Exploring the Alignment Among Employer Expectations for STEM Skills and the Design of Education Curricula and Interventions

Project Description

I. Significance and Relation to Existing Knowledge

This EHR Core Research proposal addresses the program focus of STEM workforce development, and the critical issue of how to most effectively train and teach the next generation of STEM professionals. Given the nature of work in the 21st century, which includes shifting demographics in the labor market, rapidly changing technology and distribution networks, and economic globalization, policymakers are understandably focused on how to best design an educational system that can prepare students for these new conditions (Karoly & Constantijn, 2004). These changes are especially pronounced in STEM-related sectors such as advanced manufacturing and biotechnology, which are projected to be two of the growth industries of the future (Setar & MacFarland, 2012; Indiviglio, 2011). Key positions in these industries (i.e., biomedical engineers and skilled labor technicians) will grow by over 60% between 2010 and 2020 (U.S. Bureau of Labor Statistics, 2012). Yet questions abound regarding the supply of adequately trained U.S. workers available to fill these positions of the future. The influential President's Council on Science and Technology (2012) recently argued that the nation will require over 1 million college trained STEM graduates over the next decade. Factors that may constrain the availability of skilled workers in these industries include an aging workforce, inadequate educational preparation, and limited on-the-job training programs (Competitive Wisconsin, 2012). While some question whether or not an actual shortage of STEM workers exists (e.g., Salzman, Kuehn, & Lowell, 2013), it is clear that basic competencies in core STEM skills will be indispensable for many workers across the entire U.S. economy (Carnevale, Smith, & Melton, 2011).

These concerns have led to a widespread focus on workforce or "talent" development among policymakers, educators, and employers. For example, President Obama has argued that educational programs that prepare students for success in the workforce are a national priority (Obama, 2013). While many of the nation's efforts in this area focus on vocational training and apprenticeship programs in secondary schools, many address educational offerings at the postsecondary level. Besides being required for many of today's job openings, some sort of postsecondary education enhances the earning power of individuals over their life course (Carnevale, Rose, & Cheah, 2011). Underlying the focus on postsecondary education as a tool for workforce development is the idea that these programs can meet the specific needs of employers, and that upon graduation students will be employable and can continue to excel throughout their careers. Yet this idea is based on two critical assumptions: first, that curriculum designers and STEM education professionals are cognizant of employer expectations, and second, that they are then able to design their programs with these expectations in mind.

Yet little empirical evidence exists that supports both of these assumptions. While some survey-based evidence exists regarding employer expectations for college graduates (e.g., Association of American Colleges & Universities, 2013), few rigorous analyses of STEM-related fields exist. The few surveys that have focused on fields requiring STEM competencies, such as advance manufacturing, reveal that employers desire both "hard" (i.e., technical) and "soft" (i.e., critical thinking, problem solving, team work) skills (Deloitte Manufacturing Institute, 2011). However, these surveys are limited in their methodological transparency and in their reliance on self-reported online surveys, which are necessarily limited in their ability to obtain in-depth, nuanced accounts of employer expectations. In regards to the alignment (or lack thereof) between employer expectations and the postsecondary curriculum and/or STEM education intervention design, no extant research has been identified. Finally, much of the public debate surrounding STEM skills tends to view these competencies in terms of technical skills as the primary "output" of education that are then "input" into a place of employment. This view ignores the fact that the goals of many educators go beyond the conveyance of job-ready technical skills, and that companies are complex organizations with unique sociocultural and technical systems that must be navigated by employees (Trist, 1981; Carayon, 2009). As a result, individual or company "success" must be seen as the product not solely of employee skills but as the aggregate result of the complex dynamics among organizational structure, culture, strategy, and human capital (cite). Thus, understanding how employers view the interaction among employee skills and other organizational factors is critical to improving the field's understanding of company success.

These gaps in the field of STEM education's knowledge base are problematic because assumptions about employer expectations are currently influencing national and state-level education and workforce development policy. For example, in the state of Wisconsin recent workforce development policy focused on funding technical training programs in 2-year colleges, with little attention paid to the development of "soft" skills or 4-year colleges and universities. Further, Wisconsin is considering a performance-based funding system for determining levels of state support for higher education, with metrics including the degree to which the curriculum addresses employer expectations. States such as Wisconsin are not alone in this approach, as Florida, North Carolina, and others are considering the incorporation of such metrics into their funding formulas for higher education. Yet without rigorous data regarding these expectations, policymakers are operating on unfounded assumptions (e.g., that employers solely desire technical skills) about what employers require in terms of human capital for their companies. While the focus on technical skills is important, a myopic focus on these skills is short sighted and actually contradicts the voices of employers who argue that soft skills are equally important for success in their fields (e.g., Deloitte Manufacturing Institute, 2011). Further, without insights into these issues, STEM education interventions related to workforce development lack important information about how to best design their programs so that they achieve their goals. Research shows that interventions that are designed with a robust understanding of the needs, local practices, and expectations of their "target population," which in these cases are places of employment, are more likely to ultimately succeed (Rogers, 1995; Cobb, Zhao, & Dean, 2009). Thus, an underlying assumption to this study is that a certain degree of alignment among these expectations, educational curricula, and educational interventions is desirable in order to effectively train students, enhance the nation's economic growth, and increase the prospects for STEM education initiatives to succeed.

