the term:

- An openness to the theories, methods, types of data, and philosophical perspectives employed by any discipline (as well as to the things each discipline studies).
- An appreciation that each discipline is characterized by an overarching "disciplinary perspective" and that the insights derived from any discipline should be evaluated in the context of that perspective.

The ideas of "openness" and "appreciation" relate back to the profile of an interdisciplinary generalist given by Barković (2010). Szostak (2013) also identifies the best practices involved with interdisciplinary research. These are (i) forming a research team; (ii) identifying a good research question; (iii) identifying and evaluating relevant insights from relevant disciplines; (iv) mapping the disciplinary relationships among the phenomena being studied; (v) performing multiple methods of research; (vi) integrating insights from different disciplines; and (vii) reflecting, testing, and communicating results.

By summarizing the literature and key points from the previous section, a new definition for agricultural interdisciplinary research is developed. It is a collaborative process whereby an interdisciplinarian with deep understanding of, and passion for, the multiple disciplines involved with agriculture, including plant science, soil science, pest management, and crop production, coordinates a team of individuals with specializations in the disciplines identified as being related to the specific problem. Discussion about the relatedness and interconnectedness of the disciplines in regards to the research problem should be identified and hypotheses should be created that can be evaluated through combinations of research methods and principles from all relevant disciplines. Research results should be evaluated to determine what has been learned about the research question as well as the interdisciplinary process. Finally, results should be summarized so that they can be effectively communicated to stakeholders in order to take actions to address the research problem.

While it is clear that the complexity of the problems facing the world today require an interdisciplinary approach (Borrego & Newswander, 2010), we must be conscious of what interdisciplinary research entails. Interdisciplinary generalists are an integral part of interdisciplinary research and must have some disciplinary grounding, but also be able to work in teams, integrate ideas, and communicate effectively. In the final chapter, I will conclude with a description of the educational components necessary for educating interdisciplinary agricultural generalists and address a case study that investigates a professional doctoral degree program that is focused on developing these individuals in the agricultural sciences.

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CHAPTER 3

Case Study – Interdisciplinary Professional Degree Program

The Interdisciplinary Push in Agriculture

The first chapter of this document defined interdisciplinary scholarship and discussed the benefits and challenges associated with interdisciplinary programs in universities today, primarily in the humanities. The second chapter framed the argument that interdisciplinarity and interdisciplinarians are essential to address the issues facing agriculture currently and in the future. To tie these two chapters together, the final chapter examines a case study of an interdisciplinary professional degree program that is training graduates with the skills needed to address the referenced agricultural challenges. While there is still a need for disciplinary-based research, many of the problems facing humanity require integration of insights from multiple disciplines to adequately address them. So how is interdisciplinary scholarship and research being promoted and implemented today?

A major step toward the successful implementation of interdisciplinary scholarship and research is funding. Two of the major funding institutions for science research are the National Institutes of Health (NIH) and the National Science Foundation (NSF). Both of these institutions have made a conscious effort to promote the advancement of interdisciplinary research. In the *NIH Roadmap for Medical Research*, a section titled "Research Teams of the Future" includes an initiative for interdisciplinary research that states "a series of awards will be established to make it easier for scientists to conduct interdisciplinary research" (Kantor, 2008). According to the NSF's *Strategic Plan for 2014 – 2018,* part of the institute's mission is to support "fundamental, interdisciplinary, high-risk, and potentially transformative research in science and engineering, and the education of the next generation of the STEM workforce to continue this transformation” (NSF, 2014).

The statement by the NSF to educate the “next generation of the STEM workforce” is an important charge. If the broad, interdisciplinary challenges are to be met, there must be individuals with the appropriate training to work across disciplines. In addition to the NSF’s *Strategic Plan*, the foundation also promotes interdisciplinary education through their Integrative Graduate Education and Research Traineeship (IGERT) program. Part of this program’s charge is to “meet the challenges of educating U.S. Ph.D. scientists and engineers with interdisciplinary backgrounds, deep knowledge in chosen disciplines, and technical, professional, and personal skills” (NSF, 2012). One reason for this charge was that “many employers noted that Ph.D. graduates’ training was so specialized that they were neither suitably prepared for entry-level jobs nor able to readily adapt to non-academic settings” (Carney, Chawla, Wiley, & Young, 2006). It is encouraging that there is national consensus from major scientific funding organizations that training and educating scientific interdisciplinarians is necessary.

Plant Doctors: Interdisciplinarians for Agriculture

There has been an upward trend in the number and diversity of professional doctorate programs since the first half of the twentieth century. While they may be referred to by different names, such as professional doctorates, applied doctorates, practitioner doctorates, or clinical doctorates, the primary role is to offer an alternative option to the traditional Ph.D. in higher education (Kot & Hendel, 2012). Examples of such degrees are the Doctor of Education (EdD), Doctor of Psychology (PsyD), Doctor of Engineering (EngD), Doctor of Music Art (DMA), Doctor of Dental Surgery (DDS) and others (Kot & Hendel, 2012). In the area of plant science, new professional doctorate programs are emerging to develop and train what many have called plant doctors (Agrios, 2001; Bradshaw & Marquart, 1990; Browning, 1998; Hein & McGovern, 2010; McGovern & To-anun, 2016).

Several individuals have been influential in establishing the current professional doctorates in plant health. McGovern and To-anun (2016) provides a short list of individuals and their contributions, including Cynthia Westcott (1898-1983), Robert S. Cox (1919-1999), Earle S. Raun (1924-2009), and J. Artie Browning (1923-2013). These individuals were classically trained in plant pathology (Drs. Westcott, Cox, and Browning) or entomology (Dr. Raun), but they realized the need for practitioners in plant health or medicine, similar to the need for practitioners in human and animal health or medicine. Each individual was a vocal proponent for training plant health practitioners across the multiple agricultural disciplines, "including both pest-related (entomology, plant pathology, nematology, weed science, and other pests) and plant-, soil- and water-related (agronomy, horticulture, soil and water science) disciplines to directly serve agriculture and the general public, through the prevention, diagnosis and management of plant health problems" (McGovern & To-anun, 2016).

