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Article

Laying the Foundation for Transdisciplinary Faculty Collaborations: Actions for a Sustainable Future

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Abstract: How can academicians who desire a sustainable future successfully participate in transdisciplinary projects? Transcending our hidden thought patterns is required. Paradoxically, the disciplinary specialization that enabled the industrial era and its metaphors now function to undermine our ability to recognize and participate in the transformational learning that is needed. In this paper, we offer a post-industrial era metaphor for transdisciplinarity—that of complex dynamic system—that has helped us to work through the unexpected experiences encountered in the process of transformative learning. These insights are based on an ongoing transdisciplinary research collaboration (2008–present) using action research methods; we focus on the faculty experience. Accepting the metaphors of complex systems, we describe the systemic conditions that

seem to repeatedly reproduce the emergence of transformative learning for participants, as well as what one might expect to experience in the process. These experiences include: conflict, existential crisis, transformation and renewed vitality within the necessary context of a safe and caring community. Without the adoption of complexity metaphors, these elements would have been overlooked or interpreted as a hindrance to the work. These insights are intended to serve as socially robust knowledge to support the effective participation of faculty members in sustainability projects of a transdisciplinary nature.

Keywords: emergence; complexity; transformative learning; transdisciplinarity

1. Introduction

It is perhaps obvious that what academicians call "the real world" is characterized by dynamic complexity, with emergent challenges that cannot be addressed by the usual academic methods of reductionist science. This "twenty-first century" reality is experienced more acutely in efforts to transition to sustainable development and practices. While there is hope that the "green economy" will aid this transition [1], "greening" one's business, which refers to balancing environmental and economic concerns, is considered "no small feat" [2]. Going further to include issues of social equity inherent to sustainability is likely to amplify the challenge by involving considerations of apparently conflicting social, environmental and economic needs [3]. This requires the ability to collaboratively innovate sound decisions in the face of ambiguity, to manage paradox and emergent change. It is in this space that the practice of transdisciplinarity holds promise [4–11]. Transdisciplinarity prioritizes holism [4,5], allows multiple levels of reality and simultaneously valid and conflicting points of view and recognizes that systems' behavior emerges from the whole rather than from summing the behavior of their parts [4,5,12].

In this paper, we use the definition for transdisciplinarity proposed by Jahn *et al*. [13]:

> "A critical and self-reflective research approach that relates societal with scientific problems; it produces new knowledge by integrating different scientific and extra-scientific insights; its aim is to contribute to both societal and scientific progress" [13] (p. 8).

In addition to its organization around societally relevant challenges and purpose to produce socially robust [14] solutions to these challenges, transdisciplinarity also includes a type of learning that distinguishes it from traditional disciplinary research: mutual learning amongst "science" and "lay" participants [15,16] and learning that integrates and transcends disciplinary paradigms in seeking unified understanding [15,17]. We note that the term transcending recognizes a larger "whole" reality that exists prior to the socially-constructed science/lay/disciplinary boundaries; it is this "whole" that transdisciplinarity seeks to discover/recover through transgressing/transcending the boundaries.

Paradoxically, the process of acquiring disciplinary expertise acculturates one into a set of discipline-defined, historically accepted ways of knowing and seeing the world [18–20], such that alternative ways occur as "wrong". Disciplines, created in the industrial era, arguably lasting from the 18th through most of the 20th century, naturally take as "given" the paradigms of that era. Our way of

thinking and apprehending our reality is through metaphors that contain "preconscious interpretive acts which compose the world as it is seen [and] are grounded in an interconnected gestalt of thinkable possibilities" [21] (p. 3) and, so, limit ideas to historically-encountered solutions. It is for this reason that effective transdisciplinarity requires transformational learning, which is described by Mezirow as:

> "Learning that transforms problematic frames of reference—sets of fixed assumptions and expectations (habits of mind, meaning perspectives, mindsets)—to make them more inclusive, discriminating, open, reflective, and emotionally able to change." [22] (p. 58).

Transformational (or equivalently, transformative) learning involves a reconstitution of self-identity—"the meanings that persons attach to the multiple roles they typically play in highly differentiated contemporary societies" [23] (p. 284)—and a transcendence of habitual thought patterns and behavior [21,24], such that one can then see and consciously choose alternatives if desired. In this way, transformational learning is emancipatory by nature. The purpose of transformative learning is enlightenment, which includes the freedom to choose behaviors that are alternatives to habitual (unconscious) patterns, and, thus, is foundational to transitioning to sustainability science and practices [25]. It differs from incremental adaptation or learning, where one acquires new knowledge or skills without fundamentally altering their assumptions about themselves, the nature of reality (ontology) or the nature of knowledge (epistemology). Adaptive learning is important and necessary. However, transformative learning—where socially-constructed boundaries vanish through co-learning and co-creating—is the substance of effective transdisciplinarity and the subject of this paper.

With regard to the university setting, transformative learning (and we would add, transdisciplinary research that includes transformative learning) is akin to what Ricca calls "a complexity approach" to teaching/learning [26], which parallels descriptions of complex systems—non-linear, non-static, open and recursive [27]. Like complex mathematical systems, which are not given to predictability [28], transformative learning is also outside "fixed assumptions and expectations" [29]. Clearly, this type of teaching and learning is distinct from reductionist approaches that seek to attain predictable learning and research outcomes through hierarchical, expert control of the classroom or research methods. How, then, do we foster the conditions for success for disciplinary faculty members, educated in industrial era paradigms, who seek to engage in transdisciplinarity?

Looking to the recent proliferation of publications on transdisciplinarity, we see guidelines on the form and processes for transdisciplinary research (e.g., [11,15,17,30–32]) with an acknowledgement of the need to understand "what might be required to foster and encourage it" [11] (p. 84). These insights are useful as a way of distinguishing features of transdisciplinary research from traditional disciplinary research. We notice that in terms of the four types of causality proposed by Aristotle (final, formal, efficient and material) [33], the current literature on transdisciplinarity emphasizes formal (form) and efficient (process), with some mention of material (tools, experts) cause. The final cause, or intent, is implicit. We also notice that the emotional processing that typically accompanies transformative learning [34,35] is often missing from these heuristics. It is our experience in the modest set of transdisciplinary research activities on which this paper is based that the participants' intent and emotional processes are substantive and controlling factors in the outcomes. The tendency to omit these elements occurs to us as obscuring critical dynamics that must be skillfully navigated in order to achieve the transformational aspirations of sustainability.