In response to these gaps in the literature and their implications for STEM education, a study called "Exploring the STEM Skills Gap" was initiated in the fall of 2012 by the Center for Education and Work (CEW) at the University of Wisconsin–Madison (UW-Madison). The study utilizes a comparative qualitative case study design where in-depth interviews, on-site observations, and curricular artifacts are being collected and analyzed across the cases (i.e., individual organizations). Further, the study draws on a sociotechnical theory of organizations by focusing on the ways in which successful employees are able to bring a variety of skills and competencies (e.g., hard and soft skills) obtained through their education to navigate the complex features of their workplaces to perform at a high level. In this study, I have been interviewing employers in advanced manufacturing and biotechnology companies about the types of skills and competencies that they desire. Additionally, curriculum designers in postsecondary institutions (2- and 4-year institutions) with programs related to these industries are being interviewed to examine the degree to which these expectations are built into their programs. The study is focused on Wisconsin in order to capture, in as much depth as possible, how these factors operate within a single state. At the present time (July, 2013) about 7 site visits and 13 interviews have been conducted, for which Institutional Review Board (IRB) approval has already been sought and secured. Plans for this study include an additional 23 site visits and approximately 40 interviews to be conducted between July and December of 2013. The proposed study will expand upon that study to add 56 employers (n=102 interviews) and 21 educational organizations (n=70 interviews) to the existing dataset. In addition, a component to the study focusing on 14 STEM education interventions will be added (n=28 interviews). Thus, an additional 200 interviews will be conducted as part of the proposed work.

Research Goals

This EHR Core Research project has three interrelated goals.

1. To identify employer expectations for the types of skills, knowledge, and competencies required to succeed in their companies.

2. To ascertain the degree to which these expectations are integrated into the design of educational curricula and STEM education intervention design.
3. To explore the implications of the results regarding the alignment (or lack thereof) between employer expectations and the postsecondary curriculum for STEM education, particularly in light of debates regarding the costs and benefits of attending college.

Intellectual Merit and Broader Impacts

The proposed study will be the first of its kind to empirically explore the alignment among employer expectations and instructional design in STEM-related fields, and thus will contribute new knowledge about a critical issue of national import—how to effectively train and teach the next generation of STEM professionals. While results from a single state cannot be generalized to the entire country, insights generated by this study will represent actionable knowledge that can be used everywhere to design new curricula and interventions that are tailored to the actual experiences and needs of employers. Thus, the results will have broader societal impacts and will be of immediate value and impact. The dissemination plan includes a book related to STEM workforce development, peer-reviewed research articles, policy briefs, a media campaign tailored to policymaking audiences, presentations at academic and practitioner conferences, and an actively maintained project website. Finally, the research team has the expertise to conduct this work, and an outside team of highly qualified advisors will assess the work regularly.

Relation to EHR Core Research Goals

This research directly addresses the primary goal of the EHR core research program to expand the research foundation on a critical topic facing the nation—that of STEM workforce development. In particular, the study addresses the specific program component of STEM workforce development by empirically mapping backwards from employer expectations for STEM skills and aptitudes to the design of STEM educational curricula and pedagogical interventions. This fundamental problem will be studied using a rigorous research design that will contribute new knowledge, while also underpinning it with viable theory. The results from this study have the potential to establish a coherent foundation of evidence and theory that will be broad, essential, and enduring. Furthermore, given the integration of STEM education practitioners into the study sample and the pragmatic focus of the research itself, the results promise to guide the improvement of STEM education activities in the future. Finally, the proposed work leverages current NSF investments by including them as research sites.

A Call to Educate a Workforce with STEM Competencies

An overriding concern among policymakers and researchers of workforce and economic development is that the industries of the 21st century will require workers with competencies in the STEM disciplines. This applies to both “new” industries such as biotechnology and bioinformatics, as well as “old” industries such as manufacturing that are undergoing a technological revolution in how products are designed, made, and delivered. In this section is a brief overview of the changing nature of work in the 21st century, the requisite demands being placed on the educational sector, and the current debate about the “skills gap.”

Industries of the 21st century: The changing nature of work and demand for skills. In the past 100 years the U.S. economy has undergone a dramatic shift from a reliance on industrial manufacturing to a services-oriented economy. In 2000, employment in goods-producing industries represented only 16.8% of total U.S. non-agricultural employment, whereas services represented 73.8% (U.S. Bureau of Labor Statistics, 2012). The services sector is quite broadly defined, and includes retail, information, health care, and professional services, and it is in these areas where many high-skill jobs exist. Yet even while goods-producing industries such as manufacturing have declined in terms of share of national employment, these industries still play a critical role in the U.S. economy, representing approximately 30% of total gross domestic product. In the state of Wisconsin, manufacturing is actually the largest industry sector, representing 14% of state gross domestic product (U.S. Bureau of Economic Analysis, 2013). In both of these sectors, well-paying jobs such as research scientists, robotics technicians, and quality assurance engineers represent important job opportunities for U.S. students who have the requisite skill sets, many of which are based in the STEM disciplines (Carnevale, Smith, & Melton, 2011). Indeed, STEM-related sectors such as advanced manufacturing and biotechnology are projected to be two of the growth industries of the future (Setar & MacFarland, 2012; Indiviglio, 2011).

Within this broader context of the changing complexion of the U.S. and global economy, the nature of work and skills required by employers is also changing. In the 1970s, demand for routine manual tasks and related cognitive abilities declined, and nonroutine problem solving and analytic skills increased (Autor, Levy & Murinane, 2003). This underscores the importance of both technical expertise as well as skills in problem-solving, collaboration, and abstract reasoning in terms of the types of skills valued by employers (Carnevale, Smith, & Melton, 2011; Deloitte Manufacturing Institute, 2011). A recent survey by the Association of American Colleges and Universities found that employers are more interested in critical thinking and problem solving skills than the simple acquisition of a major (AAC&U, 2013). Similarly, the ACT states in its Work Readiness Standards and Benchmarks (2013) that work readiness skills include both fundamental cognitive skills (e.g., applied mathematics, problem solving, critical thinking) and what they term "noncognitive" or soft skills (e.g., behavioral skills)." Industry specific surveys reveal a similar emphasis on both technical and soft skill sets. Even in industries such as manufacturing that are commonly associated with routinized work, the growth of robotics and computerized supply chains increased the need for workers with skills in both of these areas. Further, the demand for STEM-related skills is increasing across the entire workforce, and not just for the elite group of workers that are often associated with these disciplines (e.g., laboratory researchers). Instead, more than one third of all jobs in STEM through the year 2018 will require educational training at less than the baccalaureate level (Carnevale, Smith, & Melton, 2011). Thus, teaching and training current and future generations in both hard and soft skills related to STEM fields will be of critical importance to meeting the nation's human capital and economic needs.