Two programs have been established in the United States to train plant health practitioners. The Doctor of Plant Medicine (DPM) was established in 1999 at the University of Florida by George N. Agrios, J. L. Capinera, and J. M. Bennett (McGovern & To-anun, 2016). A similar program called the Doctor of Plant Health (DPH) was established ten years later in 2009 at the University of Nebraska – Lincoln, spearheaded by Anne Vidaver. The value of these programs is expressed by a few of the individuals influential in their creation:

> "Thus, plant doctors give hope for approaching attainable yields and feeding a hungry world…The plant health movement has the potential to effect the greatest change in world agriculture since the Green Revolution, and the D.P.H./M. to become plant agriculture's most important single degree program." – J. Artie Browning (McGovern & To-anun, 2016)

> "As a founding faculty of the DPH program, I believe ever more strongly that this program is needed in multiple areas in the public and private sector. This need is because specialists focus on less and less, with employers frustrated with lack of general knowledge by current and prospective employees. Students are and should expect to be in fulfilling and unusual careers." – Anne Vidaver (DPH, 2016a)

The two programs are similar in structure and mission. According to the Doctor of Plant Health website, the mission of the program is "to produce plant practitioners with broad expertise and experience across the various disciplines that impact plant health and plant management. These plant practitioners (plant doctors) will integrate from across this expertise to diagnose and solve plant health problems and to develop integrated plant and pest management systems that maximize the system's economic, environmental, and social sustainability"(DPH, 2016b). To further clarify the exceptionally high expectation of these programs, the current directors of each program, Gary Hein (DPH) and Amanda Hodges (DPM), state that "with these two programs… a new profession has been created that will serve to keep American agriculture competitive while addressing the many challenges to sustainable food, feed, fiber, and biofuel production at a broader system level" (Hein & Hodges, 2013).

Both programs have unique requirements for completion, including rigorous academic training across various disciplines, as well as practical training in diagnostics and professional experience. Distinctive features of the programs are listed below (Hein & McGovern, 2010):

1. Comprehensive interdisciplinary 'core' of courses provides a depth of training across the plant-related disciplines (plant pathology, entomology, plant science, soil science and weed science).
2. Required internships target professional goals of the students and enable the students to integrate their 'core' training to solve problems and address diagnosis and management issues. Internships typically include projects with agribusinesses, crop consulting firms, extension specialists, or state/federal regulatory agencies.
3. Extensive training in diagnostics that emphasizes hands-on learning.
4. Elective courses give the student flexibility to reach individual career goals.
5. Required research methodology practicum to ensure an understanding of research methods and applied plant health literature.

6. Educational opportunities in problem-solving, communication, leadership, policy, conflict resolution, professionalism and ethics.

A Case Study of Two Interdisciplinary Doctoral Degree Programs in Plant Health

It is critical to periodically assess academic programs to ensure that the objectives and mission of the program are being met. As the DPM program has been in existence for nearly 17 years and the DPH for nearly seven, it is important to evaluate the impact these programs are having on graduate education and preparing graduates for careers upon graduation. To evaluate this, a survey was conducted of alumni from both programs, as well as employers of the alumni. The alumni survey was designed with the following objectives: i) obtain demographic and career information; ii) evaluate strengths and weaknesses of the programs; iii) identify the extent to which the DPH/M degree prepared them for a career after school; and iv) obtain testimonials to document these objectives and to be used for future recruitment. The employer survey was designed with the following objectives: i) obtain demographic information of current employees; ii) assess the preparedness of DPH/M graduates compared to graduates of other graduate level degree programs; iii) identify qualities possessed by DPH/M graduates; and iv) obtain testimonials to be used for future recruitment.

Materials and Methods

Survey Construction

The questionnaires were designed in consultation with the Bureau of Sociological Research (BOSR), and administered as web surveys. The four surveys, the Doctor of Plant Health Alumni Survey (UNL), the Doctor of Plant Medicine Alumni Survey (UF), the Doctor of Plant Health Employer Survey (UNL), and the Doctor of Plant Medicine Employer Survey (UF), were all fielded in the English language and can be found in Appendix A. The alumni surveys were divided into two sections, Employment and Program Perceptions, and they consisted primarily of categorical and rank (i.e. Likert) questions. Four open-answer questions were provided at the end of the survey to generate qualitative data and personal testimony. The employer surveys were divided into three sections, Your Organization, Preparation and Performance, and Your Doctor of Plant Health/Medicine Experience, and these also consisted of categorical and rank (i.e. Likert) questions. Five open-answer questions were provided at the end of the survey to generate qualitative data and personal testimony.

Sampling Design and Data Collection

All graduates of the Doctor of Plant Health program at UNL and the Doctor of Plant Medicine Program at UF were invited to participate through a three-phase web survey. The alumni e-mail addresses were provided to BOSR from records obtained from both graduate programs. The employer e-mail addresses were obtained through the responses to the employer section of the alumni surveys.

Data collection began on March 14, 2016 with the email invitation to the Doctor of Plant Health alumni. Reminder emails were sent March 21 and March 28, 2016, to individuals who had not yet responded. The Doctor of Plant Medicine alumni received their email invitation on April 18, 2016, their first reminder email on April 25, 2016, and their second reminder email on May 2, 2016. The communication language, all sent in the English language for both alumni groups. Completed alumni web surveys were collected by BOSR through April 19, 2016 for the UNL alumni and May 18, 2016 for the UF alumni.

Upon completion of the alumni phase of the project, the employer phase began for the respective university. Email invitations were sent to the UNL alumni employers, based on information provided by the alumni, on April 21, 2016, with reminder emails on April 27, 2016 and May 4, 2016. The UF alumni employers were sent the e-mail invitation on May 23, 2016, and reminders on May 23, 2016 and May 31, 2016. The communication language for the employer survey, all sent in English, can be found in Appendix B. Completed employer web surveys were collected by BOSR through May 27, 2016 for the UNL alumni and June 16, 2016 for the UF alumni.