The intent of this paper, therefore, is to serve faculty practitioners who would undertake transdisciplinary research. We describe salient patterns within our experience of transformative learning in transdisciplinary research projects, faculty dispositions and systemic conditions that seem to be necessary for transformative results. We forward a theory of how these properties are related, based on metaphors of complex dynamic systems. One of our research questions was, "What does it take for the faculty to enact a collaborative transdisciplinary co-discovery model in an institution that is optimized for something else?" In presenting these results, we hold an assumption that learning is central to research and discovery; transformative learning is central to effective collaborating for sustainable outcomes. These insights were derived through a practice of continuously deconstructing our motivations and assumptions and enacting a theory-based praxis of change with action research methods in a series of transdisciplinary research activities dating back to 2008. These insights are not intended to validate generalized truths in the tradition of reductionist science; they do represent our attempt to provide socially robust knowledge that has use in other transdisciplinary research contexts. Our focus is the faculty experience. We submit these insights in the spirit of fostering mutual learning.

2. Background: Using Complexity Science Metaphors for Transdisciplinarity

2.1. Metaphors and Their Unintended Consequences

Why might we consider our use of metaphors in transdisciplinarity? Lakoff and Johnson assert that metaphors reveal that we experience one thing in terms of another and then act according to our metaphorical apprehension of the thing [36]. Linguists assert that metaphors are necessary as proxies for reality [37] and have unintended consequences of altering the way we act in the world [38] through entailments; in essence, the use of the metaphor has consequences, such that referring to argument as war would have different consequences than argument as play [36]. The current discourse on transdisciplinarity often draws on metaphors of "manufacturing" to describe transdisciplinary research, illustrated in phrases, such as: process, build, design, knowledge generation, knowledge products, solution-oriented transferable knowledge, prototypes and scaling-up (e.g., see [15,39]). Using these industrial era metaphors can inadvertently invoke associated value systems of efficiency, productivity, consumption, quality control, uniformity, economy of scale, profit margins and cost/benefit analysis. These are not bad in themselves; the issue is that the metaphors can cause one to act from unconsciously-held "truths", with the result being at odds with the aims. An example of this dynamic in transdisciplinary sustainability projects is the retreat to pre-packaged solutions in response to the fear of failing [15]. The perceived benefit and efficiency of the historical, non-sustainable solution is prioritized over the perceived cost of redesigning a sustainable solution. The non-sustainable costs are externalized to "others" outside the system and, thus, are not factored in the decision. This example, apparently common in transdisciplinary sustainability efforts [40], illustrates that the values hidden in the industrial era metaphors are unconsciously replicated in the behavior, despite espoused commitments.

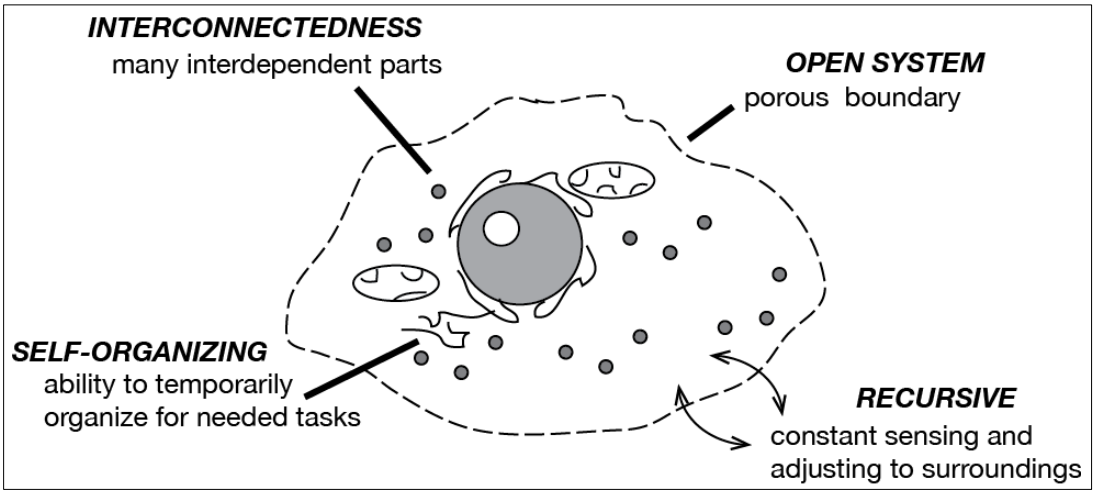
We have found that an alternative metaphor—that of dynamic complex systems—offers a new frame from which to work with transdisciplinarity. The metaphorical relevance comes from the similarities between complex systems' properties and behavior and those of a transdisciplinary research/learning system. Using complexity metaphors for transdisciplinarity offers the same utility as

vector metaphors for gravity: they enable us to effectively work with the observed phenomenon. To aid the reader, we briefly introduce complex systems and their behavior here.

2.2. Introduction to Dynamic Complex Systems

A simple analogy for a dynamic complex system is a single-celled organism, schematically depicted in Figure 1. The organism is conceptually distinct from its environment by its shared qualities; we are naming it as a system. What we see in this system is a porous cell boundary that allows the exchange of materials with the surroundings; it is an open system. The cell consists of many interdependent parts that interact to create the behavior of the whole cell; its parts exhibit interconnectedness. The parts have the ability to come together as needed and perform various tasks; it is self-organizing. The cell is constantly sensing its environment and adjusting to changes; it is recursive.

Figure 1. Crude schematic of a single cell organism and the qualities that make is similar to a dynamic complex system.



Taken together, these properties—open, interconnected, recursive and self-organizing—result in what is called a complex system. The complexity of the system causes its overall behavior to be organic in nature, which means that its behavior unfolds in a non-predictable way over time; it is emergent. "Emergence" is a phenomenon that only occurs in the presence of the system. To quote Jaewon Kim,

> "At the core of [emergence] was the thought that as systems acquire increasingly higher degrees of organizational complexity they begin to exhibit novel properties that in some sense transcend the properties of their constituent parts, and behave in ways that cannot be predicted on the basis of the laws governing simpler systems" [41] (p. 3).

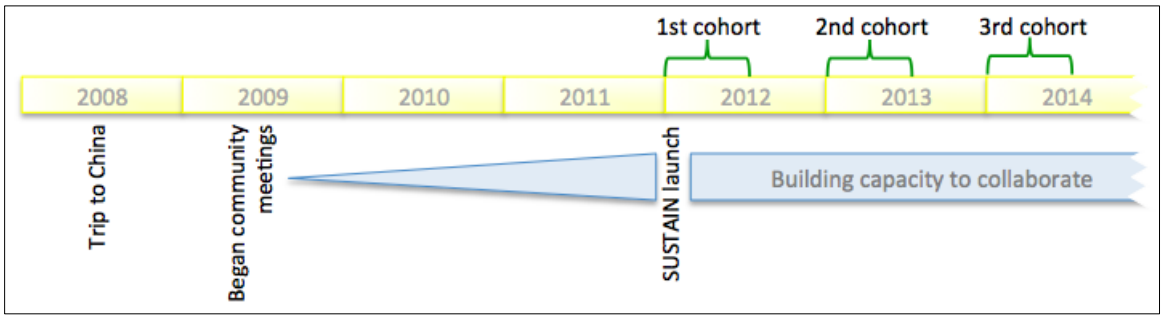
The metaphor of complex dynamic system has helped us to make sense of the patterns that we encountered in conducting this transdisciplinary research. In the following section, we describe the experimental context on which this work is based, after which we include our methodology, results and discussion.