However, a variety of factors are converging that draw into question the ability of the U.S. to adequately prepare students for these projected job openings in STEM-related fields. These include an aging workforce and subsequently high rate of retirements, rapid technological advances in particular fields, and an educational system whose quality and attentiveness to workforce needs is increasingly questioned. For example, the mechanical engineering sector is predicted to have a shortfall in the domestic supply of workers, and is seen as one of the top job types in the U.S. that employers have difficulty filling (Competitive Wisconsin, 2012). While the reasons for apparent shortfalls are increasingly being debated, including whether or not a "skills gap" actually exists (Levine, 2013; Loritz, M., Nerad, B., Sletten, P. & Cunha, J., 2013; Salzman, Kuehn, & Lowell, 2013), there is consensus that the educational system could do a better job to prepare students for the 21st century economy. Given evidence that the U.S. educational system is lagging other nations in both STEM-related competencies as well as higher-order cognitive skills that employers demand (Hanushek & Woessmann, 2008), some view education as the primary vehicle through which these economic challenges can be met. Indeed, some even go so far as to characterize the nation's schools, colleges, and universities as the primary reason for the nation's economic woes (Sullivan, 2012). Indeed, calls for schools, districts, and legislative bodies to integrate 21st century skills such as STEM competencies and higher-order cognitive aptitudes are increasing (Partnership for 21st Century Skills, 2008). Since other nations maintain a competitive advantage with lower wages and less regulation than the U.S., some argue that the nation must maximize its traditional assets of a highly skilled, knowledgeable, and innovative workforce in order to maintain a competitive edge in the global economy (National Research Council, 2010). Thus, policymakers are focused on how to best design an educational system that can prepare students for these new conditions (Karoly & Constantijn, 2004).

Workforce development: The need for effective postsecondary training. While much attention is being paid to vocational education at the secondary school level, a substantial amount of attention is being paid to the role that the nation's colleges and universities can play in addressing these issues. Many of the jobs in these and other sectors in the coming decades will require some degree of postsecondary education. For example, the Georgetown University Center for Education and the Workforce reports that

Wisconsin will have 925,000 job openings between 2008 and 2018, and that "61% of all jobs in the state will require some sort of postsecondary training" (Carnevale & Smith, 2011). Specifically, 704,000 are projected to require "some college," 366,000 to require "associate degrees," 600,000 to require "bachelor degrees" and 255,000 to require "graduate degrees." This underscores the importance of higher education to obtain a position in the first place. Importantly, the baccalaureate is not the only route to obtaining highly valued skills. Instead, Carnevale, Jayasundara, and Hanson (2012) identified five pathways to career and technical education: associates degrees, postsecondary certificates, employer-based training, industry certifications, and apprenticeships. Further, evidence indicates that with postsecondary training, one's lifetime earnings increase substantially (Baum, Ma, & Payea, 2010). While scholars debate the precise nature of the demand for workers with different skills sets (e.g., Holzer, 2012; Autor, 2010), it is clear that those without some sort of postsecondary training will be at a distinct disadvantage.

While the focus on workforce development is not overly controversial in 2-year institutions and technical colleges, in many 4-year institutions, particularly research universities, this debate can be contentious. Recently, with a statewide focus on whether or not the University of Wisconsin system was adequately preparing students for the workforce, some faculty contended that UW-Madison was not a "job training facility" and in a piece titled "College is More than Job Training" Mamerow and Conrad (2012) argued that a focus on job placement ignores the role of traditional liberal arts programs in training students for success over their entire careers. In any case, some degree of focus on employability will likely persist in regards to postsecondary education, such that attention to the alignment between employer needs and curriculum design will increase in coming years. This can be done through the design of curricula and programs that are responsive to employer expectations. Yet what is often the missing link is that few, if any collaborations exist between the employer and educational sectors, such that curriculum designers and/or STEM education professionals lack knowledge about what employers need. An exception to this common situation is the field of engineering, which generally is attuned to these needs, partially through close relationships with alumni and local employers, and also through accreditation requirements that echo the needs and standards of industry. Lacking such insights however, can lead to a disconnection between how students are trained and what types of competencies employers expect.

Implications for STEM education. Why are these issues and debates important for STEM education? First, basic insights into the types of STEM competencies desired by employers would contribute to the field on its own merit. Second, research on reform implementation shows that interventions that are designed to "meet people halfway" as opposed to levying top-down change initiatives upon them are more likely to succeed (Helman, 1997; Rogers, 1995). Indeed, paying close attention to how the "target audience" interprets a new policy or innovation is a critical feature to effective design (Spillane, Reimer & Reiser, 2002; Fishman, 2005). In the workforce development literature, this view extends to how to best engage in collaborative work with employers, where some recommend that they be viewed as "customers" in order to ensure that their needs are being met by new programs (Weigensberg et al., 2012). At the very least, mapping backwards from workplace expectations for knowledge and competencies to the design of interventions will likely increase the prospects that a given project will meet the needs of employers, students, and educators. At a time where improving the alignment between the education and employer sectors is of critical national importance, the results from the proposed work will provide new and important research-based insights into the types of employer expectations that can serve as a foundation for intervention design.

