Chapter 4
Creativity, Design, and Transdisciplinarity

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Abstract This chapter explores the relationship of creativity, design, and transdisciplinarity, with emphasis on collaborative research. It sorts through definitions of the core terms in order to identify their intersections across discourses of transdisciplinarity. Outcomes differ from extending an existing approach to redirecting or reformulating it. Contexts likewise differ from product innovation to environmental problem solving. However, shared characteristics of novelty, boundary crossing, and generativity appear widely as well as synthesis, critique, and reflexivity. In the first of three examples—architecture and urban planning—transdisciplinary approaches are generating new hybrid modes of inquiry and action that are bridging gaps between critical theory and projective design and between practice and social, political, and normative concerns. Designerly ways of thinking are also leveraging creative dimensions of practice, fostering relational knowledge while being open to subjectivity and the unexpected. The second example—environmental sustainability—highlights heuristic thinking in an "ecological rationality" or "pragmatism" that fits a particular problem, rather than deriving from a generic method. Transdisciplinary problem solving is reimagined as a creative art of invention, accentuating discovery and learning. The third example—integrations of physical sciences and engineering with life sciences and medicine—is fostering creative development of alternative methods and protocols. A process of divergence–convergence is spinning off new uses through "combinatorial innovation." The chapter closes by reflecting on an overriding topic that emerges from intersections of the core concepts—situated learning—then concludes by reflecting on the phenomenon of increased boundary crossing.

Keywords Transdisciplinarity · Creativity · Design · Interdisciplinarity
Boundary crossing

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Introduction

The concepts of creativity, design, and transdisciplinarity have rich histories.[1] Their intersections, though, have never been examined at length. This chapter tracks junctures of meaning in order to identify elements of creativity and design thinking in transdisciplinarity, with emphasis on collaborative research. It establishes a foundational link between characteristics of creativity and interdisciplinarity then extends those characteristics to designerly ways of thinking in three examples of transdisciplinary research: architecture and urban planning, sustainability, and integrations of life sciences with physical sciences and engineering. The pivotal term—transdisciplinarity (TD)—is dated conventionally to the first international conference on interdisciplinary research and teaching in 1970. The definition of "interdisciplinarity" was wide, encompassing interactions among two or more disciplines from simple communication of ideas to mutual integration of concepts, methodologies, procedures, epistemology, terminology, and data. In comparison the definition of "transdisciplinarity" was narrower, connoting a higher level of synthesis in "a common system of axioms" that transcends the narrow scope of disciplinary worldviews. The exemplar was anthropology conceived as a comprehensive science of humans, though conference participants elaborated the concept differently. Piaget (1972) defined TD as a superior stage in the epistemology of interdisciplinary relationships based on reciprocal assimilations and the prospect of a general theory of systems or structures. Lichnerowicz (1972) advocated "the mathematic" as a universal interlanguage and structure, and Jantsch (1972) imbued TD with social purpose in a hierarchical model of science, education, and innovation grounded in general systems theory and organization theory.

By the end of the twentieth century transdisciplinarity had gained visibility and new connotations across three major discourses. The first discourse of transdisciplinarity—transcendence—is linked with the historical quest for unity of knowledge and culture. As belief in a pregiven unity eroded, however, new overarching frameworks emerged including general systems theory, feminist theory, and sustainability. The second discourse—transgression—was forged in critique of the existing structure of knowledge and education shaped by critical theory, social and political movements, and interrogation of dominant systems of disciplinarity and the technical-rational model of science. The third discourse—problem solving—was fundamental to early conceptions of interdisciplinarity, including problem-focused social science research in the 1920s and defense-related research during the World War II era. A new transdisciplinary momentum evolved in the late twentieth century, though, driven by the need to solve complex "real-world" problems of society and inclusion of wider range of stakeholders in research (Klein, 2015, 2017). Elements of the three discourses appear across the three examples