3. Experimental Context

3.1. History and Overview

The overall timeline of the set of transdisciplinary research activities that form the basis of this paper is illustrated in Figure 2. The initial foundations for our work together began in 2007 as a grass-roots effort to collaboratively design innovations for sustainable communities. Several of us traveled to China with a team of 14 university and non-profit organization partners who were design and sustainability "experts". We realized that our actions to design sustainable communities were not in themselves sustainable; our means were misaligned with our ends. We also saw that our orientation as "experts" in relationship to our Chinese partners at Tongji University, Shanghai, China, was misaligned with our notions of sustainable development and the reality of our own lives relative to those of our partners. This discord then led a subset of the U.S. team at the California Polytechnic State University to commit to learning what is meant by "living sustainably" in our own geographical communities, such that we had legitimacy and knowledge to share with our partners.

Figure 2. Overall timeline for the set of transdisciplinary research activities on which this paper is based.



Note: SUSTAIN is an acronym for Sino-U.S. Strategic Alliance for Innovation.

The primary research setting was San Luis Obispo, California, USA, in a faculty-initiated effort toward sustainable aims (Sino-U.S. Strategic Alliance for Innovation—San Luis Obispo, abbreviated SUSTAIN-SLO). The overall effort, summarized in Table 1, can roughly be described as initiation (Case 0 in Table 1) and three annual implementation cohorts who were engaged in transdisciplinary research that involved sustainability projects based in our local community (Cases 1–3 in Table 1). In each of the cases in Table 1, we employed a process analogous to the transdisciplinarity process proposed by Lang *et al.* [15]. They suggest that transdisciplinarity consists of three phases: (1) problem framing and team building; (2) co-creation of solution-oriented transferable knowledge; (3) (re-) integration and application of the created knowledge. As shown in Table 2, we would retrospectively describe our phases similarly, with an emphasis on our underlying intent: (1) established a collaborative community and shared aspirations; (2) uncovered a ground of wholeness and abundance from which to co-design; (3) navigated implementation for alignment with shared principles.

Table 1. Summary of the overall set of transdisciplinary research activities involved in this paper. Details of each case can be found in the Appendix.

Case	Duration	Participants	Description
0	December 2007–September 2011 *Initiation, design*	Local citizens, business owners, government representatives, non-profit organizations, faculty, staff, administrators, students (35 people)	Open invitation to create a community who would co-create sustainable alternatives to current activities
1	September 2011–August 2012 *Implementation 1*	Same as Case 0 with a core group of 10 partners from Case 0 (58 people)	First cohort of freshmen (43) taking linked courses from SUSTAIN faculty partners and participating in community projects
2	September 2012–August 2013 *Implementation 2*	Same as Case 1 with two changes in the core partner Case 1 core partners (60 people)	Second cohort of freshmen (45) taking linked courses from SUSTAIN faculty partners and participating in community projects
3	September 2013–present *Implementation 3*	Same as Case 2 with two changes in the core partner group (85 people)	Third cohort of freshmen (63) taking linked courses from SUSTAIN faculty partners and participating in community projects

Table 2. Summary of phases that we used in the transdisciplinary research and intents, presented in a format that parallels the phases of transdisciplinarity proposed by Lang *et al*. [15].

	Intent		
Co-design activities	**Title**	**Description**	**Key questions**
Phase A: Established a collaborative community and shared aspirations	Create community around shared aspirations	Invited people to explore the possibility of learning together to create sustainable alternatives to industrial era designs	Given your busy lives, why are you here at this meeting? What is the larger thing that you are committed to in the world? Who is missing?
	Explicitly share aspirational values of our community	Co-created a small set of shared principles that we could remember at all times and use as a standard in times of conflict	Who do we want to be together?
Phase B: Uncovered a ground of wholeness and abundance from which to co-design	Co-design from an internal state that was consistent with our aspirations	In response to assertions of what was necessary, recursively explored what the need would provide until we arrived at some quality of intrinsic value (such as "peace")	What would it make possible if you had what you think is needed? What is stopping you from embody this quality of intrinsic value now, in this moment?

Table 2. *Cont.*

	Intent		
Co-design activities	**Title**	**Description**	**Key questions**
Phase C: Navigated implementation in alignment with shared principles	Ensure congruence of project with shared aspirations	Continuously adjust to align project implementation with shared aspirations	Are our actions consistent with our principles and aspirations?

Much of what we chose to do was based on theories of change in human systems and building capacities to work with theories of change. Some of the details of these activities summarized in Table 1 can be found in the Appendix; however, there is a way in which we believe that from a causality perspective, the details are less important than the systemic foundations and conditions [42] (the rationale for this claim is in Section 6). Below, we briefly describe each phase to illustrate how our intent shaped our actions.

3.2. Phase A: Establishing a Collaborative Community and Shared Aspirations

The initiation phase was organized around co-creating community. In September 2009, we convened a range of potential partners to explore the possibility of learning together for sustainable communities, with a conviction that our global state of unsustainability was caused by collective human actions in industrial-era models of commerce. Over 30 people, who represented community organizations, local government and university participants, attended this initial meeting. We sat in a circle to inhabit an egalitarian ethic and to practice our working theory that the means must be consistent with the ends. For the purpose of creating community around shared aspirations, we began these meetings with the simple question, "Given your busy lives, why did you come to this meeting?" This was asked from a disposition of genuine inquiry for the purpose of revealing invisibly-held expectations and aspirations. This question largely served to disrupt habitual actions. The normal pattern of meetings would be a series of disconnected assertions about what needed to be done or reactions to what was asserted, usually in the form of more assertions.

In this initial stage, we also sought to uncover our shared aspirations, presuming that they existed. We found that we desired to co-create a way of learning that enabled intrinsically-motivated, self-directed learning and creative methods of learning that could be applied to the challenge of creating resilient, sustainable communities.

Our next phase was to establish a shared basis for collaboration by asking, "Who do we want to be together?" For approximately a year, from 2009 to 2010, we hosted open dialogues every two months to ask this question. The result from these dialogues was a set of collaboration principles and theories, listed in Table 3. These principles and theories became mantras—honor the whole; our means must match our ends; our relationships define the quality of what we can do together—which we frequently used to test and guide our decisions.