Preliminary Wisconsin STEM Skills Gap Study

In the fall of 2012 the "Exploring the STEM Skills Gap" study was initiated with support from the CEW at UW-Madison (see http://skillsgapstudy.wceruw.org for more information; Matthew Hora is PI of this study). This small-scale study was motivated to address the growing public policy issue of the intersections among workforce development, education policy, and STEM skills within the state of Wisconsin. The industries included in the original study were selected due to their prominence in the future economic health of the nation, and also because they represent both old and new industries as they enter the 21^{st} century. The underlying theoretical framework guiding the study is that of a sociotechnical view of organizational functioning. This framework was selected in order to emphasize that employee skills are not the sole reason for a company's success or failure, but instead, that companies are complex organizations with unique sociocultural and technical systems that must be navigated by employees (Trist, 1981; Carayon, 2009). As a result, company operations should be viewed as the aggregate result of the complex dynamics among organizational structure, culture, strategy, and human capital (cite). Thus, understanding how employers view the interaction among employee skills and other organizational factors is a key goal of the study, and is also critical to improving the fields understanding of company success.

At the present time 7 site visits and 13 interviews have been conducted, and an additional 23 site visits and approximately 40 interviews will be conducted between July and December of 2013. Study sites are being identified through a list of companies compiled in part from a list of manufacturers provided by the Wisconsin Manufacturers and Commerce (WMC) group, and online listings of biotechnology companies. At this stage of the research, the response rate to solicitations for participation in the study is approximately 50%. Institutional Review Board (IRB) approval has already been sought and secured for this study, which would be extended to include the proposed work.

In addition to the seven site visits, the WMC also provided an extensive dataset based on over 30 focus groups that staff conducted in the winter of 2011–2012. Notes from the focus groups and one-page surveys administered to focus group participants regarding employer expectations were provided to PI Hora in March of 2013, and preliminary findings from these data and the seven site visits will be published in a policy brief by the Wisconsin Center for the Advancement of Postsecondary Education (WISCAPE) in August 2013. Results from the analysis of the surveys (n=181) indicate that 85% of employers surveyed were actively hiring new employees, and 74% were having trouble finding qualified applicants in categories including skilled labor, engineering (e.g., electrical, quality assurance), welding, and maintenance. In regards to the specific skills that employers felt were most desirable, 54% reported that a strong work ethic was important, while 25% reported math skills, and 20% reported social skills. Finally, 61% of the respondents stated that some of the positions in their company required an associate's degree, 60% reported that some required at least a high school diploma, and 44% reported that some required a 4-year degree or more.

At the present time, PI Hora is devoting 30% of his time to this study, which is being fully supported with funds from CEW. In regards to the proposed expansion of this study, the level of support from CEW will continue at 30% until May of 2015, with an additional 20% support from the EHR Core Research grant. After that point, the EHR Core Research grant would assume 50% support until the conclusion of the project.

A Question about Appropriate Methodologies

One of the issues raised by researchers and advocates in the field of STEM workforce development in general, and the skills gap in particular, pertains to the appropriate methodologies for research on these topics. On the one hand, most academic researchers working in these areas, especially labor economists, advocate for methodologically rigorous quantitative analyses of large-scale survey datasets. Examples of studies in this research paradigm include Salzman, Kuehn, and Lowell (2013), Levine (2013), and Loritz et al. (2013), which include replicable statistical analyses from publicly available datasets.

On the other hand, reports produced by industry-affiliated researchers (e.g., Deloitte Manufacturing Institute, 2011, Competitive Wisconsin, 2012) tend to report secondary datasets with no statistical analyses and/or replicable methods. In some cases, advocates of the skills gap idea utilize personal anecdotes from their own experiences in business, or relate stories from employers (Sullivan, 2012). The influential nature of these reports, and the apparent contradiction between their findings and those of most labor economists' analyses of skills gap issues, has led to a critique of methods that rely on anecdotes and personal stories. For example, Levine (2013) argued that proponents of the skills gap meme rely on "a stream of anecdotes from employers who claim they have lots of openings but can't find qualified workers," (p.13), which his own statistical analyses of the data seems to disprove.

II. Methodology

In this section I describe the research design for the proposed work, sampling procedures, data collection and data analysis techniques.

Research Design

The proposed study is guided by five research questions which are shown in Table 1.

Table 1: *Research Questions, and Relationships Between Data Collected and Analytic Techniques*

Research Questions	Data Collected	Analytic Techniques
1. What are employer expectations regarding the skills, knowledge, and competencies required for employees to succeed in their company?	• Semistructured interviews with employers (HR directors, CEOs, managers) • Site-visits and observations of facility and employee work	• Structured approach to grounded theory to identify categories of expectations and types of work environment; frequency counts of categories; matrices of themes by employer type
2. To what degree are curriculum designers in 2- and 4-year colleges aware of these expectations, and how, if at all, are these expectations integrated into the curricula?	• Semistructured interviews with curriculum designers • Curricular artifacts (e.g., course syllabi)	• See above
3. To what degree are STEM education intervention designers aware of these expectations, and how, if at all, are these expectations integrated into their programs?	• Semistructured interviews with STEM education intervention designers • Program artifacts (e.g., initiative websites, materials produced)	• See above
4. What are the similarities and differences in these expectations and program designs across study sites?	• See above	• Cross-case analyses of data, including search for themes across cases, interesting outliers, and patterns in similarities and differences among cases
5. What implications do the results have for STEM education in general, and workforce development and education policy in particular?	• All data collected above • Research literature on workforce development, college readiness, etc. • News and opinion articles	• Policy analysis of the collected data, research literature, and relevant policies for STEM education, workforce development, and education

Sampling

The sampling population of employers, educational organizations, and STEM education initiatives is limited to selected geographic regions of the state of Wisconsin, given the implausibility of adequately studying the entire state. The selected areas are based upon geographic, industrial, and demographic diversity, as well as the presence of both 4-year and 2-year educational organizations near population centers. The study will focus on the following seven regions across Wisconsin: the northern region (Douglas county), the central region (Marathon county), the western region (La Crosse county), the southwestern region (Crawford county), the eastern region (Brown, Winnebago, and Oconto counties), the southern region (Dane and Rock counties) and the southeastern region (Milwaukee and Ozaukee counties) (see Figure 1, below).