To capture data from the 2016 UNL graduates, a second data collection began on June 20, 2016. Reminders were sent on June 27, 2016 and July 8, 2016. UNL employer invitations were then sent on July 13, 2016 and reminders were sent on July 20, 2016 and July 27, 2016.

Statistical Analysis

Depending on the question type, frequencies, means, and standard deviations were calculated. Many of the questions required respondents to rate their agreement with a statement and were analyzed by relative sample abundance. Basic descriptive analyses were used for several questions, specifically those regarding demographics.

Results and Discussion

Response Rate

Of the eleven Doctor of Plant Health alumni who were sent the survey invitation, ten participated in the survey (90.9% response rate). Of the 65 Doctor of Plant Medicine alumni who were sent the survey invitation, 26 participated in the survey (40.0% response rate), for an overall response rate of 47.4% for the alumni portion of the project. Five of the Doctor of Plant Medicine alumni and one of the Doctor of Plant Health alumni responded only to demographic information and did not complete the survey, so these respondents are not included in the final analysis.

Of the six UNL alumni employers who were sent the survey invitation, five completed the employer survey (83.3% response rate). Nine UF alumni employers received the survey invitation with four participating in the survey (44.4% response rate) for an overall response rate of 60.0% for the employer portion of the project. One of the Doctor of Plant Medicine employers responded only to demographic information and did not complete the survey, so this respondent is not included in the final analysis.

Alumni Survey Results

Alumni from the DPH and DPM programs have found employment in states across the country and internationally (Figure 3.1). All DPH alumni responded that they were employed full-time, while 81% of DPM alumni responded that they were employed full-time, 9.5% part-time, and 9.5% were self-employed. Alumni from both degree programs have found employment from various business sectors (Table 3.1). The largest percentage of DPH alumni (44.4%) are employed by industry categorized as agricultural, and the largest percentage of DPM alumni (23.8%) are employed by universities in extension roles. Overall, 93.3% of the alumni from both programs indicated that they were either “somewhat satisfied” or “very satisfied” with their current employment. Respondents from both programs also indicated that it was “somewhat likely” or “very likely" that their DPH/M degrees enabled them to secure their current position (90%), and they indicated their degrees either prepared them "somewhat well" or "very well" for their current position (86.7%). Additionally, alumni from both programs indicated that they "sometimes" or "always or nearly always" work with individuals from different disciplines (90%). They also indicated that they "sometimes" or "always or nearly always" use the skills and knowledge learned while in the DPH/M program (96.7%).

Figure 3.1: Map indicating the states where alumni of the DPH and DPM are employed. One respondent indicated they are employed internationally.

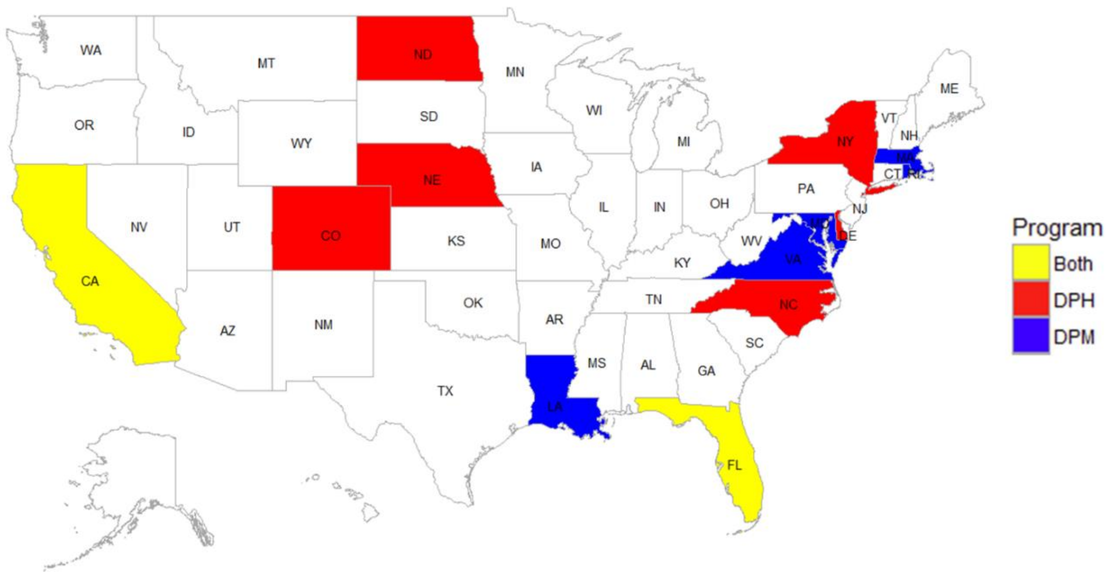


Table 3.1: Business sectors identified by alumni describing current employment.

DPH		**DPM**	
Business Sector	# of Alumni	Business Sector	# of Alumni
Industry – Agriculture	4	University – Extension	5
University – Extension	2	Industry – Horticulture	3
University – Research	1	Consultant/Advisor	3
Government	1	University – Teaching	2
Non-Profit	1	Government	2
		Other	4
Total	9	Total	19

These demographics indicate that alumni from both programs are finding gainful employment upon graduation and place value on the education and skills they learned from the programs. To identify what aspects of the programs the alumni found most valuable, respondents were asked to identify five components of the program; (coursework, internships, diagnostic training, mentorship, and networking); as either “very valuable,” “somewhat valuable,” “not very valuable,” or “not at all valuable.” Internships yielded the largest percentage of alumni responding “very valuable” (86.7%). Coursework, internships, and diagnostic training each received a response of “somewhat valuable” or “very valuable” in over 90% of the surveys, while 76% percent indicated the same for both mentorship and networking (Table 3.2).

