Chapter 3
A Regional and Transdisciplinary Approach to Educating Secondary and College Students in Cyber-Physical Systems

Cliff Zintgraff, Carolyn Wilson Green and John N. Carbone

Background

In the U. S. President's Council of Economic Advisors (PCAST) report titled *Leadership Under Challenge: Information Technology R&D in a Competitive World* [1], the Council notes four research areas which "should receive disproportionately larger increases because they address issues for which progress will have both the greatest effect on important applications and the highest leverage in advancing NIT capabilities." The first area listed is "NIT Systems Connected with the Physical World … cyber-physical systems" (p. 2). Cyber-physical systems will be an arena of intense economic competition, with the PCAST report noting EU investment of over US$7 billion between 2007 and 2013. The U. S. National Research Council (2001) [2] reports "the verge of another revolution…networked systems of embedded computers…could well dwarf previous milestones in the information revolution" (pp. 1–2).

Defined by the PCAST report as "NIT systems connected with the physical world" (p. 31), cyber-physical systems are often real-time and critical in nature. They include defense and intelligence systems, air traffic control, power grids, water supply systems, vehicles, clinical and home healthcare, environmental monitoring, industrial process control, and ground transportation management. Cyber-physical systems "[synthesize] knowledge from the physical sciences, mathematics, engineering, biological sciences, computer science, and other fields to model and simulate such systems in their full complexity and dynamics; [this includes] the interactions among potentially many dynamic systems and

C. Zintgraff (✉)
University of North Texas, Denton, USA
e-mail: cliffzintgraff@my.unt.edu

C. W. Green
Texas A&M University-San Antonio, San Antonio, USA

J. N. Carbone
Raytheon Company, Garland, USA

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components in uncertain environments" (p. 32). Lee [3] associates cyber-physical systems with "high confidence medical devices and systems, traffic control and safety, advanced automotive systems, process control, energy conservation, environmental control, avionics, instrumentation, critical infrastructure control (electric power, water resources, and communications systems for example), distributed robotics (telepresence, telemedicine), defense systems, manufacturing, and smart structures" (pp. 1–2) and notes that "the resulting research agenda is enormous, spanning most disciplines within computer science and several within other engineering disciplines" (p. 8). The PCAST report says that we must "enable industry and universities to collaborate on pre-competitive research in these systems" (p. 33).

To address workforce demand for cyber-physical systems, industry and universities will need a qualified workforce. The complexity of these systems strongly suggests that workers and researchers in these fields cannot be narrowly focused. They need to be comfortable working with people and concepts from disciplines besides their own. Ideally, their training will be from more than one discipline.

Literature Review

The authors propose a regional, transdisciplinary approach to cyber-physical systems education. The literature foundation for this proposal includes *transdisciplinarity*, *workforce context*, the *centrality of regional approaches*, and *lessons drawn from related industry clusters*.

The Transdisciplinary Approach

This chapter views the challenge of educating secondary and college students in cyber-physical systems through the lens of *transdisciplinarity*. Many find the concept difficult to distinguish from other multi-discipline approaches. Various overlapping definitions and distinctions between related multi-discipline approaches are found in the literature. As an essential foundation of this paper, it is important to identify key transdisciplinary concepts that are of particular relevance for cyber-physical systems education, in order to highlight their special nature and implications, and to clarify the meaning of the term as applied in this paper. The reader is encouraged to focus on the principles essential to transdisciplinarity, rather than on the finer points of multi-discipline definitions.

Ertas (2000) [4], Tate et al. [5], and de Freitas et al. [6] provide varying interpretations of transdisciplinarity and related concepts. Problem-solving methods involving insights from multiple disciplines are variously referred to as *multi*disciplinary, *inter*disciplinary, *cross*disciplinary and *trans*disciplinary. Definitions of these terms often overlap but tend to differ in important ways.

Approaching these distinctions narratively, it is possible to approach a problem by: (1) applying a single discipline's concepts or methods to the question at hand; (2) applying multiple disciplines to the problem, using each independently; (3) applying multiple disciplines to the problem, allowing the disciplines to co-mingle, potentially creating new concepts and methods; or (4) bringing multiple disciplines to bear, refusing to be bound by any of the disciplines' rules and methods and aggressively mixing ideas from within and outside the disciplines, unafraid to pick a concept or method from anywhere, interact with anyone, or create new concepts and methods at will.