Figure 1: Map of Wisconsin and selected study counties

Within these regions, a nonprobability sampling procedure will be used to identify participants in three distinct groups: (a) companies engaged in manufacturing or biotechnology (as classified by North American Industry Classification System codes), (b) postsecondary institutions with programs related to these fields, and (c) STEM education interventions that are affiliated with these institutions. Once a sampling frame has been generated for each of these groups, for those not yet contacted by the research team, an introductory e-mail message will be sent asking for their participation in the study.

Employers. The employers included in the sampling frame for the study will represent industries that are included in biotechnology and manufacturing, the latter of which includes a wide variety of subsectors. For this study employers working in food and clothing manufacturing will be excluded, and those in sectors such as metal manufacturing, automotive parts manufacturing, and electronic equipment manufacturing will be included.

We will use two approaches to develop the sample for employers to contact for interviews and site visits. First, some employers are being selected due to their participation in existing STEM workforce development projects that also involve local educational organizations. Employers who are involved in projects such as these, which represent a natural opportunity to explore the alignment among employers, educational organizations, and STEM education initiatives, will represent the first method for building the sampling frame. Second, in cases where these initiatives do not exist, a list of manufacturers will be prepared using a database provided by the WMC, and a list of biotechnology firms will be prepared by compiling online white page and website listings. For this group of employers, potential study sites will be selected randomly from the larger sampling frame, and solicited via e-mail regarding their participation in the study. For regions that lack significant numbers of employers in either category, the category with the most dominant industry representation will be oversampled. Overall, 8 employers will be included in the study per region, for a total of 56 employers included in the entire study. Some examples of employers are included in Table 2.

Table 2: *Example of Employers in Manufacturing and Biotechnology in Selected Regions of WI*

Region	**County/City**	**Company Name**	**Number of WI Employees**	**Participant in STEM ed project?**
Central	Marathon/Schofield	T&D Tube Benders	105	N/A
Central	Marathon/Schofield	Greenheck Fan Corporation	1,800	N/A
North	Superior/Superior	Genesis Attachments, LLC	80	N/A
North	Superior/Superior	Calumet Superior, LLC	175	N/A

West	La Crosse/La Crosse	Ingersoll Rand/Trane	N/A	N/A
West	La Crosse/La Crosse	Chart Energy & Chemicals	N/A	N/A
Southwest	Crawford/Prairie du Chien	3M	N/A	Yes
Southwest	Crawford/Prairie du Chien	Miniature Precision Components	1,500	Yes
South	Dane/Middleton	Lucigen Corporation	105	N/A
South	Dane/Fitchburg	Promega	1,200 +	Yes
East	Brown/Green Bay	Fox Valley Metal-Tech	115	Yes
Southeast	Milwaukee/Wauwatosa	Briggs & Stratton, Inc	3,000 + (U.S)	Yes
Southeast	Waukesha/Muskego	Nucleic Resources, LLC	N/A	N/A

At each of the sites, at least two individuals will be interviewed, with a focus on human resource directors, chief executive officers, and front-line managers (n=102 employer interviews). (That is, individuals who are most cognizant with the requisite skill sets for succeeding at the company.)

Educational organizations. The educational organizations included in the study represent both 4-year and 2-year institutions in the University of Wisconsin system. Notably, one of the 4-year institutions is considered an institution with very high research activity (UW-Madison) whereas the other 4-year institutions are considered smaller master's degree granting institutions (i.e., Master's S) according to the Carnegie Classification system (Carnegie Classification, 2013), thus allowing for the potential to compare across institution types within the 4-year category. In addition, 2-year institutions in the 16-campus Wisconsin Technical College System will be included in the study. These institutions were selected due to their prominent role in the state for providing vocational training to Wisconsin residents. For each of the seven regions, one of each of the three institution types will be included in the study, with the final sample including 21 educational organizations. Of the 21 sites, 14 can be considered to be large institutions (e.g., an enrollment over 10,000) and 7 can be considered to be small institutions (e.g., an enrollment under 10,000). Examples of the types of institutions in two regions (East and South) are included in Table 3.

Table 3: *Examples of Educational Organizations in Selected Regions of WI*

Region	County/City	Institution Name/Type	Enrollment	Participant in STEM ed project?
East	Brown/Green Bay	UW-Green Bay/Master's S	6,665	Yes (NSF-Louis Stokes Alliance for Minority Participation)
East	Winnebago/Menasha	UW-Fox Valley/2-year	1,822	Yes (Fabrication Lab)
East	Winnebago/Appleton	Fox Valley Technical College/2-year	51,097	Yes (NSF-TUES)
South	Dane/Madison	UW-Madison/RU-VH	42,065	Yes (NSF-TUES; NSF-ATE)
South	Rock/Janesville	UW-Rock County/4-year comprehensive	1,289	Yes

South	Dane/Madison	Madison College/2-year	39,222	Yes (NSF-TUES)

At each of the 14 larger institutions, up to 4 individuals will be interviewed, whereas at each of the 7 smaller institutions, up to 2 individuals will be interviewed, for an estimated final sample of 70 interviewees. Participants will be selected based on their central role in designing the curricula for degree and/or certificate programs that are directly related to manufacturing and/or biotechnology.

STEM education interventions. Finally, 14 STEM education interventions will be included in the study. These interventions will include both NSF-funded projects as well as other initiatives funded by other government, private foundation, and institutional agencies. Specific projects will be identified through a review of the NSF grants database for Wisconsin, which have uncovered projects such as two NSF-TUES (Transforming Undergraduate Education in STEM) projects including one at Fox Valley Technical College (DUE # 1104199 Digital Fabrication Learning Community) and at Madison College (DUE #1205015 Career Education in Renewable Energy Technology). Ideally, at least one intervention will be located in each of the seven regions included in the study, but in some locations there may be limited STEM education activity. Contacts for each intervention will be contacted via e-mail and invited to participate in the study, and at each of the intervention sites, two individuals knowledgeable about the intervention will be interviewed..