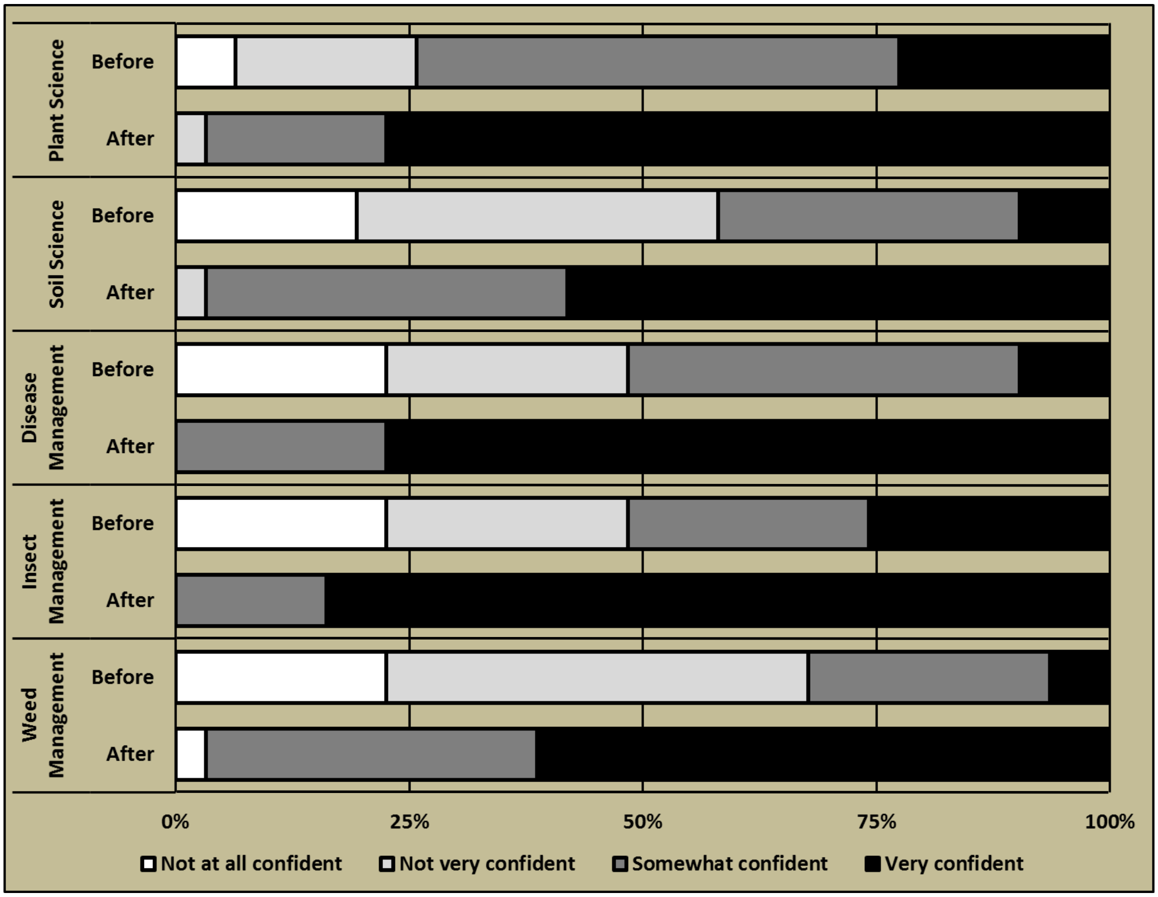
Table 3.2: Alumni perception of various components of the DPH and DPM programs.

Program Component	DPH mean[†] (SD)	DPM mean (SD)	Total mean (SD)
Coursework	3.63 (0.48)	3.73 (0.62)	3.70 (0.59)
Internships	3.88 (0.33)	3.86 (0.34)	3.87 (0.34)
Diagnostic Training	3.13 (0.60)	3.91 (0.42)	3.70 (0.59)
Mentorship	3.00 (0.71)	3.50 (0.84)	3.37 (0.84)
Networking	3.13 (0.78)	3.32 (0.84)	3.27 (0.89)

[†]Alumni were asked to rate how valuable each component was on a scale of 1 to 4, with 1 being "not at all valuable" and 4 being "very valuable."

One of the components of both programs is a rigorous course load that covers several disciplines. Alumni were asked to evaluate their confidence in the multiple disciplines – plant sciences, soil sciences, disease management, insect management, and weed management – before they started the program and after completing the program. Significant differences were observed between the two responses with greater confidence in each discipline being observed after completion of the DPH or DPM program (Figure 3.2). The alumni concluded by indicating that they were "somewhat likely" or "very likely" to recommend the DPH or DPM program to other students (90%).

Figure 3.2: Changes in confidence regarding different disciplines before starting and after completing the DPH/M programs.



Several open-answer questions were provided to gain insight into what alumni found unique about the program, how the program prepared them for their current positions, and what they would change about the programs. The interdisciplinary nature of the program and coursework was frequently commented as a unique aspect of the programs. The internship requirement was also frequently mentioned as a benefit of the programs:

> "The ability to do internships allows us to get out and get hands on experience that makes the coursework more valuable and better prepares

> us to enter the workforce. It also provides students with the opportunity to interact with so many different disciplines that they understand the ins and outs of each discipline and are able to better understand and facilitate communication between the different disciplines."

> "I enjoyed the range of course work and the excellent opportunities of internships. Compared to other graduate programs, internship experience in your area of interest, sets you apart from other applicants for jobs. I also believe that being trained in more than one plant discipline is unique. It greatly improved my problem solving ability related to agricultural issues!"