Ertas (2000) [4] described the goals of a transdisciplinary education and research endeavor. In the process, he describes the nature of the transdisciplinary model, suggesting it "transcends the artificial boundaries imposed by traditional academic organizational structures and directly addresses … [problems] related to the solution of large and complex problems by teams consisting of many people from diverse backgrounds" (p. 15). Madni [7] provides further insight into the process of developing a transdisciplinary perspective, noting that "[bridging] independent disciplines typically requires extending them, reconciling their differences, and unifying the knowledge associated with them in new and novel ways" (p. 1).

Figure 3.1 provides a summary of these concepts and an illustration of their distinct approaches. The non-partisan "unicorns" represent our view of transdisciplinarity in this paper. Calling on definitions and elaboration from Tate et al. [5] and de Freitas et al. [6], we highlight these transdisciplinary principles as foundational to the approach of this paper:

- Disciplines are good. They provide philosophy, concepts and methodologies for approaching problems that once were beyond human capacity to address.
- Like any good thing, disciplines have negative impacts when they lead to mental rigidity in situations novel to that discipline.
- Complex problems are multi-dimensional. They are scientifically complex; operate inside complex systems; involve hard and so-called soft sciences; and at a minimum appear unpredictable because of their complexity.

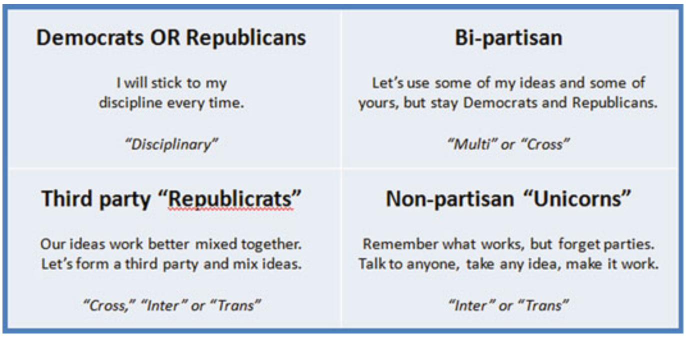

Fig. 3.1 Distinguishing *Trans*disciplinarity

- Problems like these should be approached by collaborators from every relevant discipline, within practical reason.
- Collaboration levels are high, and collaborators set aside disciplinary restrictions. Openness and a high level of mutual respect are cultural values.
- An iterative think-and-do approach is warranted, valuing philosophical inquiry, theoretical inquiry, development of solutions, and critical analysis and iteration.
- The possibility exists that a new discipline is being created with its own philosophy, concepts and methods. A transdiscipline may (or may not) be a stepping stone to a new discipline.
- The fundamental enabler for transdisciplinarity is creating the environment that allows all participants to act according the principles above.

The authors view the essential task of transdisciplinary inquiry as creating an environment where disciplinarians can, speaking colloquially, *let their hair down, relax, and create new solutions to problems*. This involves characterizing the problem domain, characterizing the larger system, identifying the relevant disciplines, and creating a platform for common work. The remainder of this paper considers cyber-physical education in the terms of this section.

Workforce Concerns: Meta-Context and Implications

The challenge of fostering industry and university collaboration raises the question of who will work in these companies and colleges to accomplish the important work at hand. This is not an idle question given the numerous examples where regions and industry clusters have struggled to reach their full potential for lack of a workforce and regional support ecosystem. A quick review of literature in other fields reveals a sobering meta-context. In the U. S., workforce shortages are acute in numerous fields. There are multiple factors causing these shortages, including the aging of the Baby Boom generation, shifting demographics, and the decline of selected industries and the rise of others; this last factor is a significant underlying cause of what the Harvard Business Review calls a *skills shortage* (Dychtwald et al. 2006 [8]). They report that "the Employment Policy Foundation (EPF) estimates that 80 % of the impending labor shortage will involve skills, not numbers of workers potentially available" (p. 6); and "overall, the United States will need 18 million new college degree holders by 2012 to cover job growth and replace retirees but, at current graduation rates, will be 6 million short" (p. 11). Shortages are reported across all sectors: in medical fields, allied health, geriatric care professionals, social work [9]; geosciences (Gonzales and Keane 2006 [10]); energy [11]; and manufacturing [12]. In cyber security, according to the Center for Strategic and International Studies, "there are about 1,000 security people in the U. S. [who can] operate effectively…we need 10,000–30,000" [13, p. 1].