[1] I thank Dena Fam, Tanzi Smith, and Dana Cordell for permission to use Fig. 4.1, from the chapter cited below. I also thank Rick Szostak and Frédéric Darbellay for comments on earlier versions of this chapter.

highlighted in this chapter, along with characteristics of creativity and designerly ways of thinking. Their intersections are situated in a broad historical shift from linear process and rote application to user-oriented and heuristic approaches that are also responsive to contingencies of context. Together they are fostering new relational forms of knowledge production and practice. The chapter closes by reflecting on an overriding topic that emerges from the intersections—situated learning—then concludes by reflecting on the phenomenon of increased boundary crossing across the divides of disciplines, occupational professions, government, industry, and the public sphere.

Creativity and Interdisciplinarity

Etymology is a good starting point for any investigation of meaning. The English noun "creativity" derives from the Latin *creativitus*, connoting a capacity or faculty for bringing something new into being.[2] The concept appears across multiple fields, including art, philosophy, sociology, psychology, and cognitive science. Case studies also appear across domains of professional practice, such as education, business, architecture, and engineering. Comparably, the source is attributed to a wide range of explanations, ranging from divine inspiration and individual genius or personality to team dynamics and organizational cultures. And, the weight of definition varies from open-ended exercise of the imagination to managed applications. Nonetheless, common characteristics appear across contexts. In defining the nature of creativity Sternberg (2006) identified eight major types grouped into three categories. The first category—acceptance of current paradigms and attempts to extend them—results in replication, incrementation, and further advancement. In contrast, the second and third categories exhibit a more transgressive imperative by challenging the status quo. The second—rejection of current paradigms and attempts to replace them—leads to redirection, reconstruction/redirection, and reinitiation. The third—higher-level synthesis of current paradigms—is associated with integration and combinations of mental models to generate holistic solutions and in rarer cases a new paradigm or field.

Looking more specifically at the relationship of creativity and interdisciplinary studies, Sill (1996) highlighted three primary aspects of creativity that Getzels and Csikzentmihalyi (1964) identified in their classic definition:

1. original production
2. cognitive problem solving
3. subjective experience.

[2]Creativity. (2016). In Oxford English Dictionary. Retrieved from http://www.oed.com/view/Entry/44075?redirectedFrom=creativity#eid [Accessed 25 May 2016].

In addition to these core traits, Sill (1996) highlighted four concepts relevant to this investigation. In his book *The Act of Creation* (1964), Koestler argued that creativity derives from "bisociative thinking," which is derived in turn from "synthesis of independent matrices of thought" Sill likened to disciplines (p. 136). Koestler also called "creative tension" the driving engine of creativity, requiring resolution when two or more matrices contradict or conflict. Finke, Ward, and Smith (1992) further called "preinventive structures" within the subconscious raw material for creativity in the form of ideas, images, and untested concepts residing in memory or emerging in the imagination. Several parallels between creativity and interdisciplinarity emerge from combining the seven defining traits and concepts Sill identified. Both entail moving beyond existing approaches. In both cases, generativity is a common trait, along with cognitive flexibility. Both also acknowledge the subjectivity of personal experience and feelings, generating alternative modes beyond technical rationality while acknowledging contingencies of context. Both require bridging separate matrices of thought, in a form of problem solving that leverages preinventive structures as resources for new insights and synthesis. And, both have a temporal dynamic of iteration, which Szostak in this volume (Chap. 2) also identifies as a shared dynamic of creativity and integration.

In defining the relationship of creativity and "integrativism," a composite term for cross-disciplinary and integrative modes of work, Dillon (2006, 2008) argued that working across and between disciplines is "inherently creative." When individuals interact and combine modes of thinking, they generate new outcomes. Dillon aligned "transdisciplinarity" with a quest for unified knowledge in the discourse of transcendence, and "interdisciplinarity" with resolving tensions and contradictions between differing forms of knowledge. However, tensions and contradictions also appear in transdisciplinary research. "Unity" is a relative term. It is not embodied in a single transcendent theory of everything, despite some continuing efforts to assert it. Unifying approaches emerge on different levels based on the context of a particular project, program, or field. Moreover, in transdisciplinary research on complex challenges such as climate change and health disparities problems are typically ill-defined, requiring creative approaches that are not prescribed in existing methods.