The format was often a Bohmian dialogue [43], convened in a circle to match our intent to honor the whole and ensure our process reflected our intended ends. This format is a process by which a group reflectively interacts with emergent topics. The safety of the community allowed the community

partners to express resentment around previous university-community ventures. The community often felt objectified by the university; they were approached to provide resources to the universities aims. Even in cases of community-engaged learning or service learning, community partners felt subservient to the university's need to provide a service learning opportunity, rather than actually being served in the partnership. Conversely, members of the community often related to students as free labor involved in some transaction to meet the goals of the community member or organization. We, the initiating faculty, emphasized that we were seeking collaborations based on mutually respectful relationships rather than those based on transactional needs. No agreements were made except to come together to consider our aspirations and attempt to design how we might work together. Attendance varied from 12 to 30 people. During this period, individuals came and went as their lives allowed or as they felt kinship with those of us who were asking questions about how to be together. We intentionally and explicitly called for an open system such as this as a way of honoring the whole of participants' lives. One of our working theories was that the universe is a unified whole, despite how it occurred to us. The alternative was to create some kind of force-based mechanism, such as a membership agreement, that causes shame when one cannot meet their commitments. Alternatives like these did not occur to us as consistent with our principles listed in Table 3.

Table 3. Summary of collaboratively-created principles for the transdisciplinary activities.

Principles
• Honor the whole • Our enacted means must be consistent with the intended ends • Trial theories through practice
Theories that we were working with
• The quality of our relationships determine the quality of what we can do together • Free attention is required for innovation • The universe is a unified whole with the fundamental property of interconnectedness • Conflict is the visible indicator that agents invisibly hold different mental models of how to achieve a shared future state • Level of change for the "system" is similar to the level of change experienced by the individual

This initiation period was filled with conflict, which we took as the visible indicator that individuals were holding different mental models of how to achieve a shared future state. Our disposition was to welcome the conflict, assuming that we had shared commitments and inquire into the mental models people were holding about the future. Many felt the need to take action. Some were angered by what occurred to them as our insufficient pace of progress. The questions we were asking (Key questions in Table 2) occurred interesting to some, but not directly relevant to others; none of these meetings had the feeling of efficiency; we reminded ourselves that relationships are not efficient and that one of our theories was that the quality of our relationships defined the quality of what we could do together.

In general, faculty members felt highly constrained in their ability to implement change, whereas those without a formal connection to our university expressed their readiness to collaborate. Over time, a core group of eight faculty members from an epistemologically wide diversity of disciplines (communication studies, industrial engineering, physics, agribusiness, materials engineering, biology,

women and gender studies, history) began to take shape. When asked why people continued to come, the responses revolved around experiencing: personal development; increased freedom from unwanted habits; compassion in the learning community; and participation in a community dedicated to meaningful, transcendent aims.

3.3. Phase B: Uncovering a Ground of Wholeness and Abundance from Which to Co-Design

Our primary intent in the design phase, September 2010–2011, was to first uncover an internal state of wholeness and abundance from which we would design together. We theorized that the quality of the design would be conditioned by the internal state of the designers. That is, if we were designing together from an unconscious frame of fear and scarcity that individual needs would go unmet, our actions together would have a quality of fear-induced pressure; individuals would strongly advocate for things that they felt were necessary without stopping to reflectively consider the preexisting construction of those necessities.

This phase was an arduous process of uncovering the motivation under the assertions; participants, ourselves included, habitually asserted what needed to happen. An example of an unexamined necessity, based on fear and scarcity, is the assertion that research results must be publishable by an assumed set of historical, academic standards; a putative criteria for academic research. This assumption shapes one's thoughts and actions in ways that can undermine shared aspirations. Instead, we attempted to recursively inquire into why our assertions were necessary until we arrived at an underlying motivation of intrinsic value, such as peace or joy. When we encountered the desire for the intrinsically valuable aspirational state of being, we attempted to "inhabit" or actively animate that state in the co-design process, with the assumption that it was abundant in nature rather than scarce and unavailable. This practice freed our unconscious attention on our needs and fears.

The community of collaborators began to experience a critical shift in ontological perspective through the practice of dialogue; we began seeing the relationship between ourselves and the behavior of the system. The means of this shift was the community of practice, facilitated by one of the authors (Burton). In meetings, we adopted a practice of releasing the things that were constraining our attention so that we could be present to one another in the design work. This involved enacting a compassionate listening within the community into which individuals could name what was distracting their attention. Very simply, an individual might show up and say, "I am distracted because my father is in the hospital." The quality of attentive and caring listening enabled the individual to suspend their concerns; they could return to their concerns after the meeting.

These two years crucially served as "capacity building" for collaborating: we became conscious and reflective of our beliefs and models of change. We began to see that we were not separate from the system that we were wanting to change; the oppressive dynamics of the system were replicated/enacted at all scales: ourselves, our classrooms, our institutional units and our transdisciplinary collaborative partnerships. Consequently, we realized that the nature of change we desired in the institutional was similar to nature of change required within ourselves, since we were participants of the very same system. This insight prompted us to adopt a principle of trialing desired systemic change in our own lives. For example, upon realizing we desired to "change someone's

mind," about some deeply-held conviction, we first experimented with similarly changing our own minds. This principle promoted compassionate understanding for differing points of view.

Incidentally, all aspects of the initiative were handled through informal collaborations rather than any formal university program. In 2010, we conducted the institutional data analysis required to choose the smallest set of common course offerings that would maximize the potential diversity of student majors who could participate and allow students to progress toward their degree as part of our commitment to "do no harm" with the student volunteers. We then sought additional partnerships with faculty who held expertise in teaching those courses in the cases where the seven core faculty did not have the expertise. We designed a learning initiative based on a two-quarter sequence of "linked" general education courses for freshmen. These courses enabled us to maximize the possibility that a freshman in any degree program could participate without extending their time to graduation. In other words, the courses for which we had faculty partners were courses that students would normally be taking to satisfy their degree requirements. While we communicated with all levels within the institutional hierarchy about our initiative, the initiative was given no special treatment or funding by the university and functioned through the principles of academic freedom and faculty-to-faculty partnerships, supported by respective department chairs. To increase learning and accountability, we invited thirteen researchers from various institutions and organizations involved in higher education to serve as thought partners for the initiative. With them, we held conference calls every two to three months where we considered together the challenges and invited critical perspectives on our efforts.