Workforce challenges are not limited to the U. S. In India, where workers of all types (unskilled, skilled and professional) had to be imported from China to build the Delhi airport, "the country needs to train 500 million skilled laborers by 2022 if its current economic growth is to continue" [14]. The health workforce crisis is global, affecting the U. S., Europe and Africa; [15, 16] the utility infrastructure workforce faces challenges in North America, Europe and Japan [17]; China faces "structural problems [with] a labor shortage in some professions, industries and regions;" South China's Guangdong province, the nation's production and export base, is short "about 800,000 laborers this year" [18].

This meta-context informs us that cyber-physical systems as a global field will demand systematic efforts to raise a competent, scalable workforce. The same underlying challenges from other fields apply. The multiple disciplines involved and the associated concerns of workforce education and training, college experiences and K-12 preparation complicate matters. Poovendran (2010) [19] asserts that "current educational and workforce training frameworks are not sufficient" (p. 1365), citing the need for courses that integrate across computer science, engineering, anthropology and sociology. The transformation needed moves beyond interaction among existing disciplines. We must "develop a workforce with new skills…where the traditional disciplinary boundaries need to be redefined in all levels of training and education" (Dumitrache 2010 [20], p. 4).

Regional Motivators: Education, Training, Workforce, and Economic Development

While there are clear global, national, regional and organizational layers to consider, much focus on education, training, innovation and economic development occurs at regional, i.e., city or greater metropolitan area scope. Cooke [21] defines a region as being homogenous around specific criteria, possessing internal cohesion, and defined and driven by its internal cohesion needs, vs. being driven from size considerations or political borders. Cooke suggests that the [22] seminal definition of an *industry cluster* can help define a region. Porter defines an industry cluster as "a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities" (p. 1998). Mills et al. [23] note characteristic attributes: participants in the cluster are concentrated, economically motivated, transact intensively, and cover a broad range of business activities like R&D, marketing, sales, services, finance, and operations.

Porter also notes the importance of regional support systems, an attribute of clusters that receives additional focus in the *technopolis* work of Smilor et al. [24]. In their *technopolis wheel* model, the authors note the broad array of elements needed to support a technopolis. The term *polis* evokes the "city-state, reflect[ing] the balance between the public and private sectors" (p. 50). One factor especially important in a technopolis is "attraction of major technology companies" (p. 50). Mills et al. [23]

note that an important factor to companies is "related research, education, and training institutions such as universities, community colleges, and workforce training programs" (p. 9), reinforcing the assertions of the technopolis model.

The regional opportunities afforded by cyber-physical systems powerfully align with classic regional interests: education, economics, quality of life, and both practical and noble desires to contribute to important national and global challenges. Kitson et al. [25] report "there is now widespread agreement that we are witnessing the 'resurgence' of regions as key loci in the organization and governance of economic growth and wealth creation" (p. 991). In Mills et al. [23], whose writings appeared in the Brookings Institute publication *Blueprint for American Prosperity: Unleashing the Potential for a Metropolitan Nation*, the authors make the case for regional strategies. They note the relative inactivity of the federal government's support for region-based strategies, despite the prominence of these strategies in the foreground of overall economic development discussion, and they advocate more U.S. federal support. Cooke (2001) [26] explains the drivers of the trend toward region-based initiatives, referring to the region as the "more natural economic zone" (p. 4). With globalization as the macro trend, Cooke views the nation-state's relative strategic position vs. regions as declining. When regions have developed robust clusters of core actors and supporting organizations, such economic communities of interest are highly motivated to compete, and they interact directly with domestic and foreign partners, directly attracting foreign direct investment. Globalization drives foreign direct investment as economic actors seek the most efficient location for business activities. A virtuous cycle ensues, as "the to and fro of adjustment between companies, markets, public authorities, research institutes, training institutions and social partners [transform] each, while creating the elements of an innovative framework that may encompass and stabilise them all" (p. 4).

It is important to recognize the deeper drivers for regional strategies. Kitson et al. [25] believe that regional strategies are more about "long-run prosperity than…restrictive notions of competing over shares of markets and resources…ultimately competitive regions and cities are places where both companies and people want to locate and invest" (p. 997). K-12 education, higher education, workforce training, robust industry clusters, and high-wage jobs, not to mention arts and culture, all connect to long-term prosperity and quality of life for citizens.