Design and Creativity in Transdisciplinary Architecture and Urban Planning

Once again, etymology furnishes a starting point. The English noun "design" is borrowed from the French word *deseign* meaning a plan or a scheme executed through action, derived in turn from the Latin word *designare* meaning to mark and to devise.[3] Like creativity, design is not the province of a single discipline. It appears, Boradkar (2010) found, in a variety of domains including architecture, urban planning, engineering, automotive and industrial design, graphic and interior design, along with newer design experiences and services. Most definitions, Boradkar added, refer primarily to practice in professional occupations that have historically had an instrumental focus, although the new field of design studies and theories of practice incorporating critique extend conception of design. Fischer (2015) has described design thinking as a tool for fostering creativity while also providing a structure for systematizing ideas without sacrificing free flow of ideas. Taking a step further Yajima (2015) proposed interdisciplinary research could be enhanced by design thinking in the context of grand challenges that have no disciplinary boundaries and require teams to combine deep expertise for a common goal. Both designers and scientists want to discover something new and both interrogate existing assumptions. Designers also like to look at a problem in different ways, and scientists confront the status quo while pushing knowledge forward in the transgressive connotation of Sternberg's (2006) second category of creativity.

Architecture and urban planning provide an insightful example of the intersection of design, creativity, and transdisciplinarity. Doucet and Janssens (2011) sketched several dimensions of their relationship in the 2011 collection *Transdisciplinary Knowledge Production in Architecture and Urbanism.* The transdisciplinary character of new hybrid modes of inquiry, practice, and learning lies in experimental approaches that have the capacity to overcome past schisms of theory, history, and practice through integration. Architectural practice is reconceptualized from rote application or instrumental service to a form of relational knowledge situated in particular contexts, responsive to their stakeholders, and open to change. The gap between critical theory and projective design is also bridged. Whether refitting metropolitan areas because of growth or moving cities because of climate change, questions of design are not separate from social, political, and normative concerns. Ethics are also placed inside of disciplinary and professional work rather than outside their borders as a peripheral concern or afterthought. And, new objects come into view while situating practices in new configurations and incorporating once excluded forms of knowledge including the experience of lay people.

Four related concepts may be combined for a fuller picture of the link between creativity and design. First, Rendell (2004) distinguished research "for" and "into" design, connoting theory in the form of historical and theoretical perspectives within existing disciplinary modes, from research "through" design, connoting practice oriented to application. Second, in a parallel distinction Biggs and Büchler (2011) differentiated studies "on" architecture, which adopt established models, from studies "in" architecture, which often contain an element of creative practice

[3] Design. (2016). In Oxford English Dictionary. Retrieved from http://www.oed.com/view/Entry/50840?rskey=v6MxwG&result=1&isAdvanced=false#eid [Accessed 25 May 2016].

not encompassed in generic approaches. Third, in another parallel concept Cross (1982, 2001) contrasted "design science," grounded in the objectivity and rationality of formal protocols, and new "designerly ways of knowing," developed in alternatives that acknowledge subjectivity, unpredictability, and an epistemology of design accountable for creativity and innovation. Like Biggs and Büchler, Cross also highlighted the fourth concept, "reflection-in-action." Schön's (1983) concept, Yaneva (2011) recalled, prompted a "revolution" in design anthropology during the 1980s. He sought a reflexive epistemology of practice implicit in artistic, intuitive processes within contexts of uncertainty, instability, uniqueness, and value conflicts (p. 117). The competence and artistry embedded in skillful practice is a starting point, rather than a prescribed linear way of knowing. A pragmatist form of inquiry and innovative approach to professional education, reflection-in-action is also situation-based and recognizes tacit knowledge.