Table 4: *Example of STEM Education Interventions in Selected Regions of WI*

Region	County/City	Institution Name/Type	Intervention name	Affiliated orgs and employers
East	Winnebago/Appleton	Fox Valley Technical College	Digital Fabrication Learning Community (NSF-TUES)	N/A
South	Dane/Madison	Madison Area Technical College	Career education in renewable energy technology (NSF-TUES)	Yes; regional renewable energy companies
South	Dane/Madison	UW-Madison	Manufacturing Engineering Technologist and Technician Education (NSF-ATE)	Yes; regional technical colleges and manufacturers

Data Collection Procedures and Measures

Types of data collected for this study include semistructured interviews, on-site observations, curricular artifacts related to formal course and/or program curricula (e.g., syllabi), and STEM education interventions. The research team will gather interview and site visit data in Year 1 of the study at 56 companies, 21 educational organizations, and 14 STEM education intervention sites. At each of these sites, we will collect a slightly different set of data. At places of employment, we will conduct in-depth interviews and on-site observations. At each educational organization and STEM education program, we will conduct in-depth interviews and collect artifacts related to course curricula (e.g., course syllabi). Finally, throughout the duration of the study, documentary evidence such as labor market reports, news media stories, and research articles will be collected and analyzed.

A team of three researchers (i.e., the PI, a project director, and a graduate student) will conduct all data collection activities. Overnight trips will be required to five of the regions, while day trips can be made to locations in the southern and southeastern regions of the state. Prior to data collection, all researchers will undergo a rigorous training program. This training will include review of human subjects protocols, practice using all interview protocols, and training on how to conduct all facets of the site visits.

Interviews. The interviews with each group of respondents will utilize a semistructured protocol. That is, while a predetermined number of questions will be developed and included in the protocol, interviewers will be encouraged to allow respondents to follow ideas and observations that are tangential to the original line of questioning. In addition, the protocol will include possible probes to encourage deeper reflection on certain topics that the interviewer deems promising. This tradition of interviewing is based on the ethnographic interview technique of Spradley (1977), in which a balance is struck between interviewer and respondent control.

Separate protocols will be developed for each group of respondents. The employer interview protocol will include questions about:

- The skills desired in new hires across various job categories;
- Employer experiences with the current labor market, and if they have experienced difficulty in finding qualified applicants for job openings;
- Views towards on-the-job training, and what opportunities exist for employees to seek professional development; and
- Employer level of understanding of local educational programs and/or STEM education initiatives, and experiences with industry-education partnerships.

The education professional protocol will include questions pertaining to:

- The different factors considered when designing the curriculum;
- The degree to which employer expectations are considered as part of the curricular design process, and how knowledge about these expectations is obtained;
- Insights into participants' experiences in the job market after leaving the program; and
- General views on the growing focus on vocational preparation in postsecondary education, and its relationship to nonvocational courses or skills (e.g., English, history).

Finally, the STEM education intervention interviews will include questions about:

- The specific activities of the program;
- The degree to which employer expectations were integrated into the design of the program;
- Views regarding the challenges and successes of the intervention, and how (if at all) better information regarding employer expectations could have enhanced the program; and
- Insights into participants' experiences in the job market after leaving the program.

Site visits. At employer facilities the research team will request tours of the facility, especially the shop floor where company activities are underway. This will provide important insights into the nature of the work being done at the company. During these tours researchers will take detailed notes about the type of work being observed, statements made by the individual giving the tour, and other interesting facts or observations. In the course of conducting preliminary data collection, several tours of workplace facilities have been given to the PI. These tours have been extremely useful and provided important data to complement interview-based statements about important worker skills and aptitudes.

Curricular artifacts. At each of the educational organizations and STEM education intervention sites, researchers will collect artifacts related to the curriculum and/or program. These will provide evidence about the types of material instructors hope students will learn, expectations for student learning, and if employer expectations or workforce considerations are built into the course or program. These artifacts will likely include course syllabi, degree or certificate completion documents, program brochures and websites, and so on.

Documentary evidence. Documentary evidence will be collected regarding STEM skills and workforce development to complement the primary dataset. These likely will include resources such as labor market reports such as those provided by the Wisconsin Department of Workforce Development and the Bureau of Labor Statistics, research articles on workforce development, news items from print and online sources, and other such information.

Data Analysis

The primary goals for the data analysis procedures used in this study are to identify common themes regarding employer expectations and curriculum or intervention design, and similarities and differences in these phenomena across the entire study sample. As a result, the techniques used in the study will include the following widely known qualitative data analysis procedures: (a) a structured approach to grounded theory in order to identify categories of employer expectations, and principles of curricula and intervention design; (b) frequency counts of key topics or themes and matrices of these topics or themes by organization and/or institution type; (c) exploratory data reduction techniques; and (d) cross-case analyses to identify patterns across cases. In addition, all secondary data (e.g., research literature and reports) will be analyzed in preparation for the writing of research papers, policy briefs, and the book.

Step 1: Developing a data archive for all datasets. Given the distinct types of data being collected for this study, it will be important to develop a data archive where all data are organized in a coherent and easily accessible fashion. To do this, we will utilize NVivo® qualitative data analysis software. NVivo® allows for the storing of text, graphic, and soundfile data by certain attributes (e.g., institution type, region) so that data can be sorted or organized according to different groupings. For example, all interviews and site visit data for the southern region for this study could be grouped and analyzed as a whole. This process will enable researchers to aggregate data according to different criteria, and to then analyze these data in an efficient manner. Perhaps most importantly, this organizational procedure is already taking place as part of the preliminary study, and will continue as long as new data are being added to the larger study dataset.