Drawing Lessons from Related Clusters

The authors performed a search for formal industry clusters in the field of cyber-physical systems.[1] No formal clusters were found. The authors speculate this is

[1] Some sites self-identified as clusters. However, the authors chose to require clear documentation of specific industry connections and evidence of a local collection of interdependent industries. Supporting data were not immediately forthcoming for the sites investigated.

simply for lack of formal definition, as based on a simple web search and the personal knowledge of the authors, there are U.S.-based clusters of *activity* in Austin, Texas; Dallas, Texas; and around Oregon State University [27] and the University of Connecticut [28]. Nevertheless, related clusters in cyber security offer a robust proxy from which lessons can be drawn for clusters in cyber-physical systems. Noted are the similarities in secondary school preparation, college coursework, job attributes, and field complexity, not to mention the concrete overlap between the two fields. U.S.-based cyber security clusters identified are geographically based in Maryland; San Diego, California; and San Antonio, Texas.

The *Maryland Cybersecurity Center* (*MC*^{2}) at the University of Maryland "[partners] with government and industry to provide educational programs to prepare the future cybersecurity workforce, and develop new, innovative technologies to defend against cybersecurity attacks." MC^2's approach is holistic, interdisciplinary, and includes solutions engineering, computer science, economics, social sciences and public policy. Cybersecurity education is workforce-relevant, applying a "teaching hospital" model that includes "undergraduates, graduate students and industry professionals" working "practical cybersecurity challenges" (MC^2[29–33], About the Maryland Cybersecurity Center). MC^2 explicitly promotes technology commercialization and entrepreneurship through connections to various university programs and competitions. Industry partners include Northrop–Grumman, Lockheed-Martin, SAIC, Google, Sourcefire and CyberPoint (MC^2[29–33], UMD and CyberPoint announce new cybersecurity partnership); (MC^2 [29–33], Corporate partnerships in cybersecurity). A Cybersecurity Club has over 300 student members engaging in competitions, and hearing from distinguished speakers and industry experts (MC^2 [29–33], Cybersecurity education). There are cybersecurity concentrations, and their ACES program is claimed as "the nation's first undergraduate honors program in cybersecurity" (MC^2 [29–33] Advanced cybersecurity experience for students). In addition to MC^2, a *National Cybersecurity Center of Excellence* (*NCCOE*) will be operated by the National Institute of Standards and Technology (NIST), the State of Maryland, and Montgomery County, Maryland. NCCOE will include or connect to efforts in workforce development; K-12 STEM education; federal, state and local program integration; and connection to U. S. Cyber Command at Ft. Meade (NIST Tech Beat, [34]).

Based in San Diego, California, *Securing our eCity*® (*SOeC*) is a regional collaboration with the mission "to enable every San Diegan to live, work and play safely in the cyber world" (SOeC [35–37], Model city). SOeC began as an effort to educate San Diego-area citizens and businesses to adopt smart cyber practices and protect themselves online. The effort is a broad partnership, with key stakeholders including ESET Internet Security, the San Diego Regional Chamber of Commerce, San Diego Business Journal, San Diego Gas and Electric, San Diego State University (SDSU), and the University of California at San Diego (UC San Diego). An additional 134 organizations representing a diverse set of large and small businesses; military, government organizations and community organizations; and professional associations are listed as stakeholders. SOeC's activities include free workshops for businesses; a collection of educational resources for persons, families and businesses; references to local Science, Technology, Engineering and Math (STEM) events; and a yearly Cybersecurity Symposium and Awards event. A major effort is the San Diego Mayors' Cyber Cup Challenge, now in its fourth year as a "cyber defense competition [that] encourages mentoring of middle and high school students through formation of local school teams that compete in a realistic cybersecurity exercise, in which they detect and defend computer systems against hackers intent on stealing data" (SOeC [35–37], Sneak peak). In 2010, SOeC was awarded the Best Local/Community Cyber Security Challenge award from The Department of Homeland Security.