3.4. Phase C: Navigating Implementation in Alignment with Shared Principles

We attempted to enact our shared principles and theories (Table 3) in all aspects of the learning initiative with the intent of aligning our means with our aspirational ends. Specifically, the implementations cohorts (Cases 1–3 in Table 1) recursively involved repeating Phases A, B and C identified in Table 2. Beginning September 2011, we invited the first cohort of freshmen to participate in the January 2012 to June 2012, set of linked courses and community projects (Case 1 in Table 1). They were invited with the same original message and asked the same questions as in Table 2: Phase A. The main challenge in this phase of the work was managing the tendency to drift to old patterns of productivity, which were misaligned with our principles. For example, under the time pressure of the university schedule and a belief that we "needed" students to select into the SUSTAIN sections of the courses, there was a temptation to use the means of mass mailing, email and flyers, rather than attempt to create relationships, which occurred to us as inefficient (fewer students "reached" per effort expended) yet a closer examination revealed that the economy of scale gained through email was inconsistent with fostering a quality of human relationship. Again, the fear of failure embedded in the perceived need put us at risk of acting from a ground of fear, rather than our aspirational state. The key question during this phase was, "Are our actions consistent with our principles and aspirations?" This created tension for us since we felt the gap between the current state of things and what we aspired. We found that inhabiting our aspirational state as an experimental practice freed our attention to creatively address our challenges. For example, when we recalled our aspirational state, we saw that we were trying to create community. Our response was to host what we called pizza traps—sessions

where we fed students and shared our aspirations together while informing them of the opportunity to take the SUSTAIN courses.

Because this was research in the tradition of action research [44], students were also researchers and research subjects in the project. We obtained approval for the use of human subjects in research through our Institutional Review Board. Each student also signed an informed consent in order to participate in the research cohort. In general, students were taking four courses each quarter, three of them with collaborating SUSTAIN faculty. We attempted to inspire students to maximize their course diversity by taking a liberal arts, natural science/engineering and communication course from among our limited set of offerings: communication (English or speech); natural sciences (physics, chemistry, food science or biology); liberal arts (history, economics, ethnic studies, music); engineering (project management, sustainability). The exact courses within each case can be found in the Appendix. The activities, courses, faculty and projects varied from Case 1 to 2 to 3, with approximately 8–10 people who participated in the previous generation (case). Details of each cohort can be found in the Appendix.

We want to make clear that our initiative is just one of many possibilities and that each university context would generate activities that draw on their local strengths. We are describing the context so that the reader can get a sense of the research activity center, but do not mean to present our activities as a recipe for others.

4. Methodology

This set of research activities was undertaken using the research practices within the family of action research—participatory action research, action research and action science—because these methods were relevant to complex social systems [45]. These methods share several attributes [46]: they focus on deriving practicable knowledge through intervention experiments that test hypotheses toward a desired outcome of social relevance (action research); they involve practitioners as both researchers and subjects of the research (participatory action research); they "[place] a central emphasis on the spontaneous, tacit theories-in-use that participants bring to practice and research, especially whenever feelings of embarrassment or threat come into play" [46] (p. 613). Action research methodology involves using emotional and somatic cues as evidence of tacit cognitive actions—expectations, mental models and assumptions. In other words, the domain of research data in action research includes the behavioral, cognitive and emotion landscape that arises from experientially grounding (*i.e.*, testing) theories in a social setting. The rigor comes in the recursive praxis of positing theories, testing them in one's life, reflecting on the results—often in the social setting of a learning community of practice—and inquiring into motivations and assumptions. Within our praxis, we drew from a range of disciplinary domains as the source of theories, both metaphorical and literal (see Section 6.3.1).

While individuals certainly contemplated their own findings, dialogue as suggested by Bohm [12] within the community of collaborators was the critical venue for transformative insights. As mentioned, Bohmian dialogue is form of reflective group process where all hold the responsibility for the process rather than the dialogue being hierarchically managed by a single individual. It is unstructured in the sense that there is no explicit agenda; the group works with the issues that arise in the moment. This format was the main venue for our practice of action science, which critically relies on uncovering

implicit assumptions and mental models through group reflection; one needs the community to see these hidden elements in the same way that an eye requires a mirror to see itself.

One of the ways we practiced aligning our methodological means with our ends was through consciously hosting the dialogues with an intent of wholeness. Oftentimes Burton practiced inhabiting the emotional and cognitive dispositions consistent with wholeness and interconnectedness grounded in wholeness during the dialogues. This was our explicitly desired state of being. He intervened in the group process when the dialogue took on a quality that was inconsistent with our desired state. This practice is related to the proposition that resilience is accomplished through the conscious integration of reflection and practice across multiple scales (e.g., classes, university organizational units, communities, societies, higher education); that is, resilience comes through a state of wholeness. Initially the faculty inclination might be a pressing concern for the design of their particular class, without meaningful reference to larger frames: the totality of classes; the faculty collaboration as a community; the possibility of an active student community or community practice; design integrating across scales to include community actors outside of a traditionally defined academic setting. It is often the case that the primary forms of actively produced separation that inhibit such integration, are institutional, geographic and temporal boundaries, assumed to be fixed. A simple example is the presence of some deadline associated with something asserted as and experienced as a need: the need and associated perceived urgency displaces the group's ability to ground practice in a strategic future. This can be understood as operational needs displacing the capacity for the strategic reflection upon which design and action are based. Or, said another way, the internally-produced sense of urgency displaced the ability to integrate. Because our actions are correlated to our perception of the future, when we act from a disposition of necessity or need, our actions drift to serve those needs rather than the larger shared aspirations. In practice we would often jump frames to intentionally integrate the perspectives across different scales, with a theory that what was missing was a consideration of the whole: If the conversation was abstract and depersonalized we would inquire into the personal; If it was focused on the immediate we would recall the larger planetary frames of the transition from the Holocene to Anthropocene Eras.

Individual narratives authored from 2008 to the present were an additional means for us to reflect on our own methods, develop hypotheses and experiments to guide the emergence of meanings. We employed a qualitative research technique known as constructivist grounded theory (CGT) in their analysis [47]. This theory has been used by other researchers in conjunction with Action Research [48,49] since the methods share underlying assumptions about the nature of reality and knowing: both acknowledge that we, the researchers, are "influenced by [our] history and cultural context, which, in turn, shape our view of the world, the forces of creating, and the meaning of truth" [47] (p. 27); both purposefully maintain an emergent orientation, with an attempt to remain open to new interpretations and meaning throughout the research process. In other words, CGT and action research are analytical and experimental means with ontological assumptions consistent with complex, open, interconnected, recursive phenomena; they are therefore relevant methods for working with such phenomena.

