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Interrogating the Learning Sciences as a Design Science: Leveraging Insights from Chinese Philosophy and Chinese Medicine

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Abstract
Design research has been positioned as an important methodological contribution of the learning sciences. Despite the publication of a handbook on the subject, the practice of design research in education remains an eclectic collection of specific approaches implemented by different researchers and research groups. In this paper, I examine the learning sciences as a design science to identify its fundamental goals, methods, affiliations, and assumptions. I argue that inherent tensions arise when attempting to practice design research as an analytic science. Drawing inspiration and insight from Chinese philosophy and the practice of Chinese medicine, I propose that the learning sciences may better attain its claims to science through greater reliance on inductive synthesis rather than linear causal analysis. In so doing, I reposition the endeavor of science making within the metaphysics of process philosophy instead of classical Western philosophy. I suggest that theory building will be strengthened empirically and pragmatically by more careful observation and systematic generalization of the stability patterns of design related phenomena. It also needs to be more situated in its orientation.

Keywords: Chinese philosophy; Chinese medicine; design science; inductive synthesis; learning sciences; stability patterns

Introduction

Design research, variously also referred to as design-based research (Design-based Research Collective 2003), design experiments (Brown 1992; Collins 1992), and formative experiments (Newman 1992), has been held up as an important methodological contribution of the learning sciences. Reinking and Bradley (2008) observe that learning sciences researchers have "promoted the legitimacy of this new approach to research as the basis for a new field referred to as *learning sciences*" (p. 14). Positioned as an approach to close the "credibility gap" arising from "unscientific research approaches" and the "detachment of research from practice" (Design-based Research Collective 2003, p. 5), design research also attempts to overcome the perceived limitations of traditional experimental and naturalistic approaches to educational research.

The banner of design research has drawn together researchers from a wide variety of disciplines, united only by a perceived need for change in the ways in which educational research is conducted. Reinking and Bradley (2008) note that researchers who gravitate toward the term *design experiment* tend to view their work as an extension of conventional laboratory work that is grounded in quantitative methods. Such researchers are keen to create a *design science* that claims legitimacy by using conventional views of causation and generalization. They essentially view design experiments as a precursor to randomized trials based on quantitative methods. Researchers who orient to use of the term *formative experiment*, on the other hand, tend to be guided by a more local and less formalized workability grounded in more pragmatic and qualitative approaches to educational research. They are less concerned with establishing specific causal relations and view generalization more broadly than extrapolation from sample to population. Literacy and activity theory researchers have favored use of the term *formative experiment* over *design experiment*.

Any new discipline or field spawns the publication of a handbook, in due course of time, to mark its coming-of-age. Just as the learning sciences spawned the *Cambridge Handbook of the Learning Sciences* (Sawyer 2006), design research has likewise spawned the *Handbook of Design Research Methods in Education* (Kelly, Lesh, and Baek 2008). Inspection of the Handbook by Kelly and his co-editors reveals that the practice of design research in education remains an eclectic collection of specific approaches implemented by different researchers and research groups. Reinking and Bradley (2008) state bluntly: "There is no single, agreed-upon methodological framework for conceptualizing, planning, conducting, and reporting formative and design experiments" (p. 61). Given the relative methodological infancy of design research, it is thus best conceived of as an approach to research (Reinking and Bradley 2008) or a set of methods for conducting research (Kelly 2004), rather than a coherent research methodology.

Characterizing design research

How might we characterize design research? Van den Akker, Gravemeijer, McKenny, and Nieveen (2006) propose that design research is (1) interventionist, (2) iterative, (3) process oriented, (4) utility oriented, and (5) theory oriented. Reinking and Bradley (2008) propose the following criteria: (1) intervention-centered in authentic instructional contexts, (2) theoretical, (3) goal oriented, (4) adaptive and iterative, (5) transformative, (6) methodologically inclusive and flexible, and (7) pragmatic. The extent of overlap between the two sets of criteria suggests a high degree of congruence as to how learning sciences researchers construe the field. A common concern for theory and utility-cum-pragmatism is noteworthy. In a recent analysis of the impact of design research to date, Anderson and Shattuck (2012) suggest that a quality design-based research study is characterized by (1) being situated in a real educational context, (2) focusing on the design and testing of a significant intervention, (3) using mixed methods, (4) involving multiple iterations, (5) involving a collaborative partnership between researchers and practitioners, (6) evolution of design principles, and (7) practical impact on practice. A constant motif expressed by learning sciences researchers is the aspiration that the learning sciences be a *design science* that evolves educational design principles. What might a design science mean, and to what extent does the foregoing characterization of design research help to enact the learning sciences as a design science? We examine these issues next.