In San Antonio, Texas, the *Cyber City, USA* initiative is a broad-based community collaboration promoting education, business, and workforce development in the cyber security field. San Antonio's effort is anchored by the city's large military presence, which includes "the nation's largest military installation…Joint Base San Antonio, with nearly 80,000 Department of Defense personnel assigned" (San Antonio Greater Chamber of Commerce, [38]) and the 24th Air Force, which "establishes, operates, maintains and defends Air Force networks" ([39], 24th Air Force fact sheet). Military missions are supported by numerous large defense contractors, small companies, and information security startup companies. Fortune 500 companies support the effort, including USAA and Valero Energy Corporation, and significant support is provided by Rackspace. Three local universities are designated as centers of excellence in information security by the National Security Agency and Department of Homeland Security, including the University of Texas at San Antonio (UTSA), Our Lady of the Lake University, and Texas A&M University-San Antonio. The Cyber Innovation and Research Consortium (CIRC) was formed in 2007 to "[link] San Antonio area academic institutions" and "[work] closely with government, industry, workforce, and economic development initiatives to form a robust public–private partnership" (San Antonio Greater Chamber of Commerce, [40]). The CIRC includes five local universities and the local community college system. The CIRC is expanding to include local high school programs. The Information Technology and Security Academy (ITSA) is a high school dual credit program operated since 2002 by Alamo Colleges, the local community college system, with credit articulated into degree programs at Alamo Colleges, Texas A&M University-San Antonio, UTSA, Our Lady of the Lake University and St. Mary's University [41]. The community has organized to compete in the national Cyber Patriot Cyber Defense Competition, entering 54 teams for competition in 2013, awarding the Cyber Patriot Mayors' Cup, and fielding the national competition's winning team, from ITSA. The City of San Antonio has been named a Cyber Patriot Center of Excellence. The UTSA Center for Infrastructure Assurance and Security (CIAS) is specifically concerned with the security of cyber-physical infrastructure. CIAS has developed a Community Cyber Security Maturity Model (CCSMM) as the basis for "exercises, seminars and workshops" conducted at the community and state level ([42], CIAS). The development of a community-wide Program of Study clearinghouse for educators and students covering the cyber security and cyber-physical systems programs in this region is the topic of the final section of this paper.

Considering these clusters through the lens of the technopolis model highlights the importance of robust, regionally based ecosystems in support of clusters. The technopolis model consists of seven main elements: universities, large corporations, emerging companies, federal government, state government (including education), local government, and support groups (chambers, business associations, community advocacy groups). The University of Maryland, UC San Diego, SDSU, UTSA and Texas A&M University-San Antonio play anchor roles in their communities. Northrop–Grumman, Lockheed-Martin, SAIC, Google, ESET Internet Security, USAA, Valero and Rackspace provide key corporate support. Emerging startups are mentioned prominently on the web sites of these programs. The federal government plays a crucial role, including the support of NSA and DHS and the prominent role of military organizations in cyber security. State governments fund the universities and assist with education and workforce policies that support technology-driven economic development and education. State or local governments fund community colleges that are at the forefront of building a skilled technology workforce. Local governments create education and business friendly policies and bring focus to local industries. Support groups like chambers of commerce and advocacy groups provide relatively turf-free settings that facilitate collective impact. The examples of these cyber security industry clusters, viewed through the lens of the technopolis model, demonstrate the importance of regionally-based strategies that set vision and coordinate resources to achieve maximum community impact.

Forming the Transdiscipline

As noted by Poovendran (2010) [19] and Dumitrache (2010) [20], addressing the workforce challenge associated with the burgeoning world of cyber-physical systems will require new educational and workforce frameworks. Transdisciplinary education programs will be needed that address the complexity and dynamics of networking and information technology systems connected with the physical world [1]. A key ingredient will be the development of a provisional definition of the *cyber-physical systems education transdiscipline*. Such a definition can be the starting point for advancing research and defining a body of knowledge for preparation of professionals who conceive, design, develop, deploy, defend and support cyber-physical systems. Cyber-physical workforce development will require identifying potential job categories associated with the system life cycle and defining the kinds of work these professionals might do, the types of knowledge and skills they need to possess, and the types of academic programs needed to help prepare them to work in this field. Academic program development would draw on these foundations to identify program types and levels (e.g., high school-, associate-, baccalaureate-, masters- and/or doctoral-level programs) and instructional methodologies appropriate to preparing students for these careers. Highly related is the need to establish strong partnerships among academic, industry, government and community leaders to garner input and support and to facilitate communication about local workforce needs and career opportunities afforded by academic programs associated with cyber-physical systems. To be effective, these activities must proceed in a coordinated manner. To illustrate how this might be done, the authors will explore possible approaches to developing a provisional cyber-physical education transdiscipline, establishing an initial set of job categories with their knowledge and skill requirements, and identifying a framework for education and workforce development activities.