Step 2: Inductive thematic analysis of interview transcripts, site visit notes, and curricular artifacts. The interview and documentary data will be analyzed using an inductive approach to thematic analysis, which entails an open-coding process based on grounded theory techniques. This approach involves a combination of inductive analyses of textual data and consideration of theory that is external to the data (Strauss & Corbin, 2007). The first step in this process entails segmenting the complex transcripts into more manageable units. To do this, the research team will use an inductive, open-coding process in which new codes were created from terms, phrases, or ideas in the text. To develop the initial codes the analysts will review five randomly selected transcripts and independently create a list of codes that describe higher-order categories that align with the interview questions (e.g., employer expectations regarding soft skills). The researchers will then meet to develop a final code list, which will involve each analyst comparing each successive instance of the code to previous instances in order to confirm or alter the code and its definition (i.e., the constant comparative method; Glaser & Strauss, 1967). After coding the initial selection of data, the analysts will meet to discuss the new codes and collaboratively developed a new code list. The researchers will then apply the coding scheme to all transcripts, which will result in an extensive NVivo® library of coded text.

Next, the researchers will analyze the coded text to identify themes and patterns in the data. This process will involve reviewing transcripts and/or "reports" of coded text categories, and then identifying recurring language, ideas, or themes in the text (Ryan & Bernard, 2003). This is an inductive analytic process where close attention will be paid to discerning meaning from the statements of respondents themselves. For this critical analytic step, interrater reliability checks will be performed in order to guarantee that emerging ideas and themes are not simply the product of an individual analyst's interpretation. Additionally, data will be presented at regular team meetings to help develop robust interpretations and to confirm or dispute emergent findings.

Step 3: Preparing frequency counts and data matrices of results for different categories. Once themes and patterns have been identified from the transcripts, site visit notes, and curricular artifacts, it is useful to report these findings in graphically appealing ways (Miles & Huberman, 1994). For this study two common methods will be used. First, frequency counts for each theme will be provided in tabular form. For example, a common theme among employers may be that they expect a strong work ethic from their employees. If 34 employers mention this theme, that figure would be reported in a data table. Further, these data can be disaggregated by various attributes linked to respondent groups, including employer type and size, geographic location, educational organization type, and so on.

Step 4: Conducting exploratory data reduction analyses. It is worth noting that these qualitative data, once translated into frequency counts and put into tabular form, can also be analyzed using exploratory data reduction techniques such as multidimensional scaling and exploratory factor analysis (Namey, Guest, Thairu & Johnson, 2007). Such analyses can help to identify patterns in the data that are not readily apparent in frequency counts and data matrices. Using the tables prepared in Step 4, such analyses will be undertaken in order to explore trends or patterns in the data. Examples of exploratory data reduction analyses utilized with qualitative data can be found in Ferrare and Hora (2012).

Step 5: Cross-case analysis to identify similarities and differences across cases. Data tables and matrices can be used to conduct cross-case analyses, which entails identifying similarities and differences across cases. Analyses across the entire sample with no consideration of organizational attributes (e.g., size or type of employer or institution) will be conducted first, which will allow for the identification of unique situations, common themes or instances, and interesting outliers among the entire study sample (Yin, 2008). Then, analyses across cases with these attributes in mind can be conducted, in order to discern patterns across institutions of a similar type (e.g., large employers, 2-year educational organizations).

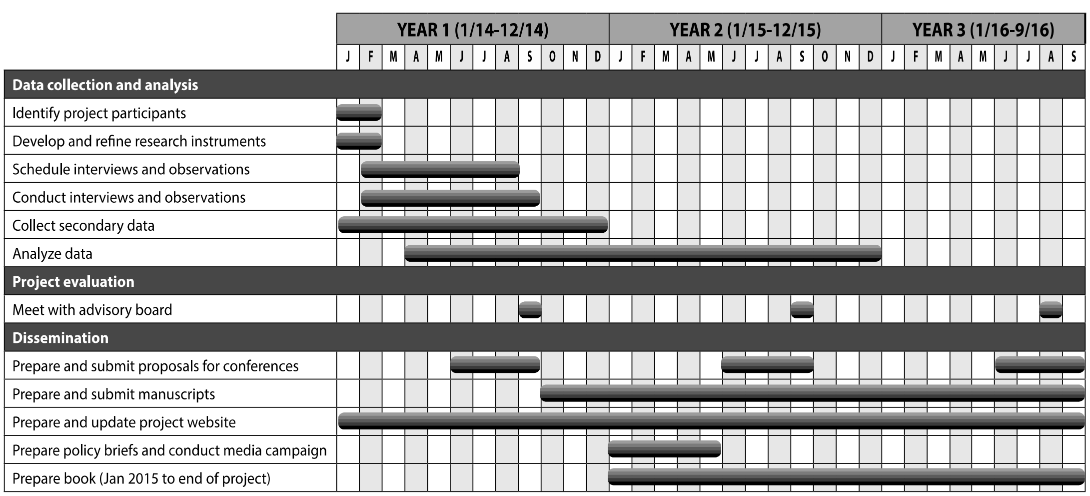
Step 6: Documentary analysis of secondary datasets. Finally, publicly available research papers and reports, news articles, and other secondary data will be analyzed to provide supplementary evidence and background information for the interview and documentary data. These datasets will be mostly used to provide background context for publications coming out of this project, especially the policy briefs and the book, both of which will require situating the study within the broader national debate about workforce development and STEM education.

III. Project Personnel and Management

Plan of Work

Table 5 depicts the plan of work over the course of the proposed project.

Table 5: *Plan of work*



PI and Senior personnel

The PI, Matthew Hora (.20 FTE) will act as the project director, and in this role, he will develop the research design and data collection instruments, as well as oversee all data collection and analysis activities. Hora will also coordinate the plan for broader dissemination of the project's work and mentor the UW-Madison based graduate student. As previously noted, the UW-Madison Center for Education and Work is supporting PI Hora on this study at 30% FTE until May of 2015. The requested support from this grant is to increase Hora's time by 20% between January 2014 and May of 2015, and then to assume 50% support from June 2015 through the end of the grant period. A to-be-determined Associate Researcher (.50 FTE) will assist PI Hora in all project activities, particularly in coordinating all site visits, cataloguing data, and assisting with data analysis and manuscript preparation.