Interrogating the method of the learning sciences

Collins (1992) argues that a design science of education cannot be an analytic science such as physics. Rather, it should be a design science, like aeronautics or artificial intelligence. For him, a design theory will identify all relevant independent and dependent variables by which the success or failure of an innovation can be measured, and the theory will specify how these variables interact. Drawing from Simon's (1969) book *The Sciences of the Artificial*, Collins, Joseph, and Bielaczyc (2004) cite professions such as architecture, engineering, and education as exemplar sciences of the artificial upheld by Simon. Unlike the natural sciences where analysis serves to achieve the primary goals of explanation and prediction (Dubin 1978; Reynolds 2007), the goal of a design science is to determine how designed artifacts behave under different conditions.

Is there an inherent tension, perhaps even a contradiction, between the goal of design science thus described and the proposed method of theory development framed in terms of independent and dependent variables? I believe so. The language of independent and dependent variables implies a traditional scientific quest for understanding processes in terms of cause-effect relationships between variables. As Reynolds (2007) notes, "[t]he . . . variable that is the cause is referred to as the 'independent variable' (because it varies independently), and the variable that is affected is referred to as the 'dependent variable' (because it is dependent on the independent variable)" (pp. 71–72). This quest for causal explanation *imputes* causal claims expressed as X and W caused Y based on a predictive model such as $Y = a + bX + cW$. Using methods of statistical inference (typically multiple regression or analysis of variance), the model accounts for variance in one unit by specifying a systematic linkage of this unit with at least one other (Dubin 1978). The nature of the systematic linkage is one of *regularity of co-variation* and not one of causality in the linear cause-effect sense of the word. Klabbers (2009) refers to this non-strict sense of causality as the *regularity conception of causality* that is derived from the philosopher David Hume.

As Reinking and Bradley (2008) suggest, users of the term *design experiment* tend to adopt conventional views of causation and generalization implied by the conduct of controlled experiments and randomized field trials, the implicit gold standard of research for analytic science. Thus, Brown (1992) states that "[t]he contemporary agenda is for experimentalists to fulfil this legacy [of earlier educational theorists] with concrete design experiments" (p. 171). Her examples of intervention "effects" from the "experiments" focus on "content knowledge acquisition," "retention of knowledge," and "responses to transfer tests." Anderson and Shattuck (2012) speak of the "*transfer* and translation of education research into improved practice" (p. 16, italics added) and, citing Barab and Squire (2004), of the agenda of design-based research to "*uncover*, explore, and *confirm* theoretical relationships" (p. 5, italics added). These discourse terms underlie the analytic mindset of positivist and rationalist science that assumes the possibility of widespread generalization of causal effects due to an underlying stable and objective world of teaching–learning phenomena. Kincheloe (2008) proposes the acronym FIDUROD to encapsulate this objectivist epistemology that such researchers tacitly appeal to, where knowledge is regarded as (1) Formal, (2) Intractable, (3) Decontextualized, (4) Universalistic, (5) Reductionistic, and (6) One-dimensional. Systematic variation is assumed to be present, thus rendering the testing of hypotheses plausible (Collins 1992). Adopting this positivistic mindset to research, the role of the researcher is cast negatively in terms of introducing the potential for bias (Anderson and Shattuck 2012). As with randomized controlled trials in medical research, human involvement and influence are regarded as contaminants to the research process.

The widespread quest for causal explanation is further evidenced by the following examples drawn from the design research literature:
(1) "Claiming success for an educational intervention is a tricky business. If success means being certain that an intervention *caused* learning, then we need to look carefully at the intervention in a particular setting" (Design-based Research Collective 2003, p. 5, italics added).
(2) "*Is there a systematic effect?* This question is about the intent to establish cause and effect. The Committee [referring to the American National Research Council's Committee on Scientific Principles for Education Research] concluded that randomized experiments, when feasible, are the best approach to ferreting out cause-and-effect relationships. We believe that experiments, quasi-experiments and causal models have a role to play in design studies" (Shavelson, Phillips, Towne, and Feuer 2003, p. 28).

The examples above stand in stark juxtaposition to Olson's (2004) observation that "[t]he reputation of educational research is tarnished less by the lack of replicable results than by the lack of any deeper theory that would explain why the thousands of experiments that make up the literature of the field appear to have yielded so little. That explanation would take us more deeply into an analysis of the school's place in the institutional structures of a bureaucratic society and the categories of rules, knowledge and procedures, that are required for successfully participating in it" (p. 25). A key contribution of the philosopher Dilthey (1991) was to argue that the goals and methods of *Naturwissenschaften*, the natural sciences, are entirely inappropriate for *Geisteswissenschaften*, the human sciences, because an understanding of human phenomena cannot be meaningfully reduced to physical world descriptions of cause and effect. Rather, the human sciences are more productively framed in terms of the relation between human means and ends. Solutions to human issues and problems are assessed on pragmatic criteria. Satisficing is a common feature of such solutions. Proof of "correctness" is not. By advancing educational research as a design science located within the analytic tradition of the natural sciences, learning sciences researchers in effect choose to construe their education-as-design-science as an analytic science akin to the natural sciences rather than as a human science. This positioning leads directly to deep conundrums.