Conversations about what constitutes the *cyber-physical systems transdiscipline* have already begun. Lee [3, 43, 44] has suggested that the disciplines necessary to advance research and development of education programs include computer science, mechanical and electrical engineering, mathematics, physics, and system theory, noting that the intellectual core of cyber-physical systems is modeling and meta-modeling (2010). Pappas [45, 46] also emphasizes the importance of modeling, mathematics, networking and physics, and adds disciplines associated with high confidence, system verification, certification, robustness, resilience, security, privacy, and trustworthy systems. Poovendran (2010) 19 suggests that sociology and anthropology may provide valuable insights. The requirements for secure, safe, and reliable systems also suggest that risk management, safety engineering and secure system development methods provide additional insights for cyber-physical system development and deployment. Although it is likely that additional disciplines will be identified, the current discussion is a starting point for ongoing elaboration.

As Ertas (2000) [4] noted in his article introducing the Academy of Transdisciplinary Education and Research (ACTER), the academy's education and research objectives also include "the development of new models of learning and innovative teaching environments to complement transdisciplinary curricula. Such innovations will include active learning environments, less dependence on formal lectures, project based learning, learning through teamwork, and motivations that inspire lifelong learning" (p. 16). Teaching and learning methods that share these characteristics include constructionist and constructivist project-based learning which involve "learning by making" and the construction of models or "public entities" as a means of constructing knowledge [47, 48]. Constructivism includes performing authentic tasks in a real-world context, using project-based or case-based learning, reflection, and collaborative construction of knowledge, working in groups in cooperative environments [49]. In addition to learning experiences associated with formal curricula, active learning experiences may also include internships, mentoring, service learning in students' career fields, and participation in career-related competitions. Methods like these can serve as a reference point in the development of teaching and learning models that complement the emerging cyber-physical transdiscipline.

In the transdisciplinary spirit, it is appropriate to note that while less dependence on formal lectures and more on interactive learning environments is appropriate, the most important design consideration is to apply learning theories appropriate to the task at hand. The authors hold the general belief that typical teaching and learning practices rely too heavily on behaviorist so-called *sit-and-get* methods. Nevertheless, various theoretical perspectives should be considered, deployed where appropriate, and integrated in a transdisciplinary fashion. In *Behaviorism, Cognitivism, Constructivism: Comparing Critical Features from an Instructional Design Perspective*, Ertmer and Newby (1993) 50 assert that “many designers are operating under the constraints of a limited theoretical background” (p. 50). Those authors quote Snelbecker [51] in noting that “individuals addressing practical learning problems cannot afford the ‘luxury of restricting themselves to only one theoretical position’” (p. 52; [52], p. 8). Ertmer and Newby, citing a turn-of-phrase from Snelbecker, refer to “instructional cherry-picking [that] has been called ‘systematic eclecticism’” (1993, p. 70) and argue there has been significant support in instructional design literature for such a position [51]. A mix of methods can be persuasively argued. Nevertheless, it must be remembered that constructivist, constructionist approaches are those the field must move toward. Tate et al. [5] describe the direction of movement from “authority and regurgitation [to] instruction [to] primarily based on facilitation” (p. 13). In this paper’s transdiscipline, an opportunity exists to promote this approach in a consistent and coordinated fashion across all grade levels of instruction.

Addressing workforce needs and the educational programs necessary for preparing students entails identifying what types of jobs will need to be filled and the knowledge and skills required. One model to consider is the NIST [53] NICE National Cybersecurity Workforce Framework. The framework identifies seven categories of job specialties associated with cyber security, including *securely provision*, which involves conceptualizing, designing and building secure IT systems; *operate and maintain*, which involves providing system support, administration and maintenance; and *protect and defend*, which involves identification, analysis and mitigation of threats. The framework identifies sample tasks associated with the job category and required knowledge and skills. The framework’s job categories range from specialties that would require advanced education at the baccalaureate and graduate levels (e.g., in the *securely provision* category) to specialties that could be potential jobs for students completing associate degrees or high school advanced technology programs (e.g., in the *operate and maintain* category). Given its overlap with many of the types of jobs that would be associated with cyber-physical systems, a similar framework could be an initial model for defining job categories for cyber-physical workforce development. The framework also includes a four-phased call to action which addresses activities that would be necessary to make effective use of the framework: collect and analyze workforce and training data; recruit and retain; educate, train and develop; and engage and energize the workforce and public.