In regards to preparedness for current employment opportunities and the ability of the alumni to succeed in their current professions, respondents offered several comments related to their broad technical knowledge and ability to work across disciplines:

> "It developed proficiencies across a broad swath of ag disciplines. I have experienced no reservations in the job arena about a DPH/M degree. If there are any questions, I simply address them and the employer is satisfied. I have also taken the liberty of describing the nature of these degrees in cover letters. Extension, private, and public institutions all view the DPH/M pairing as functionally equivalent to a PhD or EdD. I have had absolutely no issues securing positions in academia."

> "I work as an IPM Manager and deal with insects, diseases, abiotic/biotic factors, nutritional environmental, scouting and management of all these listed on a daily basis. The DPH/M program prepared me for all these subject matters and many more that I wasn't prepared for until graduating with the DPH/M degree."

Finally, the alumni offered several suggestions for changes to the program. Many of these responses can be categorized as i) the poor recognition of these degrees in the professional world, and ii) the lack of funding available to students in the program:

> "It has got to get easier to obtain money for funding to keep students as well as educating peers on what the DPH/M program is, how important it is to have DPH/M degrees as well as PHD programs. Also, to change people's negative view of the DPH/M program through education of ignorance along with creating a positive and equal view of people with a DPH/M degree vs a PhD degree."

> "Opportunities for a paid assistantship with the program, fully paid or even half of tuition paid. Funding was always a difficult issue."

> "Help in job placement… employers still don't quite understand what the degree is or what it stands for."

> "Better understanding of the industry about what a DPH/M is able to do and what the DPH/M is. Build in PCA license, so that at graduation you also have PCA license."

Employer Survey Results

The number of employers who responded to the surveys is much smaller than that of alumni. Only eight total employer surveys were completed and analyzed. Of the respondents, only one had more than one employee with a DPH/M degree. On average, the respondents each managed 10.1 Ph.D. degree holders, 9.0 M.S. degree holders, 4.6 B.S. degree holders, and 3.3 individuals specified as other.

In a survey of environmental and crop science professionals, employers indicated that communication skills, interpersonal skills, research/hands-on work experience, and technical aptitude ranked as the top criteria for hiring new graduates (Madewell, Savin, & Brye, 2003). Using these data as guidance, employers were asked to determine how prepared new hires with different terminal degrees (DPH/M, Ph.D., and M.S.) were in four key competencies: communication; teamwork/collaboration; innovative approaches to problem solving; and ability to assess technical information (Table 3.3). Alumni were asked a similar question, but more specifically if the DPH/M degree set them apart from their peers in any of these areas. Both the employers and alumni rated the ability to assess technical information highest for DPH/M alumni. Employees with DPH/M or Ph.D. degrees were rated similarly by employers, but both received higher scores in all four competency areas than employees with a M.S. degree.

Table 3.3: Alumni (*n* = 30) and employer (*n* = 8 for DPH/M, 7 for Ph.D., and 6 for M.S., respectively) ratings of core competencies upon graduation.

		Employer Perception[‡]		
Employee Competency	Alumni mean[†] (SD)	DPH/M mean (SD)	Ph.D. mean (SD)	M.S. mean (SD)
Communication	3.10 (0.75)	3.63 (0.48)	3.71 (0.45)	3.00 (0.58)
Teamwork/Collaboration	3.23 (0.80)	3.50 (0.71)	3.57 (0.49)	3.00 (0.58)
Innovative approaches to problem solving	3.53 (0.72)	3.50 (0.50)	3.86 (0.35)	2.67 (0.47)
Ability to assess technical information	3.63 (0.71)	3.88 (0.33)	4.00 (0.00)	3.00 (0.58)

[†]Alumni were asked to rate how the DPH/M programs set them apart from their peers on a scale of 1 to 4, with 1 being “not at all” and 4 being “a great deal.”
[‡]Employers were asked to rate how prepared recent hires with different degrees were on a scale of 1 to 4, with 1 being “not at all” and 4 being “a great deal.”

Of the eight employers, three indicated they would be “somewhat likely” and three indicated that they would be “very likely” to hire another DPH/M graduate. One respondent did not provide an answer and one indicated they would be “very unlikely” to hire another DPH/M graduate because the positions they are currently hiring for require applicants to have a Ph.D.

Employers provided only positive responses to open-answer questions regarding employees with a DPH/M degree. The following list was compiled from a question that asked employers what adjectives describe the DPH/M graduate they employ: applied, broad, skilled, expert, collegial, interactive, knowledgeable, hard-working, futuristic, self-starter, energetic, and industrious. Similarly, when asked what unique qualities the graduates possess, answers ranged from “exposure to multiple disciplines” to “academic background is more holistic” to “breadth [and] applied experience.” Additional employer comments regarding DPH/M graduates are provided below:

> “I don’t know much about [the program], except what I know, and see, through [current employee]. On that basis, it must be an exceptional program that produces well-rounded, and ready-to-engage technical senior managers…Also a lot of fun to work with!”

> “We actually just hired another [graduate]”

> “Very happy with the hire. Keep training more!”

My Perspective as a Doctor of Plant Health Student

After three years in the Doctor of Plant Health program and researching the pedagogy of interdisciplinary studies, I have formed several opinions supported by experience and literature about the need for interdisciplinary professional degree programs in agriculture. As specialists become more narrow in their focus, generalists will become integral to prioritizing scientific endeavors and translating scientific knowledge into practice. The DPH and DPM programs have been established to produce individuals with these capabilities, but they can still be improved. Below is a personal reflection on the benefits of these programs, as well as areas that can use improvement.

When establishing a curriculum for any degree program, administrators are often limited to currently available courses, with the potential of adding a few independent studies to emphasize the particular focus of study. In an interdisciplinary degree program, this is a challenge because few courses offer interdisciplinary learning opportunities. The result is a multidisciplinary selection of courses that will hopefully provide an underpinning of disciplinary knowledge that the student must find a way to integrate. So how can this be improved? I offer two suggestions.