As an emergent method, CGT involves recursively and reflectively analyzing data with the intent of constructing themes that capture the salient patterns. One of the distinguishing features of CGT is that it begins with the qualitative data, rather than preconceived categories. The coding of the materials and the iterative nature of recoding, category and theory development allow both inductive and deductive

insights to emerge. In our analysis we began by reading the whole of the material so that we could remember and experience the context, from there two of the authors began to use chunks of the narrative (usually paragraphs or groups of several sentences) and developed codes that indicated evocative attributes in the text. These were discussed and then grouped into categories. After developing these themes, the data was sampled for consistency and exhaustiveness of the themes.

5. Results

The faculty (and other participants) encountered a number of things that were entirely unexpected in the course of this transdisciplinary research. For example, we were often moved to tears over genuine heartbreak arising from our current state (personal, local and global). Our naive expectations, shaped by the industrial era, were that we would enact new techniques or processes that would result in better results for the transdisciplinary research. What we encountered instead was that we, ourselves, were embroiled in conflict and faced with crises of identity that had profound implications for our professional and personal lives. We did not anticipate that creating the conditions for transformative learning would mean that we, ourselves, would undergo a transformation. If we had not shifted to viewing transdisciplinarity as a complex system, we would have concluded that these experiences were indicators of our inherent deficiency for doing the work. From a systems point of view, we saw that dynamics of domination were located and unconsciously enacted in our habitual patterns of thought and behavior. There was strong emotional content in encountering this gap between our espoused and enacted values.

In this section, we explain the patterns that emerged from the process of making meaning of the qualitative data. In Section 6, we posit a plausible coherent theory that ties these patterns together.

In making meaning of the narratives, we constructed five salient themes: a safe and caring community; conflict, both internal to individuals and open conflict between individuals; existential crises; personal growth and transformation; and renewed vitality in teaching. These patterns, listed in Table 4, were present in participant narratives to different degrees. Our emphasis in this paper is the faculty cohort. Below we provide excerpts from faculty members' reflections that illustrate the patterns; the author's initials are indicated with each excerpt.

Table 4. Thematic patterns arising in the participant narratives.

A safe and caring community; Conflict, both internal to individuals and open conflict between individuals;
Existential crises;
Personal growth and transformation;
Renewed vitality

5.1. A Safe and Caring Community

Most of the collaborating SUSTAIN faculty reported a deep sense of safety and care in the weekly faculty dialogues. The safety manifests in the form of respect and acceptance of each other. This was especially profound for about half of those participating who were part-time faculty. (Incidentally,

all of the part-time faculty participants are female.) At our institution, as in most of higher education in the United States, lecturers or adjunct faculty often experience oppressive, hierarchical power dynamics.

> "SUSTAIN has taught me that there are people (at this university!) who do respect me and do value me. The group of instructors who teach in SUSTAIN are kind and different and intelligent and kind and wonderful and thought-provoking and kind (did I already say that? Oh well, it deserves to be said again). They have a way of challenging me without making me feel inferior." (C.B.).

> "I see that I am not the only one suffering here….I see how valuable my work is here. I see how little valued it is and also how that matters very little." (C.B.)

> "I see how much my soul is hungry to write and write and how tired it is of sending students off to try to do it. I see what a kind, real group of humans you all are and how privileged it's been for me to work alongside you... But I do want to say thank you. Thanks for loving me in a way that's helped me to be courageous." (G.H.)

The caring nature of our learning community expressed itself in making room for emotional processes, both positive and negative. It is perhaps not strange that in universities where a factory model of education is a widely-used metaphor (e.g., graduates as products), that it is unusual to encounter a quality of caring and community. Yet, this report of experiencing care in our transdisciplinary collaboration was strongly present in the narratives.

> "Here at SUSTAIN headquarters [50], I am surrounded by some of the kindest people I have ever met, intelligence levels that truly are off the charts and a sense of community I never thought possible on the Cal Poly campus." (C.B.)

> "This crisis [a SUSTAIN faculty member having a brain hemorrhage] revealed to us how we are with each other. We are a community who care for each other, not only the faculty, but the students too." (L.S.)

The weekly gatherings were a place where people could express emotions relating to their institutional experience and encounter a supportive community.

> "This group of people, faculty, community members, staff and students has shown me what a life of caring really means. I experience with these [SUSTAIN] people inspiration, acceptance, challenge and hope." (L.S.)

5.2. Conflict

One unique aspect of having created a learning community of faculty members who were responsible for teaching some of the same students was that it liberated students to talk openly about what they were experiencing. This enabled us to see the total impact of our individual teaching methods through the emergence of a student community. For example, success from a positivist frame of physics included students spending many hours per day solving physics problems. This student behavior was often rewarded (or punished if absent) through grades; this provided a means of ensuring that students "learned", with the presumption that applying known solutions to like problems was an

accurate proxy for understanding the concepts. Often, this successful system of "learning" externalized costs to more contemplative courses like history, where students were asked to read and consider case studies for each course meeting in the absence of external rewards or punishment. This pattern of domination of courses involving quantitative, positivists frames (e.g., physics, economics) was often felt by faculty members who were teaching courses with qualitative, heuristic frames (e.g., history, English, communication studies). This lead to a great deal of conflict within the faculty collaboration and from the students who felt empowered to speak to the faculty members about their experience of an oppressive learning environment.

Through the dialogue, our habits and assumptions became visible, but again, only in the context of the safe and caring community, where people were serving one another through reflecting hidden assumptions. Epistemological differences became evident when comparing natural science and social science methods. This conflict was very useful to the work; faculty reported experiencing the results of this hidden dynamic within the institution, but had no means of working through it. The following entries point to the conflicts.

> "Physics, all full of forces and gravity and friction, is pushing everything out." (L.S.)

> "[The physics teacher] and I recreated a conflict that we allegedly 'had' during the day. It turned out that it was a live conflict, rather than one that we were 'over'." (L.V.)

5.3. Existential Crisis

About a third of the participants experienced a profound existential crisis. In an existential crisis, one comes into conscious contact with the previously hidden assumptions that they are enacting in their worldview; they question the basis of their own identity and purpose in life. For example, after 16 years of teaching English composition, a faculty member decided to resign from the university after teaching with SUSTAIN. She reported that the SUSTAIN teaching experience was the most satisfying she had ever experienced, yet also saw, upon return to the non-SUSTAIN teaching experience, that "regular teaching" was empty for her and impeding her calling to write (see quote above from G.H.). Another example is a senior faculty member who was tenured and highly-accomplished in the conventional system of teaching, experienced a crisis so profound, it disabled her from being able to prepare for classes in the ways she had done prior to SUSTAIN.

> "I am in a personal collapse of 'ego', of all that I once believed to be true about myself and my life—my professional and my personal life. Over the last year, my friendship with Roger has catalyzed in me a far deeper ability to 'see'. I can now witness my own thought patterns and habits of mind. I find myself able to interrupt my enactment of what I experience as 'suffering'. I feel so profoundly grateful for this, yet liberation is strangely uncomfortable because I have lost the story of who I am (or who I thought I was)." (L.V.)