One popular model used for describing and assessing the state of workforce development in particular careers is the *Program of Study*. A Program of Study (POS) documents available academic and training programs that prepare workers for a career field, support services that assist those who are interested in pursuing those programs, and public policy and community support resources that facilitate the success of the workforce development efforts. It is often used to document career preparation involving a sequence of academic of programs (e.g., from baccalaureate to graduate or associate to baccalaureate program) that permits a student to continue to more advanced education while having the option to enter the workforce at different points in the program's sequence. A cyber security POS might, for example, document a path that starts with completion of a high school diploma with an information technology certification, continue to an associate degree in networking and security with additional certifications, followed by completion of a baccalaureate degree in information technology and cyber security. At each point where an academic program is completed, the POS would document career-related job opportunities available upon degree completion.

The OVAE (Office of Vocational and Adult Education) [54] POS design framework, for example, identifies ten components that support the development and effectiveness of a program of study. The framework provides a template for documenting legislation and policies that affect the POS, partnerships that support the program, professional development programs for faculty and administrators associated with the program, accountability and evaluation systems that assess the program's effectiveness, college and career readiness standards associated with the program, POS course sequences, credit transfer agreements, guidance counseling and advisement services, the program's teaching and learning strategies, and the program's student learning outcome evaluation process. The POS framework can be used for planning curriculum and related structures, and for documenting the current state of the POS and planning for improving its quality and effectiveness. It can also be used as a platform for communication and coordination of a community's efforts to advance their workforce development objectives in a particular career field.

Pilot Case Study: Applying the Transdiscipline to San Antonio's Cyber Security and Emerging Cyber-Physical Systems Clusters

In the technopolis model, one challenge is creating and articulating a framework that is strategically compelling, while simultaneously providing opportunities for contribution by a diverse set of partners, without losing collective impact. The authors of this paper are active in the San Antonio education, cyber security and emerging cyber-physical systems communities. They have proposed an education-workforce focused strategy with the potential to engage partners from all seven technopolis elements while addressing key observed challenges. These challenges were observed:

- Cyber, cyber security and information technology of all types is growing rapidly in the community [55].

- Organizations verbally report not being able to fill open positions.
- Educators, parents and students do not demonstrate awareness of local opportunities to complete cyber education pathways and enter the workforce in skilled or professional positions.
- Students are frequently not making the coursework choices required in high school to be accepted into college programs that lead to cyber degrees and jobs.

In considering these challenges through the lens of this paper's transdiscipline, the authors recall the concept of *Programs of Study* and offer it as the core element of a cyber-physical systems education transdiscipline and regional development strategy. The strategy proposed recommends a *regional Programs of Study clearinghouse* as a pragmatic foundation for numerous activities.

The POS clearinghouse approach offers multiple potential benefits: (1) it facilitates education of students and parents about the importance of rigorous STEM high school coursework starting in middle school (grades 6–8); (2) it informs educators and other stakeholders about these same education and career opportunities; (3) by promoting informed secondary school course selection, it reduces the need for remedial education for students entering college; (4) it helps keep college costs in check by helping students and parents clarify their interests, set their goals, and focus on goal-related coursework; (5) it creates POS-wide context within which philosophical and pedagogical approaches can be promoted, crossing traditional boundaries, to strive for improved educational outcomes. In short, a Programs of Study clearinghouse strategy creates clarity and pragmatic context. It is proposed that a Programs of Study clearinghouse will provide a common, robust, and flexible platform, building on the partnership-driven culture of the community, which in turn builds organizational capacity to counsel and educate students, parents, and community stakeholders about the cyber opportunities that exist in their community.

From a systems perspective, the effort to create a Programs of Study clearinghouse will lead to identification of gaps. Funding proposals can be developed to enhance current programs, build new programs, and/or build additional systemic capacity. Awareness of important local programs will facilitate engagement of all stakeholders to support the formal and informal educational activities that are documented in the Programs of Study. The proposed approach also supports building both the skilled and professional workforce, with multiple entry and exit points that provide maximum flexibility to lower income and middle class families.

Pilot Project

Sponsored by the regional Cyber Innovation and Research Consortium (CIRC), a pilot project was engaged to document the cyber pathways for three schools: Texas A&M University-San Antonio, Our Lady of the Lake University, and San Antonio College, a community college campus of the larger Alamo Colleges system.