The first is to encourage faculty to create new courses that are problem-oriented instead of discipline-oriented. This is a challenge under the current university structure because it is difficult to find faculty that have the broad disciplinary background to take on such a feat. A common remedy is to create a course that is team-taught by individuals with different backgrounds, although, team-teaching is challenging because of the high level of collaboration needed. The default for team-teaching is to break the course into many parts that faculty can take turns teaching. The outcome of this is rarely better than multiple courses that can achieve the same results. However, by keeping the problem as the center of the course, faculty can apply their knowledge to the problem and allow students to understand the methodologies and insights achieved by different disciplines. If the students are given the time to integrate the insights from the different disciplines, they can actually achieve a higher level of problem solving that will benefit them as future professionals.

Creating new courses is rarely an option because it also requires dedicated time and effort from faculty that may not be invested in the interdisciplinary program. Therefore, I suggest one of the most realistic courses of action is an increased emphasis on independent courses where interdisciplinary students can interact with each other. Creating spaces for interdisciplinary thought to occur is absolutely essential for higher level cognitive thinking to be developed. In the DPH program, colloquium is a required course that serves to help students develop professionally. This course could be improved by adopting the “problem-oriented” approach that I mentioned earlier. Students could be given a problem in the beginning of the semester, and explore the various disciplinary components of the problem throughout the course. Guest lecturers can be invited to give their disciplinary insights and examples of primary literature that is relevant to the problem. Small-scale research can be conducted in conjunction with extension faculty and university diagnostic technicians. By the end of the semester, the students will have had the opportunity to dissect the various components of the problem, understand the relationship between the disciplinary insights, experimented to discover new truths, and ultimately, increased their problem-solving abilities. The onus is on the faculty involved with the interdisciplinary program to create the time, space, and resources necessary for this interdisciplinary thought process to occur.

Beyond classroom learning, students of the DPH program have the opportunity to gain valuable experience outside of the university setting. It is important to learn how research occurs in the university, but it is no less important to understand how industry conducts research, and how research is ultimately applied. This is the most unique benefit of the DPH program that typical graduate students are deprived of. While it is useful for graduate students to work on a project and learn how to conduct research, I have seen far too often that the understanding of the graduate outside of their specific project is limited. An example would be a plant pathology graduate student that solely focuses on the interactions of a single fungal species with a single plant species. Beyond the few courses they may take to learn about the biology and ecology of bacteria, nematodes, and viruses, they may not have the opportunity to truly understand how plant pathology and the management of plant pathogens is essential in agriculture, let alone other disciplines.

This is an opportunity where interdisciplinary students should be encouraged to expand their current understandings of the relationship of pests, plants, inputs, and environment. Because they do not have one experiment that they must focus on, DPH students have the opportunity to engage with extension faculty and help conduct demonstration plots and company trials. They have the opportunity to help the diagnostician identify potential diseases, nutrient problems, herbicide injury, and insect damage on samples that are sent in from around the state. They can initiate their own small-scale research with the help of interested faculty. These are all opportunities to gain practical experience in applied research and diagnostics that is desperately needed in agriculture today.

Students in the DPH program should also be encouraged to work on publications with faculty throughout the university. This could be as simple as working on extension publication, or working on a review paper on a topic of interest to the student. Although the majority of students graduating with the DPH degree are not seeking employment as a faculty in a research 1 level university, publications will still be appealing to potential employers. And if the story behind the publication is one of student initiative to seek out the opportunity, this can demonstrate to the employer the initiative of the graduate.

With this being said, the DPH program needs to improve on all of these fronts. As the program is currently structured, I would concede that it is more multidisciplinary than interdisciplinary. Although we take a wide range of courses from various disciplines, there is rarely a space or time where integration of insights is encouraged. Students take it upon themselves to engage in deep, interdisciplinary thought, but a formal time for this would be beneficial.

We have the opportunity to engage with faculty to gain experiences outside of the classroom, but most extracurricular experiences are focused on the internships. It should be incumbent upon the supervisory committee to encourage and facilitate these experiences and opportunities, present opportunities for research, extension, and publications, and encourage teaching assistant positions that could help the students gain experience synthesizing knowledge and transferring it.

The DPH program has given me the opportunity to bring different insights into the classroom because of the various disciplines I am studying at the same time. I have had teaching opportunities that my peers in other graduate programs are discouraged from because of the time commitment. I have had extension experiences where I have gained experience in small-plot research and transferring knowledge to the end user. However, many in academia who know about the program are still resistant to the concept, and many in industry still do not know about the program. One of the goals of this document, and the survey described previously, was to start to address these struggles. Alumni have found great value in the programs and are finding gainful employment upon graduation. Additionally, employers who typically hire Ph.D. graduates view DPH and DPM graduates comparably in key competency areas, and well above M.S. graduates. We are performing in the workplace and, I believe, are on our way to breaking down the conceptual barrier that is currently surrounding these interdisciplinary programs.

Conclusion

The major challenge facing agriculture today can be summarized as meeting the growing demand for food and food security in a sustainable way. Throughout this document, this “challenge” has been deconstructed to illustrate the multitude of individual problems that must be addressed to ultimately achieve this goal. Clearly, solving these problems will require insight from multiple disciplines and individuals who can integrate these insights into holistic solutions. At the same time, however, university systems are designed to train disciplinarians with deep expertise in specific arenas. Therefore, programs are needed to provide a new educational experience that can train agricultural interdisciplinarians that will complement the traditionally trained experts. The Doctor of Plant Medicine and Doctor of Plant Health are programs that have been established to meet this challenge. As more graduates of the DPH and DPM enter the workforce, the value of the professional plant practitioner will be realized as an essential contributor to sustainable food production systems.

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APPENDIX

Doctor of Plant Health/Medicine Alumni and Employer Survey Questions

Alumni Survey

Welcome Screen

Welcome to the Doctor of Plant Health/Medicine Program Alumni Survey. You are invited to participate in this survey because you are a graduate of the program. The following survey asks about your current employment situation, your perceptions of the program, and about the impact that the Doctor of Plant Health/Medicine Program has had in your profession.