New approaches to design education are further bridging the gap between engineering principles of efficiency coupled with performance specifications and artistic principles of beauty and form. In the context of a Transdisciplinary Design Studio, Guyotte, Sochacka, Costantino, Walter, and Kellam (2014) conceived of engineering problems as creative challenges in which different forms of knowledge are manipulated. Engineering, art, and landscape architecture were integrated in a case of STEAM education, which extends STEM's focus on science, technology, engineering, and mathematics by including art. The authors further conceptualized STEAM as a transdisciplinary social practice of community engagement and ecological sustainability. Two faculty from engineering and from art collaborated on the course, with 11 students from art education, landscape architecture, and civil and environmental engineering. The first of two design challenges asked students to conceptualize a community initiative on solid waste reduction if landfill diversion goals were extended to zero waste by 2030. The instructors felt, though, students would have gained deeper conceptual and experiential understanding if they actually undertook community initiatives. So, the second challenge combined organizing and implementing an initiative. By exhibiting art in a public gallery, students also engaged with and learned from community stakeholders outside the boundary of academic walls.

Chou and Wong (2015) also linked integrative design to reflection-in-action in a student project called "Public Art" that brought together art and technology in order to establish an interactive environment for citizen awareness and participation. The students also came from varied backgrounds, in this case including design, information technology, management, art, engineering, and education. Several lessons emerged that echo earlier parallels between creativity and interdisciplinarity. To begin with, inter- and trans-disciplinarity constitute "a heterogeneous conglomeration of different research activities" (p. 219). Knowing-in-action and reflection-in-practice are also essential when cooperation is more unpredictable and team members need to be more flexible. Moreover, an integrated working process requires removing hierarchies among disciplines to generate more options and potential solutions. And, finally, characteristics of creative design in transdisciplinary contexts are situated within a broader historical shift in design research from production of artifacts to a user-centered approach focused on integration of knowledge and fields. In calling design “antidisciplinary,” Ito (2016), Director of MIT’s Media Lab, cites a transgressive imperative as well. He deems design in the laboratory “antidisciplinary” because work occurs in spaces that do not fit into existing academic disciplines and may even constitute a new field, such as cybernetics.

The second example further illustrates the transgressive role of design thinking in alternative modes of thought and action responsive to context, this time in the realm of sustainability. Comparable to architecture and urban planning, complex challenges of environmental sustainability cannot be adequately tackled using established methods alone.

Creative Design in Transdisciplinary Sustainability

Complex problems associated with transdisciplinary collaborative research are often likened to “wicked problems” characterized by uncertainty, indeterminacy, value conflicts, unexpected outcomes, and lack of ready-made criteria, answers, and solutions. In describing the stages of a transdisciplinary sustainability science project, Hall and O’Rourke (2014) identified five phases that often appear in descriptions of research process: *Framing*, *Launching*, *Integrating*, *Generating*, and *Deciding*. Pressure can result in settling too quickly on a “right” answer due to time, money, and defaulting to an established approach or past experience. Doing so, though, can slow or scuttle the process of generating ideas and identifying options. In the fourth stage of *Generating*, diversity can improve both the quality and creativity of solutions, allowing individuals to voice views not normally expected in their prescribed roles. Some descriptions of creative process accentuate freedom from structures, though Hall and O’Rourke found that structured dialogue can boost creativity even if the balance of structure and freedom differs by the activity in question. Constructive criticism of alternatives is a form of priming that can lead to innovative possibilities.