In an insightful critique, Engeström (2011) identifies three crucial weaknesses of current design research. The first weakness relates to under-specified theoretical units of analysis that revolve around vague phrases such as "dynamical learning environments" and "learning ecologies". The scope and boundary of phenomena that fall within the limits of any research investigation are unclear because of the under-specification of these terms. The second weakness is that the design research process is construed as linear, culminating in the achievement of completeness and closure. However, this linear view ignores the fact that humans are intentional and agentive beings. They constantly interpret and reinterpret the challenges and tasks they face, making use of multiple changing lenses that often lead to unpredictable outcomes. As Engeström argues, humans "do not neatly obey the laws of linear causality" (p. 599). Intervention sites are always contested terrains full of resistance, constant reconstruction, and ongoing reinterpretation by actors involved. The intervention process is thus inherently non-linear. More than being elusive objectives, completeness, control, and closure are unattainable and hence inappropriate goals in the first place. The third weakness Engeström identifies is that "a variable-oriented approach to research is tacitly endorsed, without questioning the underlying problematic notion of causality" (p. 602). This variable-centric mindset, with its concomitant research model framed in terms of independent and dependent variables coupled with the quest for the specifying and including of all variables in the model, ignores the fact that educational innovations are open-ended and continuously co-configured social processes unlike automobiles and consumer products that Collins appeals to as his inspiration for design research. To overcome these weaknesses, Engeström advances the approach of formative interventions based on Vygotsky's method of double stimulation (Vygotsky 1978). This approach introduces a mediator as a facilitator of a social change process in tandem with the introduction of an innovation.

Design science vs. analytical science

In a thoughtful article on the saga of ISAGA, the International Simulation and Gaming Association, Klabbers (2009) argues that the simulation and gaming research fraternity is fractured into two communities. In this field, "the analytical and design sciences meet each other, causing much confusion, misunderstanding, and sometimes frustration. As long as both communities are not aware of their different epistemologies, methodologies, and crafts, they run the risk of judging each other on the wrong terms using criteria of success that apply to their particular domain, which are not suitable for the other community" (p. 45). Drawing on insights from Klabbers, I argue in this article that the learning sciences community needs to clarify its understanding of the differences between design science and analytic science. It appears that while the community represents itself as practicing a design science, the underlying values of community members as manifested in the methods of research they adopt and their modes of discourse suggest that they in fact practice an analytic science.

The science of game design is a science of the artificial. Game design entails a form of instrumental design oriented toward achieving specific pragmatic purposes. As a design science, game design does not seek to produce general theoretical, or universal, context-independent knowledge. Klabbers (2009) argues: "Game design is science, a craft, an art. Design scientists produce and apply knowledge for unique circumstances in order to create effective artifacts. Key research activities are building and evaluating (assessing). . . . Contrary to the theory-driven approach of the analytical sciences, *the design sciences are issue driven*. They address human needs, conquer bottlenecks, and capitalize on opportunities" (p. 34). Klabbers continues by observing that professional communities of practice (including engineers and educational researchers) usually have a lower position on the academic ladder. This lower standing arises from the more applied character of their work that fits more naturally into the realm of post-normal science (Funtowicz and Ravetz 1993). According to Klabbers, the term post-normal science refers to "issue-driven research in a context of hard political pressure, values in dispute, high decision stakes, and high epistemological and ethical uncertainties" (p. 34). This description characterizes the realm of educational research and should resonate with learning sciences researchers.

Work in game design involves two distinct levels of design: what I might call *design-in-the-small* (DIS), referring to game design as such, and *design-in-the-large* (DIL), referring to changing existing situations in the field into preferred situations. Both levels of design are closely interconnected. As March and Smith (1995) explain, design scientists produce and apply knowledge of tasks and situations in creating useful artifacts. In so doing, they produce four types of work products: (1) constructs: a basic language of concepts, (2) models: higher order constructions, (3) methods: ways of performing goal-directed activities, and (4) implementations: instantiations intended to perform certain tasks. In this context, note that design-oriented work is not theory-free. Using game design as an analogy, I argue that theory in design research operates at two distinct levels: *theory-in-the-small* (TIS), referring to the dialectical interplay between design work and ideational work, and *theory-in-the-large* (TIL), referring to the broader conceptual and metaphysical framings that guide the theorization of student learning. In a design science, progress is ultimately achieved when existing technologies and media, including the attendant practices of using such technologies and media, are replaced by new designs that are more effective (March and Smith 1995).