> "If I release the role of Progress Manager/Learning Warden/Content Expediter, then what role could I embrace in its place?" (G.H.)

5.4. Renewed Vitality

The weekly dialogues of the faculty collaboration enabled people to see that their untested assumptions about the students' (lack of) motivation required the constant application of force on their part. This came in the form of frequent quizzes, assignments or exams that counted toward students' aggregate score in the course grade and required faculty oversight—faculty enforcing self-created course rules and regulations. After encountering their hidden mental models, several faculty members' inquiry of the students revealed that their assumptions were in error. What was more accurate was that students' intrinsic motivation to learn did not have a place of expression in most university courses, since almost all aspects of the learning experience were prescribed by faculty, rather than allowing some level of autonomous choice by students. Consequently, faculty members reported removing the structure that they previously put in place to manipulate students' behavior in a way that conformed to their mental model of what was necessary for learning. Paradoxically, faculty reported that no less was accomplished relative to "regular" courses; some observed that students far exceeded expectations. Several reported a shift to a much more life-giving experience for all:

> "I feel pedagogically alive after this year. I feel full of hope and love. Thank you SUSTAIN." (C.B.)

> "What happened is that the students left hungry for more content. Most of them asked if they could attend the course again this quarter, without receiving credit, just because they wanted to learn more. What if at the end of every course the students want more? What if they didn' t see the class as a box to be checked, but as something interesting? What if we stopped cramming stuff down their throat in order for them to regurgitate the content on an exam and gave them tasty morsels that they will seek out in the future? This is my yardstick now: When the course is over, are the students hungry for more?" (L.S.)

6. Discussion

6.1. Failure of Normal Cause-Effect Relationships to Account for Patterns

Early in the work, we were aware that normal cause-effect relationships could not account for the patterns that we were experiencing. For describing the behavior of simple systems, one uses variables to create mathematical equations that model the conceptual relationships between variables and outcome; as we describe, there were no systemic patterns between the variables and the apparent outcomes. At the time of this writing, we are in our third cohort—students, faculty, community partners—of projects involving transdisciplinary research. Each cohort was unique in the make-up of the participants; however, there are overlapping student volunteers, faculty and community participants from cohort to cohort, as indicated in Section 2. Despite the personnel changes in the cohorts from year to year, we observed similar patterns of transformative learning, although not uniformly across the participant population. The particulars of each year are different, yet the pattern of existential crisis and subsequent successful (or unsuccessful) navigation is common. Direct theories of cause and effect did not seem applicable because the pattern of existential crisis occurred independent of the variables: the specific participants; the exact courses involved; the pedagogical

form of the courses; the projects particulars. We neither intended to produce existential crisis nor took direct action to encourage the exploration of the questions that one considers in an existential crisis (*i.e.*, Who am I? Why do I exist? What is my purpose in the world?).

We wondered if the pedagogical styles were responsible for the patterns we encountered. We note that within the transdisciplinary research initiative, faculty practiced a range of pedagogies, which we have indicated in Table 5. The first four rows are adapted from Mingers [51]; we created the remaining rows to facilitate comparison between the pedagogies. As shown, pedagogies have different utilities and therefore are designed and experienced in different ways. Although we had a bias for "emancipatory/learning in action" column of the table, all three pedagogies were represented in each annual cohort. We recognize that there are situations where positivists and constructivist frame are fit for a particular purpose. One of the difficulties is that the emancipatory frame allows access to all the pedagogical options. We do not believe the inverse is true; from the "positivist" frame, it is inconceivable that activities associate with freedom will bring about learning, let alone transformative learning.

Table 5. Comparison of three different pedagogies that were present in the collaborative learning system of the transdisciplinary research (frame, cognitive interest, social domain and purpose from Mingers [51]).

Type of Science	Natural	Cultural	Critical
Frame	Positivist	Hermeneutic constructivist	Emancipatory
Cognitive Interest	Technical: predicable outcome of practical skills for employment	Practical/meaning; Intellectual development and practical skills for understanding	Liberation*/enlightenment to enact conscious choices
Social domain	Work	Language/culture	Power/authority
Purpose	Prediction/control	Understanding/consensus	Enlightenment
Assumed system dynamic	Simple, controllable, predictable	Complicated	Complex, unpredictable
Status of participants	Student = fungible object; Faculty = authorized subject Community partner = resource to be used in transactions for desired outcomes	Student = individual; Faculty = guide Community partner = Contractual partner	Student, faculty and Community partners = Co-learners
Motivational assumption	External reward/punishment	Intrinsic values	Freedom as human vocation. Liberty and equity
Learning emphasis	Reproducing authorized content	Applying authorized content, developing individual voice	Mastery, learning capacity, ability to manage one's attention
Structure	Prescriptive order (faculty-centered; lecture)	Imposed organization, optionality (mixed: active learning modalities)	Self-organization, networked, high level of autonomy (self-directed learning modalities)

Table 5. *Cont.*

Type of Science	Natural	Cultural	Critical
Institutional metrics	Efficiency, cost, throughput	Student evaluations	Citizenship
System metaphor	Machine, factory	Organization	Living organism
Means	Application of control and force by authority figure (hierarchical)	Negotiated agreement between student and faculty	Dynamic, emergent, co-operation and collaboration
Learning process	Prescribed order (recipe)	Prescribed process (formulae)	Experimentation: situated practice with reference to formulae
Expertise	Field expertise required, but no expertise as a teacher is required	Pedagogical expertise across a variety of disciplines	Expertise does not necessarily ensure success
Disciplinary Status	Separate, bounded, fragmented	Interdisciplinary	Transdisciplinary
Type of learning that is assessed	Reproducing known results, information or applying such	Understanding, adaptive capability to apply concepts	Critical inquiry, transformational, situated learning by doing
System Boundaries	Closed	Open, bounded	Open, mutable: based on shared qualities and properties
Outcomes	Prescribed, fully described	Partially described	Not predictable, emergent
Collaborative dynamic	Possible only at the level of content	Collaboration at the level of pedagogy including content and process	Requires collaboration at the levels of content, process and context
Scope	Intentionally constrained to teachers' areas of expertise; hierarchically determined; taken as determined by discipline	Partially constrained by class design with open boundaries to students' areas of interest	Directed toward shared course aims, but limited only by one's attention; Challenges boundaries of understanding for all participants

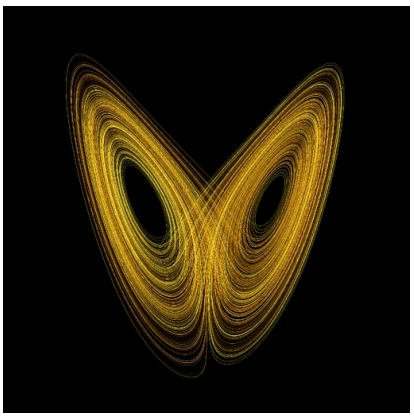
Note: * Liberation indicates the process by which models and paradigms are revealed as such, introducing both consciousness and choice into aspects of the system where they were previously missing or artificially constrained.