Hall and O’Rourke (2014) also emphasized the centrality of communication. It is one of six core qualities of transdisciplinary research that Fam, Smith, and Cordell (2017) identified in interviews with 14 leading transdisciplinary researchers. The others are creativity, curiosity, commitment, critical awareness, and connectedness. Their informants associated creativity in particular with five traits depicted in Fig. 4.1, while further describing the process as “thinking out of the box,” “thinking laterally through a puzzling challenge,” and being willing to “push the boundaries.” Like Huutoniemi and Willamo (2014), they also likened the process to de Bono’s (1970) concept of lateral thinking. The six areas are not separate. Curiosity entails a flexible willingness to explore new insights beyond one’s own expertise. Commitment often involves “challenging the status quo.” Critical awareness, in turn, is a form of reflexive thinking and openness to others’ suggestions. And, communication is essential both to clarify one’s own perspective and to work

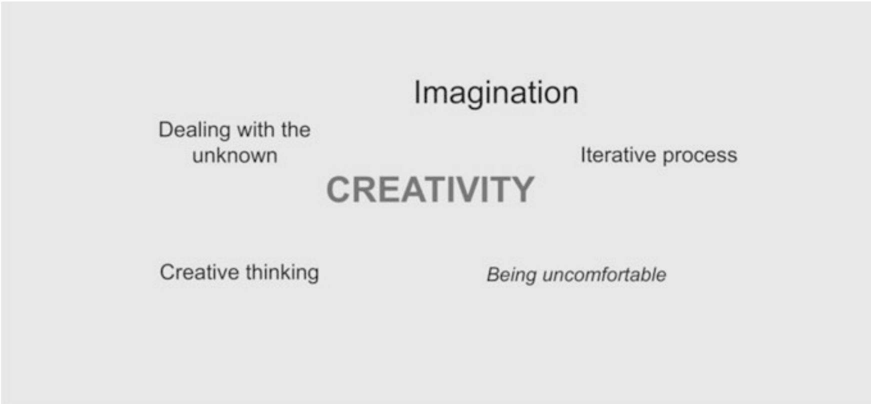

Fig. 4.1 Attributes of creativity in transdisciplinary research (from Fam, Smith, and Cordell 2017, p. 83)

successfully together with others. Finally, connectedness is key to synthesizing different matrices of thought.

When focusing on novelty as a defining trait of creativity, Sill further (1996) emphasized heuristic thinking. The English word "heuristics" derives from a Greek word meaning "to find."[4] Over the centuries the concept became associated with an art or form of logic that is more fluid and ad hoc than linearity and the mechanical rule of algorithmic thinking, relying instead on rules of thumb or incomplete guidelines to drive discovery. Introducing the book *Transdisciplinary Sustainability Studies,* Huutoniemi (2014) framed heuristics as a cognitive concept in an "ecological rationality" or "pragmatism" (pp. 10–11) that fits a particular problem, rather than a generic method. Existing methods still have value for generating new ideas though, including scenario building, expert deliberation, "what-if" modeling, and the Delphi technique of controlled iterations. Willamo joined Huutoniemi (2014) in adding "outward thinking" (p. 27) as a search tool for systemic understanding, achieved by looking outward from an object of interest and thereby opening up the possibility of inventing new categories or rearranging established ones. They likened outward thinking to de Bono's (1970) concept of "lateral thinking," which redirects thinking away from the "vertical logic" of Western reasoning and may lead in surprising new directions. It also parallels a "design turn" (p. 26) within systems thinking that shifts attention from the ontological status of a system to its heuristic functions and technologies.

Ultimately, heuristics constitute a form of invention that lies at the heart of heuristics, a branch of logic associated with the art of discovery or invention. The rhetorician Ulmer (1994) extended this concept in his book *Heuristics*. In seeking

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[4]Heuristics. (2016). In Oxford English Dictionary. Retrieved from http://www.oed.com/view/Entry/367823?redirectedFrom=heuristics#eid [Accessed 25 May 2016].

forms for cultural studies research and teaching writing in the digital age, Ulmer contrasted traditional methods of interpreting print-based texts to the "generative productivity" that occurs in avant-garde expression and in composition of digital works that mix word, image, and sound. Transdisciplinary sustainability is not focused on hypermedia, but it too requires creating solutions that do not derive from applying traditional methods. Like Ulmer, Huutoniemi (2014) noted poststructuralist and postmodern theories have been influential in critique of the modern techno-scientific paradigm along with pragmatist philosophies, literacy criticism, feminist and standpoint epistemology, and science and technology studies.