This online survey will take about ten minutes to complete. Completing this survey is voluntary and all responses are confidential. You do not have to provide an answer for any question you do not wish to. All responses will be reported in such a way that no one person can be identified. You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study. If you are interested in discussing the research you can contact the investigator, Josh Miller, at (402) 440-5033 or joshua.miller@huskers.unl.edu.

We appreciate your participation.

About You

To make the conclusions we draw from the following survey accurate, we'd like to ask a few questions about you before we begin. All responses are confidential. The following questions will guide analysis and help us categorize graduates by institution and graduation date.

From which institution did you receive your degree?

- University of Nebraska-Lincoln (Doctor of Plant Health)
- University of Florida (Doctor of Plant Medicine)

In what year did you graduate with your Doctor of Plant Health or Doctor of Plant Medicine Degree?

- 2000-2003
- 2004-2006
- 2007-2009
- 2010-2012
- 2013-2015

In what state do you currently live? (drop-down list of states)

How many different organizations have you worked for since graduating with your Doctor of Plant Health or Doctor of Plant Medicine degree? (open-ended numeric)

Employer information

In order to learn more about what types of organizations hire Doctor of Plant Health/Medicine graduates, and gauge employers' perceptions about the program, we would like to contact the current employers of program alumni. If you choose to share your employer's information for this purpose, be assured that all of your responses to the following survey will be kept strictly confidential and none of your answers will be shared with your employer.

Who is your current employer?

- Organization name: (open-ended)
- Direct supervisor's name: (open-ended)
- Direct supervisor's email address: (open-ended)
- Direct supervisor's phone number: (open-ended)

Transition Screen

Thank you for keeping the Doctor of Plant Health/Medicine Program informed about your professional activities and reflections on the program. Your participation is crucial in helping us evaluate and improve the programs and to promote the value and impact of your profession. Please click "Continue" to begin the survey.

Section 1. Employment

1. What is your current employment status?
    - Working a full-time job for an employer (35 hours per week or more)
    - Working a part-time job for an employer (less than 35 hours per week)
    - Self-employed
    - Attending graduate school
    - Unemployed, laid off, looking for work
    - Other, please specify: (open-ended)

2. What is/are your job title(s)? (open-ended)

3. In what employment category are you currently working?
    - University – Research
    - University – Teaching
    - University – Extension
    - Industry – Agriculture
    - Industry – Horticulture
    - Consultant / Advisor
    - Non-profit
    - Federal or state government
    - Other, please specify: (open-ended)

4. Are you currently working in the United States, or internationally?
    - In the United States
    - Internationally

5. How long have you been employed at your current position?
    - Less than six months
    - Six months to less than one year
    - One year to less than three years
    - Three years to less than five years
    - Five or more years

6. Have you received a promotion since you began working for your current employer?
    - Yes
    - No
        i. *If yes*, how long after you began working for your current employer did you receive a promotion?
            - Less than six months
            - Six months to less than one year
            - One year to less than three years
            - Three or more years

7. Overall, how satisfied are you with your current position?
    - Not at all satisfied
    - Not very satisfied
    - Somewhat satisfied
    - Very satisfied

8. How much of your current job responsibilities are related to plants?
    - None
    - Some
    - Most
    - All or nearly all

9. In your current position(s), how often do you work with people from other disciplines?
    - Never
    - Rarely
    - Sometimes
    - Always or nearly always
    - Not applicable

10. How often do you use skills and knowledge learned in the Doctor of Plant Health/Medicine Program in your current position?
    - Never
    - Rarely
    - Sometimes
    - Always or nearly always
    - Not applicable

11. How important do you think your Doctor of Plant Health/Medicine Program degree was in helping you secure your current position(s)?
    - Not at all important
    - Not very important
    - Somewhat important
    - Very important

12. Overall, how well did the Doctor of Plant Health/Medicine program prepare you for your current position(s)?
    - Not well at all
    - Not very well
    - Somewhat well
    - Very well
    - Not applicable

Section 2. Program Perceptions

13. How valuable were each of the following aspects of the program?

	Not at all valuable	Not very valuable	Somewhat valuable	Very valuable	Not applicable
Coursework					
Internship					
Diagnostic training					
Mentorship					
Networking					

14. How challenging were each of the following aspects of the program?

	Not at all challenging	Not very challenging	Somewhat challenging	Very challenging	Not applicable
Coursework					
Internship					
Diagnostic training					
Mentorship					
Networking					

15. Please indicate how confident you felt in each of the following areas BEFORE you began the Doctor of Plant Health/Medicine Program.

	Not at all confident	Not very confident	Somewhat confident	Very confident
Plant Sciences				
Soil Sciences				
Disease Management				
Insect Management				
Weed Management				

16. Please indicate how confident you felt in each of the following areas AFTER you completed the Doctor of Plant Health/Medicine Program.

	Not at all confident	Not very confident	Somewhat confident	Very confident
Plant Sciences				
Soil Sciences				
Disease Management				
Insect Management				
Weed Management				

17. Please indicate how important each of the following areas are to your current position or career.

	Not at all important	Not very important	Somewhat important	Very important
Plant Sciences				
Soil Sciences				
Disease Management				
Insect Management				
Weed Management				

18. Do you believe that the Doctor of Plant Health/Medicine Program has set you apart from peers who completed a different graduate degree program in the following areas?