From a systems theory perspective, properties of the whole cannot be adequately understood from an understanding of individual parts. Hence, the properties of a person cannot be derived from the clinical study of human organs in isolation. Neither can the properties of a collective social network be constructed from the properties of individual members. These examples illustrate the limitations and limits of analytic approaches to science making because causal analysis cannot deal with emergent phenomena that involve more than one level of analysis. In the study of educational designs and outcomes, however, two levels of analysis—that of small and large—are essential. Opposing the linearity of cause-effect studies, Klabbers (2009) argues that the *process approach* of design science requires a different mode of explanation: one that is rooted in the comparative and observational richness of data that designers and users utilize (Laurel 2003; Margolis and Buchanan 1995).

Maxwell (2004) critically interrogates the National Research Council's assumptions underlying "scientifically-based research," arguing that these assumptions lead to a misrepresentation of the nature and value of qualitative research for causal explanation. From his perspective, process theory deals with events and the processes that connect them. He states that process theory "is based on an analysis of causal processes by which some events influence others. It is fundamentally different from variance theory as a way of thinking about scientific explanation" (p. 5). While the notion of causality is preserved, it is not encapsulated in a direct and linear cause-effect relationship between variables. This important difference is described by Klabbers (2009) as follows: "Following the variable approach, as a member of a community of *observers*, research is focused on establishing the *x-y correspondence through* [the function] *F*. Following the process approach, as a member of the community of *practice*, assessments involve designers and users and the way they *construct meaning about the artifact in its context of use*. The users are actors and agencies in public and private space. Process causality refers to linkages between actions and events and the way they simultaneously and in parallel unfurl over time and in space" (p. 38, original italics). This notion of process causality accords well with that held by Dewey (1925/1988) when he said, "causality is another name for the sequential order itself; . . . this is an order of a history having a beginning and end" (pp. 84–85). In similar vein, Engeström (2011) asserts that, from the perspective of process-oriented research, in contrast to variable-oriented research, "causation can actually be observed and reconstructed as a real sequence of events. It uses historical methods and narrative evidence, as well as close observation and recording of unfolding chains of events" (p. 610).

A process worldview thus allows for observing causality as regularity of co-variation in evaluation studies of artifacts operating in unique circumstances as single cases and as unique events. This perspective provides meaning to local causality, helping researchers to understand and explain human action in relation to an innovation or artifact in use, in a context dependent fashion. Process causal relations, as reconstructed by Dewey, arise from the coordinated instrumental actions of human agents. They are embedded in artifact use. Their effects are consequently not fixed but contingent. The classical scientific method fails to incorporate the *interpretive character of human thought and action*, a key tenet of Chinese philosophy, vis-à-vis the artifact. As Klabbers (2009) asserts, "it needs to be abandoned as a viable approach to design science" (p. 39).

From linear causality to inductive synthesis: Chinese philosophy, Chinese medicine, and process philosophy

One of the distinctive features of Chinese philosophy and Chinese medicine is their unabashed holism. The split between man and nature and between mind and body have never touched Chinese philosophy. Consequently, the Cartesian dichotomy that has paradoxically both benefited and plagued modern Western medicine cannot be found in the theoretical constructs of Chinese medicine. In the practice of Chinese medicine, the person is treated, not the disease; the disease simply *is* (Campbell 2008; Unschuld 2009).

From the viewpoint of Chinese philosophy, an individual is a relationally constituted and situated self. Relationships and environments largely influence and construct an individual's values, thoughts, beliefs, motivations, behaviors, and actions. Cheng (2007) proposes that human consciousness be understood in terms of three integrated layers. The first layer is a consciousness of the cosmological context within which all life is embedded. This consciousness is informed by pre-conceptions as well as observations of the world that yield an onto-cosmology of change and the transformation of all things. Reality is understood as a comprehensive totality of entities generated from a common source. These entities are interconnected and constantly undergoing transformation. The second layer is a consciousness of the human self. It is derived from reflection and an understanding of the unique position of the human person in the world, including the functions of the human heart-mind (*xin*). This consciousness becomes the root for moral, ethical, and religious consciousness of human identity. The third layer of consciousness is a socio-political consciousness that concerns moral consciousness on one hand and cosmological consciousness on the other. This layer guides an individual on how to act to develop oneself as a "superior man" or *junzi* (Cua 2007) and how to relate to others so that human values may be realized through society's institutions and infrastructure. Thus, the first layer defines the world of being and becoming. The second layer accentuates human personhood based on self-reflection of one's unique place in the life-world of humanity. The third layer addresses human selves living meaningfully in a socio-political and practical context within which they can realize their desires for creativity and freedom of action (Cheng 2007).