The triangulation of creative process, a designerly way of thinking about a complex problem, and transdisciplinarity is further apparent in the third example. Szostak, in this volume, observes that "Creativity is generally defined in terms of both novelty and utility" (p. 18). Likewise, Sternberg and Lubart (1999) contended that creativity is characterized by not only *novelty* but something *useful*. This quality is central to new integrations of life sciences and medicine with physical sciences and engineering.

Utility and the Generativity of Divergence–Convergence

Creativity is often deemed an "engine" of innovation and invention in the economic sphere. A recent survey by the American Management Association, for instance, identified creativity as one of the "4Cs" of twenty-first century skills, along with communication, collaboration, and critical thinking (Reilly, 2010). Fillis and Rentschler (2010) located the heightened role of creativity in a historical shift from knowledge-based activities in the economy to creativity, innovation, entrepreneurship, and imagination. The criterion of success does not lie in novelty alone. It is forged in the marketplace of ideas. The full title of a 2013 report issued by the American Academy of Arts and Sciences reinforces the connection between innovation and utility. *Arise 2, Advancing Research in Science and Engineering* is subtitled *Unleashing America's Research and Innovation Enterprise*. Citing "Transdisciplinary Opportunities" as a common theme in current discussions of the research enterprise, the report calls for "deep integration" across disciplines for both basic discovery and development and application. In contrast to interdisciplinary collaborations between disciplines, the authors contend, deep integration is a "true conceptual leap" of transdisciplinary scope across physical sciences and engineering (PSE) and life sciences and medicine (LSM). The report claims interdisciplinarity borrows techniques from different fields without integrating them, ignoring a sizable literature on the centrality of integration in interdisciplinary research and education. Yet, it captures the power of transdisciplinarity to transgress disciplinary boundaries while fostering emergence of new disciplines (American Acadey, 2013).

The report also cites numerous examples of what a refigured research ecosystem looks like. Life sciences and medicine rely increasingly on sophisticated instrumentation, intensive computational resources, and systems approaches in collaboration with physical sciences and engineering, including nanotechnologies and supercomputing. The aggregation of elements provides “nucleation points” for further integration and collaboration in a “massive ‘knowledge network’.” A transdisciplinary systems-level approach to the cell, for instance, is leading to a new level of understanding that merges expertise in molecular and evolutionary biology with the chemistry of small molecules and macromolecules plus the physics of energy storage and transfer, network and chaos theories, mechanical and systems engineering. Likewise, efforts to develop economically and ecologically viable replacements for fossil fuels bring together expertise from chemical, systems, and environmental engineering as well as microbiology, plant science, ecology, computational science, and economics. Moreover, in both cases multiple boundaries are being crossed, not only between disciplines but also basic and applied research as well as the academy, industry, and government.

Many of the drivers of change in *Arise 2* also shape the underlying concept of *Convergence*, a report issued the following year by the National Research Council in the USA (2014). Subtitled *Facilitating Integration of Life Sciences, Physical Sciences, Engineering, and Beyond*, the report defines convergence as “an expanded form of interdisciplinary research” (p. 20) that integrates knowledge, tools, and ways of thinking from different domains. Aligned explicitly with the concept of transdisciplinarity, it aims to create a transcending synthetic framework for dealing with current scientific and societal challenges, including understanding complex biological systems, improving patient outcomes, revolutionizing manufacturing, improving energy storage systems, and meeting the need for secure food supplies in the midst of climate change. Here too, multiple boundaries are being crossed in interactions and partnerships across the academy, national laboratories, industry, clinical settings, and funding bodies.