The goal of the pilot project was to document all cyber-related pathways, and link those pathways in a multiple-entry, multiple-exit format that shows students the various ways they can reach cyber degrees. A second goal of the pilot project was initial connection to cyber-specific high school programs and middle school career and technology education (CTE) courses. An information technology platform called SooperMinds was selected for this project. The platform contains features supporting entry of courses, collection and sequencing of courses toward an end goal, integration of CTE and academic courses, inclusion of extracurricular activities to engage students, and the ability to document multiple, alternative articulations from specific high schools/programs, into local colleges, and on to advanced degrees and the workforce. SooperMinds' features also support communication between students taking courses in a sequence, and the educators operating later programs to which students might aspire (for example, a high school freshman can communicate via SooperMinds with the director of a college program, moderated by their high school teacher). Finally, features allow students and parents to co-explore courses and sequences, and share their preferences among the co-explorers.

During the two-year pilot project, 22 *pathways* were populated into SooperMinds and linked together in Programs of Study that cross secondary and college boundaries. A SooperMinds pathway is one segment of a POS; for example, the four years of a high school program, or the two years of a community college associate degree program constitute a pathway. Each pathway is maintained by its host school. An owner of a pathway can initiate a link to other pathways, which can in turn be accepted or rejected by the "target" pathway's owner. With these features, the community is encouraged to self-organize, assume responsibility for content, and collaborate with partner institutions.

Initial Usage and Findings

As noted, three colleges took part in the pilot study, taking responsibility for entry of their colleges' pathways. As part of a larger project that reached 587 middle school students across Texas, seventeen additional middle schools in three local school districts were also exposed to Programs of Study in their local regions. The results from this initial study were sobering, with a small mix of good news for the cyber, cyber security and cyber-physical systems communities. Statewide, the three pathways that received greatest interest from students were Culinary Arts, Fashion Design and Criminal Justice/Law Enforcement. This result reinforces popular conceptions and qualitative results that indicate failure to educate students about cyber, STEM, and other high-paying technology-based education and career opportunities. Nevertheless, the pathways to receive the most interest in the San Antonio region were Bachelor of Applied Arts and Sciences in Information Technology and Security (a Texas A&M University-San Antonio program) and Web Programming Level 1. This provides some early indicators that students can be made aware of programs which offer greater academic challenge and education/career opportunities in their local community.

Ongoing Efforts

CIRC has completed the pilot project and is moving forward with full implementation, proceeding to document pathways for all CIRC partner higher education institutions. The Programs of Study clearinghouse strategy will be used to highlight the breadth of cyber education and jobs in the region for all stakeholders; drive awareness and activity in creating cross-boundary Programs of Study; drive awareness activities for the primary feeder schools for CIRC institutions; provide a view of gaps that require institutional and systemic action; provide a basis for pedagogical discussions across boundaries to pursue improved outcomes; and provide the basis for additional research and programs amenable to external funding. Because Programs of Study are fundamentally multi-disciplinary, they provide context for multi-stakeholder discussions. While such discussions are not required to be transdisciplinary in nature as defined in this paper, the region intends to make them so. The transdisciplinary approach which honors disciplines, while working across and outside disciplines in an integrated and holistic fashion, provides a defining culture for discussions. In the view of the authors, the approach leads to solutions that are not falsely bounded by disciplinary constraints, but are instead grounded in the multi- and extra-disciplinary realities of building a robust education and workforce system for cyber, cyber security, and cyber-physical systems in the region.

Conclusion

This chapter proposed a regionally focused, transdisciplinary approach to creating education-workforce systems that support industry clusters important to local communities. The discussion has been placed in the context of the growth of cyber-physical systems clusters, drawing heavily from the overlapping and somewhat more mature field of cyber security. The transdiscipline proposed creates a holistic, integrated culture, and the pragmatic foundation of Programs of Study provides a basis and context for immediate action and further research.

This study is limited in several ways. It has primarily focused on regions in the United States, and may be less applicable to concerns in other countries. The relative newness of cyber-physical systems required accessing information and lessons from the cyber security field, which may or may not be fully applicable. The Programs of Study clearinghouse strategy applied in the pilot study is in its early stages. Additional potential research questions include: How applicable are these concepts globally? Can effective discourse take place in a complex transdisciplinary context? Can a distributed Program of Study definition strategy be effective? Does promotion of local Programs of Study to middle and high school students positively impact student behavior? Does the context provided by Programs of Study lead to gap identification and actions to address those gaps? Does a Programs of Study strategy lead effectively to fundable projects? The authors propose these as important questions in a global economy where regions must compete to serve the education and workforce interests of their citizens.

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