The Chinese metaphysical tradition constructs reality as a dynamic of interconnected events and entities in constant transformation. Creative change manifests itself in the generation of life and in the transformation of states of being and becoming. Change takes place in two modes of becoming—*yin* and *yang*—the invisible and the visible, the formless and the formed. The transformation of things in these two modes of becoming expresses itself in terms of growth and decline. Transformation is also expressed through the interchange of vital forces (*qi*) that embody relevant forms and principles (*li*). Thus, any event or entity in the real world is both concrete and principled. It is both phenomenal and noumenal. The two cannot be separated. Their unity is realized in an ontological-cosmological process. A human person is part of this process-reality. She comes to understand this process by comprehensive observation (*guan*) of the things in the world. Ideally, she develops and realizes herself through processes that unite thinking and action (Cheng 2007).

Daoist philosophy "embraces multiplicity and plurality, often reflecting on natural kinds and events in the natural world in order to cast doubt on anthropocentric and reductive interpretations of events and processes" (Lai 2008, p. 9). Continuities and correspondences are posited between the cosmic or heavenly and the natural or earthly. The *Yijing*, or classic *Book of Changes*, focuses on change and on how its effects can extend across different realms. It foregrounds changing situations in life, how these changes may impact individuals and their environments, and how individuals might respond to these changes to minimize harm.

Change, according to the *Yijing*, is a continuous and non-isolable phenomenon. Individuals are exposed to much that is beyond their immediate control. Their influence, and the impact of individuals, in turn, extends well beyond what is immediately obvious or directly quantifiable. This interdependent, coupled relationship involving the individual constitutes the theory of *ganying* or mutual resonance.

Lai (2008) identifies six predominant features, *inter alia*, of Chinese philosophy that are consistent with the *Yijing*. These features are: (1) the primacy of observation, (2) a holistic, all-encompassing perspective, (3) a dialectical and complementary approach to dualisms, (4) correlative thinking and resonance, (5) an interpretive approach to meanings and correspondences, and (6) constant movement marked by the inevitability of change.

As articulated by Lai (2008), early Chinese philosophy has a palpably empirical character that derives from experiences in and observations of the world. Observations are vital to reflective thinking, and they usually precede it. Perceptions of patterns, regularities, and correlations arise from observations of connections, movements, and transformations in the world. A general feature of Chinese philosophy is its implicit awareness of a larger context and of attention paid to the whole. The self, for instance, is construed as a contextually embedded being who is interdependent with others and whose existence, beliefs, and actions can only be understood with reference to his or her broader environment. This environment subsumes not only the natural environment but also the historical, cultural, social, and political dimensions (Lai 2007b). There is a distinct lack of postulations of entirely independent or transcendent entities in Chinese philosophy. Abstract theoretical absolutes or universals that control the order of the world are noticeably absent. As part of its conceptual framework, the *Yijing* also sets up complementary opposites by means of contrastive concepts. In Chinese medicine, for example, the complementarity between *yin* and *yang* is well known. Paired concepts constitute part of the explanatory framework of change. Zhuangzhi, the ancient Chinese philosopher, is noted for rejecting the kind of Western logic that reduces things to either being *so* or *not-so* in favor of a dialectical approach that values contrasts between perspectives.

Chinese philosophy is noted for its correlative thinking that views events and situations in one realm as being parallel to or helping to explain those in another. Resonances refer to more specific correspondences that postulate some coupled, causal connection in contrast to the linear causal models of Western thinking. In addition, Chinese philosophy favors the local over the universal. It adopts an interpretive approach that emphasizes what is relevant in the particular circumstances of everyday life, focusing on the specific situation at hand. The *Yijing* is noted for embodying an attitude that is expectant of change and of seeking ways to prepare for and to deal with change given its inevitability and imminence.

The alignment between the Chinese worldview and that of process philosophy (Mesle 2008; Rescher 2000, 2008) is remarkable. Long before the days of Plato and Aristotle, Heraclitus, who lived around 540 B. C., recorded his depiction of the world as a manifold of opposed forces in mutual rivalry. From Heraclitus, we have the well-known saying that "one cannot step into the same river twice." As Heraclitus saw it, reality is not constituted by a constellation of *things*; rather, it is constituted by a complex of *processes*. Thus, process is fundamental: the river is not an object but an ever-changing flow of water.