Graduate Student Training Opportunities

As part of the proposed work two graduate students will be directly involved in implementation of a major STEM education research project. As a result, the study will play a role in training the next generation of STEM education researchers in rigorous qualitative research methods and in a topic that will be of critical importance to the nation in coming decades (i.e., workforce development). This study will provide opportunities for two graduate students at UW-Madison in STEM education or other aligned fields. Students will assist with instrument design and field-testing, data collection, analysis, manuscript preparation and data dissemination. They will be encouraged to take a leadership role in particular aspects of the project that fit their career goals, and writing research papers and presenting at academic conferences will give them the opportunity to develop technical skills needed as aspiring scholars.

Project Capacity: Results from Prior NSF Support

Matthew Hora is the PI on the "Tracking the process of data-driven decision making in higher education," NSF DUE-1224624 ($593,844) funded from 2012 through 2015. This grant is examining the use of formative and summative data in how faculty and administrators make curricular decisions. The study is also field-testing the "Instructional Systems of Practice" framework (see Hora & Ferrare, 2013) by collecting interview, observation, and student focus group data and reporting the data back to decision makers to ascertain its utility in the field. Data from the first wave of data collection (spring 2013) are currently being analyzed. Hora was also the co-PI and Project Director on the "Culture, Cognition and Evaluation of STEM Higher Education Reform," NSF EHR-0814724 ($797,748), funded from 2008 through 2012. This grant examined the cognitive, cultural and contextual factors related to faculty teaching. Five publications have appeared from this research, including two WISCAPE policy briefs and three peer-reviewed journal articles such as "Instructional systems of practice: A multidimensional analysis of math and science undergraduate course planning and classroom teaching" which appeared in the Journal of the Learning Sciences, and "Perceived norms for interactive teaching and their relationship to instructional decision-making: a mixed methods study" which appeared in Higher Education. In addition, eight manuscripts are in various stages of the publication process based on data from this project.

IV. Evaluation and Dissemination

An external advisory board will provide technical and managerial oversight to the project. The advisory board will provide substantive external review through both formative evaluation of the project's research design and initial progress, as well as summative evaluation of the project's success in meeting its objectives. A core feature of a robust evaluation plan is a set of measurable objectives that external evaluators can use to objectively gauge the progress of a particular project (Frechtling, 2007; NSF, 2002). The primary objectives for Year 1 include: conduct 102 interviews at 56 places of employment, conduct 70 interviews at 21 educational organizations, and conduct 28 interviews at 14 STEM education intervention locations. The advisory board will evaluate the project objectively and provide rigorous assessments of its progress and ultimate efficacy. Board members will meet with project staff via videoconference each year, whereupon they will assess the progress in meeting the project's goals and objectives, as well as any emergent issues. The following individuals will serve on the advisory board:

Dr. Allen Phelps is a senior scientist at the Wisconsin Center for Education Research (WCER) and director emeritus of the Center on Education and Work. Dr. Phelps is a nationally recognized expert on career and technical education, and is currently the PI of the NSF-funded METTE project that focuses on workforce development in manufacturing engineering. **Dr. Sam Stern** is a professor of education at Oregon State University where he specializes in workforce development, continuing education, and international technical education issues. **Dr. Matthew Zeidenberg** is a Senior Research Associate at the Community College Research Center at Columbia University. Dr. Zeidenberg is an expert on the evaluation of student development programs, and has extensive experience on studying student pathways throughout their educational trajectories. **Dr. Valerie Lundy-Wagner** is also a Senior Research Associate at the Community College Research Center, where she specializes in postsecondary access and completion issues in the STEM disciplines.

Dissemination Plan

The impacts of the proposed work will be extended through the dissemination of research findings through multiple venues and to academic, practitioner, and policymaking audiences. The results of this research will address a critical issue of national import—how to effectively train and teach the next generation of STEM professionals. While results from a single state cannot be generalized to the entire country, insights generated by this study will represent actionable knowledge that can be used to design new curricula and interventions that are tailored to the actual experiences and needs of employers. Thus, the results will have broader societal impacts and will be of immediate value and impact to diverse audiences across the nation. In order to maximize the potential of the study results to have such broad impacts, a multifaceted dissemination plan has been developed in order to effectively reach a variety of audiences.

Book on STEM workforce development. We plan to write a book on STEM workforce development. The book will include quotes, and graphics (e.g., charts of data) and will be written in a nonacademic tone. The model for the book will be "A Guide to Building Education Partnerships" (Hora & Millar, 2010), which was written as a practical guide for how to design and then implement a partnership. While the book based on the proposed study will not provide such hands-on advice regarding educational work, it will be written in an engaging and jargon-free style in order to appeal to a wide readership.

Research articles. We will produce several research articles that will be submitted to peer-reviewed journals. These papers will be written for academic audiences and will constitute the primary venue through which the study contributes to the knowledge base on STEM workforce development. Prospective outlets for these manuscripts include the Journal of Education and Work, the Journal of Higher Education, and the American Educational Research Journal.

Policy briefs and media campaign. We will write summaries of research findings in short policy briefs through WISCAPE. WISCAPE provides editing services for UW-Madison-based scholars to translate empirical research findings into short pieces that are designed to reach policymakers. Two widely read policy briefs have been written in the past based on prior NSF support (Hora, 2010; Hora & Holden, 2012). In addition, with the publication of a policy brief, a media campaign will be implemented in order to disseminate key findings and policy recommendations to a wide audience. With support from communications specialists at WCER, the PI will work to craft a press release that will be widely disseminated to local, regional, and national media outlets, including the Chronicle of Higher Education, and the Milwaukee Journal-Sentinel.

Conference presentations and project website. We will present preliminary and completed research findings at conference presentations such as the Association for the Study of Higher Education, the National Association of Workforce Development Professionals, and various STEM education meetings and conferences. We will also establish a project website to disseminate our findings, news related to STEM workforce development issues, and related activities to a worldwide audience.