	Not at all	Not very	Somewhat	A great deal
Communication				
Teamwork/Collaboration				
Innovative approaches to problem solving				
Ability to assess technical information				

19. What is unique about the Doctor of Plant Health/Medicine Program compared to other programs? (open-ended)

20. In what ways, if any, did the Doctor of Plant Health/Medicine program prepare you for your current profession? (open-ended)

21. If you could change one thing, big or small, about the Doctor of Plant Health/Medicine Program, what would that be? (open-ended)

22. How likely would you be to recommend the Doctor of Plant Health/Medicine program to other students?
    - Not at all likely
    - Not very likely
    - Somewhat likely
    - Very likely

23. Please provide any additional comments you have about the Doctor of Plant Health/Medicine program: (open-ended)

24. We would like to use quotations from responses to open-ended questions on this survey for promotional purposes (e.g., website, Facebook, brochures) in the future. All quotations will be presented in such a way that no one person can be identified. Do we have your permission to use your non-identifying quotations from this survey for future program promotional purposes?
    - Yes
    - No

Exit/Thank you screen

Employer Survey

Welcome Screen

Welcome to the Doctor of Plant Health/Medicine Program Employer Survey. You are invited to participate in this survey because you currently employ a graduate of the program. The following survey asks about your organization, your Doctor of Plant Health/Medicine employee, and about your perceptions of the program.

This online survey will take about ten minutes to complete. Completing this survey is voluntary and all responses are confidential. You do not have to provide an answer for any question you do not wish to. All responses will be reported in such a way that no one person can be identified. You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study. If you are interested in discussing the research, you can contact the investigator, Josh Miller, at (402) 440-5033 or joshua.miller@huskers.unl.edu.

We appreciate your participation.

Section 1. Your Organization

1. What is your current job title? (open-ended)

2. How many individuals does your organization employ?
   - Less than 10 employees
   - 10 to 49 employees
   - 50 to 99 employees
   - 100 or more employees

3. Please select all of the positions in your organization that you personally manage from the list below. (check all that apply)
   - Researcher
   - Educator
   - Consultant
   - Salesperson
   - Management
   - Other (please specify):
   - Other (please specify):
   - Other (please specify):

4. About how many employees do you manage with each type of background degree? (if none, please enter ‘0’)
   - Doctor of Plant Health or Doctor of Plant Medicine: (open-ended numeric)
   - PhD: (open-ended numeric)
   - Master’s degree: (open-ended numeric)
   - Bachelor’s degree: (open-ended numeric)
   - Other type of background degree: (open-ended numeric)

Section 2. Preparation and Performance

The purpose of the following questions is to determine your perception of how new employees are prepared to perform various tasks.

5. On average, how prepared is a new, recently hired Doctor of Plant Health/Medicine graduate in each of the following areas?

	Not at all prepared	Not very prepared	Somewhat prepared	Very prepared	Not applicable
Communicate clearly and efficiently					
Work in a team/ Collaborate with others					
Develop innovative approaches to problem solving					
Assess technical information					

6. On average, how prepared is a new, recently hired PhD holder in each of the following areas?

	Not at all prepared	Not very prepared	Somewhat prepared	Very prepared	Not applicable
Communicate clearly and efficiently					
Work in a team/ Collaborate with others					
Develop innovative approaches to problem solving					
Assess technical information					

7. On average, how prepared is a new, recently hired Master's degree holder in each of the following areas?

	Not at all prepared	Not very prepared	Somewhat prepared	Very prepared	Not applicable
Communicate clearly and efficiently					
Work in a team/ Collaborate with others					
Develop innovative approaches to problem solving					
Assess technical information					

8. In what areas do you feel the average new, recently hired Doctor of Plant Health/Medicine graduate is most prepared? (open-ended)

The purpose of the following questions is to determine your perception of how employees perform various tasks after one year of employment at your organization.

9. On average, how proficient is a Doctor of Plant Health/Medicine graduate in each of the following areas after one year of employment?

	Not at all proficient	Not very proficient	Somewhat proficient	Very proficient	Not applicable
Communicate clearly and efficiently					
Work in a team/ Collaborate with others					
Develop innovative approaches to problem solving					
Assess technical information					

10. On average, how proficient is a PhD holder in each of the following areas after one year of employment?

	Not at all proficient	Not very proficient	Somewhat proficient	Very proficient	Not applicable
Communicate clearly and efficiently					
Work in a team/ Collaborate with others					
Develop innovative approaches to problem solving					
Assess technical information					

11. On average, how proficient is a Master's degree holder in each of the following areas after one year of employment?

	Not at all proficient	Not very proficient	Somewhat proficient	Very proficient	Not applicable
Communicate clearly and efficiently					
Work in a team/ Collaborate with others					
Develop innovative approaches to problem solving					
Assess technical information					

12. In what areas do you feel the average Doctor of Plant Health/Medicine graduate is most proficient in after one year of employment? (open-ended)

Section 3. Your Doctor of Plant Health/Medicine Employee

13. How long has [name] been employed by your organization?
    - Less than six months
    - Six months to less than one year
    - One year to less than three years
    - Three or more years

14. Were you involved in the hiring process for [name]?
    - Yes
    - No

    a. *If yes* -How important was [name]'s Doctor of Plant Health/Medicine degree in your decision to hire them?
        - Not at all important
        - Not very important
        - Somewhat important
        - Very important

15. Why did you decide to hire a Doctor of Plant Health/Medicine graduate? (open-ended)

16. Thinking about [name], since they started working for you, have they received a promotion?
    - Yes
    - No

    a. *If yes* – About how long after they began working for you did [name] receive their first promotion?
        - Less than six months
        - Six months to less than one year
        - One year to less than three years
        - Three or more years

17. What unique qualities or abilities, if any, does a Doctor of Plant Health/Medicine graduate bring to your organization? (open-ended)

18. Please list five adjectives that describe the DPH/M graduate that you employ.

19. How likely would you be to hire another Doctor of Plant Health/Medicine in the future?
    - Not at all likely
    - Not very likely
    - Somewhat likely
    - Very likely

20. Please provide any additional comments you have about the Doctor of Plant Health/Medicine Program or your Doctor of Plant Health/Medicine graduate. (open-ended)

21. We would like to use quotations from responses to open-ended questions on this survey for promotional purposes (e.g., website, Facebook, brochures) in the future. All quotations will be presented in such a way that no one person can be identified. Do we have your permission to use your non-identifying quotations from this survey for future program promotional purposes?
    - Yes
    - No