Adoption of a process view refigures our understanding of the world ontologically and epistemologically. Process, as a sequentially structured chain of successive stages or phases, possesses temporal coherence and unity. It has an emergent structure that arises by virtue of statistical regularities. (Consider, for example, the apparent structural regularity of rice fields in Bali.) Crucially, from the perspective of process ontology, enduring "things" are never more than patterns of stability in a sea of process change. Processes are not the machinations of stable things; rather, things are the *stability patterns* of variable processes (Rescher 2008).

Rescher (2000) espouses process philosophy as a metaphysics committed to the following basic assumptions:

1. Time and change are among the principal categories of metaphysical understanding.
2. Process is a principal category of ontological description.
3. Processes are more fundamental than things for the purposes of ontological theory.
4. Several, if not all, of the major elements of the ontological repertoire (e.g. Nature, persons, material substances) are best understood in process terms.
5. Contingency, emergence, novelty and creativity are among the fundamental categories of metaphysical understanding.

These metaphysical commitments challenge classical Western metaphysics. However, they align well with the philosophical position of pragmatism (Biesta and Burbules 2003; Bredo 1994; Garrison 1994; James 2000; Peirce 1878/1992) and the conduct of educational research with an orientation toward constructing improved social futures (Chee 2010; Elkjaer 2009).

Consistent with a process worldview, Chinese medicine derives its functional efficacy and widespread adoption by virtue of a different mode of science making, namely *inductive synthesis*. Porkert (1983) asserts that Chinese medicine "relies exclusively upon inductive synthesis. In its classical teachings, it perfectly complies with the general criteria of science in the modern sense, viz. (1) positive experience (to be checked and re-checked at will), (2) univocality of statements, and (3) the stringent rational investigation (systematization) of empirical data" (p. 7).

From the viewpoint of Chinese medicine, health is understood in terms of effective harmonies between all aspects of the human body. Chinese medicine emphasizes resonances between the different (Chinese) organs (Lai 2007a). Key to grasping the Chinese construction of health and wellness is understanding the functioning of the human body in terms of the central concept of dissipative structure: a structure that emerges from and is maintained by energy flow. As Herfel, Rodrigues, and Gao (2007) explain, existence and structure depend on the flow of energy through a system, as with a standing wave in a rapidly flowing river. Such structures are far from being in equilibrium. If the energy throughput (e.g. the flow of water) is removed, the structure (i.e. the standing wave) immediately collapses. Thus, the patterns exhibited by dissipative structures are self-organizing. They emerge from the components of the system responding to the energy flow, giving rise to new constraints that reconfigure internal relations within the system. The internal dynamics of the system are sustained while the energy gradient is maintained. The genesis of such seemingly stable but nevertheless transient self-organizing systems accords with the biologically grounded understanding of the emergence and organization of human cognition as advanced by Maturana and Varela (1980, 1992).

Following traditional Chinese cosmology, it is not objects that populate the world. Rather, the world consists of interrelating processes. These processes arise and are maintained by *qi*, or energy flow. The "objects" of

Western philosophy are stabilized patterns of flow in Chinese terms. Thus, the world is a complex dynamic system. Each entity is a process within a larger process. Nothing exists in the absence of energy flow. In Chinese medical practice, therefore, human beings are not individual objects that exist independently. Rather, they are identifiable stability patterns within the myriad flows that constitute the world. Human beings are dissipative structures and hence constituted by process through and through.

While linear causal analysis may have served the purposes of the natural sciences well, it is a severely limited mode of science making for the conduct of Chinese medical practice because linear cause-effect analysis deliberately suppresses actual, momentary, and *present* impressions that a Chinese physician is faced with (in effect treating these aspects as "noise") so as to foreground *past* effects—that is, causes—of presented illness. In doing so, cause-effect analysis reinforces the material view of Western medicine that focuses on substrata, matter, bodies, and somatic aspects of illness at the expense of every other aspect of reality—for example, emotional and spiritual (in the sense of the Chinese concept of *shen*)—experienced by the patient in her present condition. To the extent that there is *homogeneity of substrata*, the Western approach works well because of the relative insignificance of individual differences between single instances. Scientific claims concerning oxygen atoms, for example, are highly generalizable because the homogeneity of such atoms is extremely high. However, as we move from elementary particles to molecules, cells, lower then higher organisms, human individuals, social, political and cultural communities, etc., the homogeneity of strata decreases, with a concomitant decrease in the stringency and applicability of linear causal analysis. Western medical science when "consistently applying causal analysis, cannot conceive of a patient as a unique personality but . . . only as a random specimen of the human species" (Porkert 1983, p. 15). In contrast, what diagnosis in the practice of Chinese medicine "strives for and produces is . . . *a synthesis of numerous individual factors*, assembled in each patient [who is] examined in a unique and characteristic manner. Moreover, the positive character of the statements of Chinese medicine rests upon the stability of function. In other words, only such functions will be attributed significance which, from a human perspective, offer sufficient stability to permit a precise and univocal definition. . . . [E]ach disease is seen and treated as an individual and unique event, as disorder in an individual personality" (p. 15). In this way, Chinese medical diagnosis exercises a re-humanizing influence in general medical practice.