The underlying dynamic of transdisciplinarity in the report is a process of divergence and convergence that fosters creative development of products or practices that are both novel and tailored to context. Routine problem solving, Steiner (2009) explained, does not need divergent thinking since neither novel procedures nor outcomes are needed. In contrast, creative problem solving requires both divergent and convergent thinking modes, leveraging critical analysis and connections between disparate ideas. Problem solving and creative approaches also combine to yield a mixed form of *creative problem solving* oriented toward discovery and innovation. In a 2013 report on *Convergence of Knowledge, Technology, and Society*, Roco, Bainbridge, Toon and Whitesides depicted the convergence-divergence process as an escalating and potentially transformative development linked with combinatorial innovation. It occurs when a new technology or set of technologies yields components that may be combined and recombined, spinning off applications and elements that might continue to be recombined and integrated. In a subsequent phase of divergence, new convergences are then applied in new areas, discoveries, and outcomes.

Roco, Bainbridge, Toon, and Whitesides (2013) depicted the historical evolution of combinatorial innovation in three stages. The first stage, dating from the late 1990s into the 2000s, occurred in efforts to develop nanotechnology through

Table 4.1 Three phases of CKTS convergence (Roco, et al., 2013, p. 17)

Time frame	Phase	Characteristics
2001–2010	Reactive convergence	Coincidental, based on ad hoc collaborations of partners or individual fields for a predetermined goal
2011–2020	Proactive convergence	More principled and inclusive, approaching convergence through more explicit decision analysis; the immediate future of CKTS
After 2020	Systemic convergence	Holistic, with higher-level (multidomain) purpose, with input from convergence/governance organizations

convergence of separate scientific and engineering disciplines. The second stage, moving into the 2000s, catalyzed the convergence of nanotechnology with biotechnology, information, and cognitive technologies (abbreviated as NBIC). It connected emerging technologies based on shared elemental components such as atoms, DNA, bits, and synapses that were integrated across scales. The third stage, unfolding in the 2010s, is connecting emerging NBIC technologies with platforms of human activity on multiple scales. Table 4.1 depicts the trajectory of Converging Knowledge and Technologies for Society (CKTS).

The significance of this timeline lies in degrees of intentionality and formality, moving from the coincidence of ad hoc collaborations to more principled and inclusive efforts to ultimately a holistic level across domains. The development of new languages, it should also be said, is essential to CKTS, generating higher-level languages for constructing shared technology and concepts common to multiple domains.

The Cross-Secting Role of Situated Learning

Several implications follow from the intersections of creativity, design, and transdisciplinary research though situated learning stands out. The "Ah-ha" moment or *Eureka* flash of insight is often associated with creativity. Yet, Lozano (2014) emphasized, change in mental models and behavior requires constant learning that is not simply additive but transformative. Argyris' (1977) theory of learning loops accounts for the difference. In single-loop learning, organizations compare their performance against pre-established standards, detecting and correcting errors in order to carry on present policies or to make adjustments. In double-loop learning underlying assumptions, norms, objectives, policies, goals and programs are questioned. Delving deeper into the structure of a system facilitates interrogation of established models. Others have extended Argyris' theory to include triple-loop learning: new processes or methodologies are developed that take the further step of reframing thinking.

Mitchell, Cordell, and Fam (2015) brought together the concepts of triple-loop, deep, generative, and transformative learning in describing transdisciplinary sustainability research. It entails a social process of reflection throughout interactions, communications, and relations among actors in a particular project. As a result, it is constructivist in nature. Problems are never simply received, Fry (2011) emphasized. They are always interrogated and redefined. Put another way, practice never "prefigures the form of the solution" or more specifically "architecture never just begets architecture" (p. 21). Transdisciplinary process entails continually learning what the problem is through critical reflection. The form of "relational thinking" that emerges from situated learning not only dissolves disciplinary differences. It has a capacity for "redirective practice" that stems from transgressive rupture of current practice, not pragmatic problem solving alone.