On the premise that stability patterns emerge from variable processes, inductive synthesis provides us with a viable mode of scientific theory construction. Stability patterns, or functions, from the vantage point of any human observer, appear to be immensely great in the realm of galaxies, decreasing continuously in the direction of planetary systems, cultural, political, and social communities, human individuals, higher and lower organisms, cells, molecules, atoms, and elementary particles. Thus, a stability pattern develops in *inverse proportion* to the homogeneity of the corresponding substratum (Porkert 1983). In short, the more complex a phenomenon, the greater the likelihood of a stability pattern emerging from self-organization and observer generalization.

From the viewpoint of Chinese medicine, the stringency of statements in the field of human physiology, based on linear causality, suffer from a marked decline. Diagnostic claims and assertions fade away into utter vagueness and uncertainty in the field of psychic and social phenomena. "In order to perceive and define functions, movement, dynamic effects, psychic or vital phenomena, inductive synthesis is required – in other words an approach viewing a given effect within its *present* setting of other likewise *present* phenomena" (Porkert 1983, p. 4, italics added). Western medicine, by focusing predominantly if not exclusively on matter and physical substrata, is cognizant only of events accumulated and sunken into the past. Consequently, it lacks a sense of movement and change oriented toward the future: namely, the process of healing.

Given that a design science of education addresses classroom phenomena with relatively low homogeneity of substrata, it follows logically that the work of design research in "messy classroom settings" is better approached through science making via inductive synthesis and a search for stability patterns of co-variation than through the method of linear cause-effect analysis. An inductive mindset is also likely to strengthen research by orienting it toward the construction of improved futures.

Implications for conducting research in the learning sciences

What might the approach of inductive synthesis imply with respect to the role and place of theory in the learning sciences? We have noted previously that learning sciences researchers attach great importance to the role of theory in their work. DiSessa and Cobb (2004), for example, state that theory is critically important, but they also lament that it is currently underplayed in design research studies. They agonize that educational theories lack the breadth, precision, and detailed validation prevalent in the physical and biological sciences. They decry educational theories that seem to replace one another rather than subsume, extend, or complement one another. They bemoan the difficulty of telling whether scientific progress is being made. They are dismayed that theories such as Piagetian developmental theory and constructivist theory have little power to influence the design of classroom interventions. They lament how the complexity of real-world intervention research makes the development of useful theories extremely difficult. Part of this difficulty may arise from too liberal a use of the term "theory." Kelly (2004, p. 123) suggests, for example, that he prefers to "use the word 'theory' and 'theoretical' very sparingly and instead to use working words" such as "hypothesis", "conjecture", "observation", "framework", "explanation", and so on.

Notwithstanding, the foregoing laments stem from a doctrinaire approach to developing a scientific body of knowledge that Reynolds (2007, pp. 146–147) describes as "theory-then-research." It proceeds as follows:

1. Develop an explicit theory in either axiomatic or process description form.
2. Select a statement generated by the theory for comparison with the results of empirical research.
3. Design a research project to "test" the chosen statement's correspondence with empirical research.
4. If the statement derived from the theory does *not* correspond with the research results, make appropriate changes in the theory or the research design and continue with the research. (Return to step 2.)
5. If the statement from the theory corresponds with the results of the research, select further statements for testing or attempt to determine the limitations of the theory (the situations where the theory does not apply).

The steps outlined above may feel very familiar because they are the stuff of a research methods course. The procedure is understood as an aid to developing good theories that embody generalization as a goal of science, while also allowing discrimination between relations that are necessary and those that are contingent (diSessa and Cobb 2004). Implicit in the use of the term "generalization", however, is the assumption that scientists extrapolate from researching a few instances to making claims about the whole population. This approach contrasts with the process approach, which generalizes from as many available instances as possible.

In view of the above tension, does an alternative approach exist for developing a scientific body of knowledge? Yes, indeed. Reynolds (2007) refers to this method as "research-then-theory." It proceeds in the following manner:

1. Select a phenomenon, and list all the characteristics of the phenomenon.
2. Measure all the characteristics of the phenomenon in a variety of situations (as many as possible).
3. Analyze the resulting data carefully to determine if there are any systematic patterns among the data "worthy" of further attention.
4. Once significant patterns have been found in the data, formalize these patterns as theoretical statements that constitute the laws of nature.