The element of surprise can also foster learning. Darbellay, Moody, Sedooka, and Steffen (2014) acknowledged Repko's 10-stage model of interdisciplinary research process (2006) in a textbook for students doing individual projects. Repko himself also recognized the role of potential feedback, iterativity, and negotiation mechanisms capable of introducing flexibility. Yet, Darbellay et al. contended Repko's model follows a standard procedure: moving from formulating a problem and questions and hypotheses to methodological choices and analyzing and interpreting results. While valuable, Darbellay et al. acknowledged, this approach does not account for the unexpected, which could intervene at any stage and even reconfigure the research process through digression and diversion. They likened serendipity to Peirce's concept of *abduction* (1965), an intuitive and exploratory way of reasoning that allows the possibility of a surprising fact paving the way for new avenues of thought, theories, and innovation. The research process may even be radically reconfigured.

Both creativity and learning, Lozano (2014) further observed, occur in units ranging from individuals and groups to organizations and society. Individual learning entails examining assumptions underlying mental models and considering how different models can be brought together. The combined intelligence of collaboration fosters development of new or revised models and capacities for collaborative action. Collaborative creativity, Steiner (2009) emphasized, is not the simple sum of individual performances. Creative solutions emerge as a result of associative thinking and communication among people with different backgrounds, experiences, value systems, and expectations. Steiner also acknowledged the value of stage models. All problem solving processes share common fundamental steps, moving from finding and defining a goal to scanning and generating information then deriving viable solutions. Yet, he admonished, routine and creative problem solving differ with respect to their initial events, process characteristics, and novelty of outcomes.

Conclusion

The intersections of creativity, design, and transdisciplinarity identified in this chapter underscore the increasing ambiguity of boundaries: not only divides of disciplines but also occupational professions, sectors of society, and domains of science and technology, social sciences, humanities, and arts. Reflecting on changes in architecture and urban planning, Doucet and Janssens (2011) called attention to the hybridization and relationality of knowledge today. Tasks lie at the boundaries of and spaces between systems and subsystems. The widening shift from prescriptive linear and generic models to relational knowledge has also expanded the heterogeneity of approaches that are available, while bringing new objects into view beyond conventional taxonomies of disciplines and placing practices in new configurations. As a result, the ability to cross boundaries has become an essential skill, not only individual capacity for Koestler's (1964) notion of "bisociative thinking" that bridges "independent matrices of thought" but also group capacity for negotiating difference and generating collective intelligence.

Ultimately, transdisciplinarity may be understood as a creative process that is itself a form of design. In the absence of an a priori unity of knowledge or universal paradigm of practice, synthesis must be constructed. Several other concepts from this investigation also have general import. Huutoniemi's (2014) notion of heuristics as a cognitive concept in an ecological rationality or pragmatism highlights the need to test both existing and new models and methods in the forge of context and contingency. The concept of deep integration reinforces the idea of transdisciplinarity as a conceptual leap of greater scope and power. The notion of aggregated elements providing nucleation points for further integration and collaboration also situates individual activities within a massive knowledge network. Degrees of change, though, will still vary, echoing Sternberg's (2006) spectrum across modifications and extensions of current paradigms to transgressive redirections and reformulations to higher level of synthesis in new transcending frameworks.

Several closing caveats, however, check the unbridled rhetoric of transformation. To begin with, priorities conflict when resources are limited. Inventing new goods and services for the marketplace has greater economic and social capital than a democratic solution to an environmental problem. Echoing Chou and Wong (2015), connections among disciplines are not always clear either, requiring greater attention to teamwork for integrated solutions to multidimensional problems. Roco et al. (2013) also concluded the research and development focus for converging technologies has been more reactive and coincidental, not the holistic systematic approach a theory of transdisciplinary convergence beckons. Comparably, reports on inter- and trans-disciplinarity, as well as team science, tend to repeat the same recommendations for removing barriers to integration and collaboration, including devising new administrative policies, training programs, and mechanisms for funding and communication. Moreover, the agora of public space championed in the discourse of problem solving is not without limits. Russel, Wickson, and Carew (2008) caution the agora is heterogeneous and complex, with its own imbalances of power. Even strategic targeting of environment and climate runs the risk of creating "mega-silos" that consolidate interest and resources into institutional blocks stifling further connections while limiting creativity and innovation.

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