Interestingly, the above method was advocated by Francis Bacon (1620, cited in Reynolds 2007) in the following terms: "This is the true way, but as yet untried." Bacon argued that there can be only two ways of searching into and discovering "truth": one is the deductive approach (theory-then-research) that starts off with general, or grand, theory, and working "downward" to specifics, and the other is the inductive approach (research-then-theory) that starts off with particulars and working "upward" to "the most general laws." Readers will surely notice that the research-then-theory approach is consonant with the method of inductive synthesis adopted in Chinese medicine. Following this approach, theory, in the form of broadly applicable, empirically robust, and stable claims, is a logical *derivative* of the research process, not its antecedent. Theory building, understood in this way, aligns with Dewey's (1925/1988) argument that the "conversion of eventual functions into antecedent existence" constitutes "*the* philosophic fallacy" (p. 34) Theory, as human construction, is always subsequent, not antecedent. It constitutes the formalization, in language-based and hence representational terms, of observed regularity of co-variation arising from multiple process events.

From a practical point of view, adopting the theory-then-research approach raises a serious logical issue of bootstrapping. In the absence of prior theory, how does one go about proposing a general theory? It appears that the only way to do so is by purely speculative thinking. Theories, thus derived, are unlikely to serve us well. It is vital that theory construction, while surely requiring the exercise of creative thinking and imagination, be grounded to some reasonable extent in an individual's prior experiences in and observations of the world.

Based on the foregoing, I propose that design research must necessarily engage theory at multiple levels. Referring again to the constructs of TIS and TIL, TIS provides the basis for design at the level of curricular materials, technology design, and in-class processes, while TIL provides the basis for the theorization of student learning and hence the conceptual framing of the design research intervention (with its many tacit assumptions). It should be noted that both levels of theorizing are inherently *value-laden*. Being design oriented, the theories are inherently *future* oriented and instrumental in nature. They are also dialectically coupled, with each level mutually constraining and, at the same time, supporting the other level. Such theories are advanced and enhanced through the dialectic coupling of action and reflection. By contrast, derivative statements of theory are scientific descriptions based on stability patterns. These theories, which I shall call SP Theories (stability pattern theories), are of a different type compared to TIL and TIS. By their very nature they are oriented to the *past* because they are derived from prior observations. SP Theories are strong only to the extent that the stability patterns entailed are strong. They always lie open to revision (rather than falsification) as the nature of underlying processes change over extended time scales, leading to "generalization decay" (Cronbach 1975). This is the case with Chinese medicine, where the body of accumulated understandings derived from many centuries of observation and generalization constitute the know-how and expertise of the domain. SP Theories, then, serve as conceptual tools. Derived from collective experience of co-variation regularities in the past, they are applied in the present and directed toward achieving the good of the patient in the imminent future. They are not attempts to state generalizable and immutable "truths." We can thereby jettison the classical metaphysics of eternal and intrinsic essences, as advocated by Dewey (Garrison 2001). We can also avoid the impossible quest for certainty that Dewey (1929/2008) cautioned us against and sidestep the "intellectualist fallacy" that seeks to equate what we can know with what is "real" (Biesta and Burbules 2003; Dewey 1925/1988). Thus, "truths" are always local in context, situated in nature, and perpetually "humble" (Cobb, Confrey, diSessa, Lehrer, and Schauble 2003).

Conclusion

In this article, I interrogated the claim that the field of the learning sciences is a design science. As part of my analysis, I offered two theoretical contributions. The first contribution relates to clarifying the nature of a design science. My analysis suggests that there is an inherent inconsistency between the pursuit of linear causal analysis, an activity that orients to the past, and the practice of a design science, an activity that is instrumental in its goals and always oriented toward the future. The second contribution, based on insights from Chinese philosophy and the practice of Chinese medicine, relates to highlighting the inverse relation between heterogeneity of substrata and the power of linear cause-effect analysis. As substrata become more heterogeneous, generalizations emerge through inductive synthesis as stability patterns in the domain of concern. As a corollary to the second contribution, I have reframed design research within the metaphysics of process philosophy. I have proposed that stable scientific descriptions of phenomena, or SP Theories, related to intervention research in classrooms are better derived via inductive synthesis than through piecemeal causal analysis because such intervention work is constructive, not replicative, and always contextual and contingent. Stringent use of close and careful observation coupled with systematic generalization of stability patterns will likely yield empirically and pragmatically robust theories. It will also strengthen a humanistic orientation toward the conduct of educational research where individual differences are respected and human agency is valued. Looking ahead, I suggest that learning sciences researchers pay greater attention to deriving holistic system-level theories that articulate multiple relations and interdependencies simultaneously rather than focusing on cause-effect theories of restricted scope and significance.

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