6.2. Learning as Emergence: A Model of Transformative Change

The failure of simple cause-effect explanations led us to consider metaphors of complex dynamic systems to make meaning of the patterns that we encountered. Adopting these metaphors, allowed us to see that what we encountered in transformative learning was part of the process; indicators of transformation rather than an imperfect or poorly managed research collaborative: chaos, ambiguity, non-linearity, inability to directly control results. The value of a metaphor relies on how well the metaphorical domain maps to the phenomenon to which one is applying the metaphor. Therefore, we begin this section by demonstrating that transdisciplinarity that includes transformative learning can indeed possess many characteristics of a dynamic complex system; we first consider the nature of complex systems.

Complex systems in a non-metaphorical sense are a set of interrelated equations that (metaphorically) describe the behavior of some physical phenomenon. An example of a complex physical system is a fluid flow pattern for which we could divide the medium into very small volumes and then define properties of each (e.g., viscosity, velocity). We could further define how the values of these properties in one small volume of the fluid depend upon those of the surrounding volumes of fluid. Mathematically modeling these properties and how they change with time would result in a set of differential equations, coupled together (*i.e.*, dependent upon shared variables in particular mathematical ways). The state of the system is the collection of variables for each small volume at any given time. If we were to graph these systemic states and their transition over time, we might see that the system was attracted to a particular state or collection of states. When graphed in two- or three-dimensional space where the axes represent variations in the system's state, these attractors exhibit geometric shapes. One such shape is a point attractor where the system is pulled toward a singular (point) state. Another such shape is that of "strange attractor" [52], Figure 3. A strange attractor is characterized by a fractal structure by which a pattern repeats itself at different scales within the system [53]. That is, over time the system returns to a shifting set of states that contains the fractal pattern; this often occurs in chaotic systems. Standing back from the system, an observer would see the strange attractor as a complex geometric pattern; moving into the system, an observer would see this pattern being repeated in finer and finer resolution within the system. The differentiating feature of strange attractors is the presence at all levels of the system—one might say they are patterned in to the system at small and large scales.

Figure 3. The Lorenz attractor. Computed in Fractint by Wikimol (Creative Commons Attribution license, public domain), via Wikimedia Commons [54].



Complex systems consist of many, interconnected parts; they have open boundaries through which the system can interact with its environment; their parts can self-organize; they exhibit non-linear behavior through feedback within the system and across its environment. Complex systems are always changing states. Additionally, complex systems are not given to predictable behavior like simple, mechanistic systems of classical science [55]. These systems exhibit emergent states. Emergence is a phenomenon where a systemic state arises that cannot be found in the parts of the system when they are separated from the whole system [28]. Two types of emergence from complex systems are salient: weak emergence, where the phenomena can be predicted on the basis of the properties of the parts; and strong emergence, where a new state arises, unpredictable from the properties of the parts. In both

cases, neither state that arises is found in the parts, separate from the ensemble. A strange attractor is a kind of emergent behavior.

If we consider the nature our transdisciplinary research for sustainability, the similarities with dynamic complex systems are evident. Transdisciplinarity is often recognized as complex [17,56,57] involving a variety of participants who interact in teams and networks [39]; many interconnected parts, self-organizing. Nowotny *et al.* make the case that understanding in these settings co-evolves through the mutual influence of "science" and "society" [45]—recursive, open systems, with high diversity. Emergence in our transdisciplinary system occurred in many forms: conflict, adaptive learning, existential crisis, personal transformation and a renewed vitality. To illustrate the mapping of the metaphor to the transdisciplinary context, Table 6 summarizes the similarities between the qualities of complex systems and those of our transdisciplinary research.

Table 6. How the properties and behavior of complex systems were manifest in this research.

		Occurrence in our transdisciplinary system
Properties	Complex system	The context of the transdisciplinary research, to include participants and all other situational factors
	Open boundaries	Participants were participating in SUSTAIN courses as well as other experiences, rather than only SUSTAIN courses.
	Dynamic	Participants freely making self-regulated choices about their actions with the result of an ever-changing set of states within the human system
	Interconnectedness	Individuals interacted across boundaries at all different scales: peers, courses, projects, organizational and institutional boundaries
	Recursive	Individuals' actions were immediately felt by the community, which causes recursive responses.
Behavior	Non-linear	Learning measured by traditional measures was non-linear with large developmental increases demonstrated at the end of the quarter
	Emergent (self-organizing)	Adaptive learning and conflict as weak emergence; Existential crisis, transformation and revitalization as strong emergence.

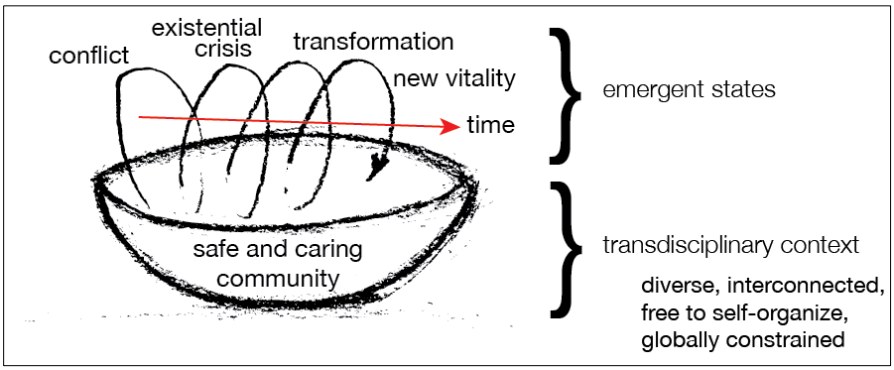
Because the complex system metaphor aligns with the behavior or our transdisciplinary research experience, it is useful as a way of interpreting the experience. Consider the thematic patterns: safe and caring community, conflict, existential crisis, transformation and renewed vitality. A plausible explanation for these patterns is that recursive inquiries in the context of a safe and caring community lead to the systemic emergence of the thematic patterns. Figure 4 illustrates a simplified version of this model. What is shown here is that the safe and caring community created the container in which our human system could go through cyclic changes in state. The cycle in this model begins with the community which gives rise to conflict, proceeds to existential crisis and is followed by transformation and renewed vitality. Another way of saying that is that conflict, existential crisis, transformation and renewed vitality are emergent states of this complex system of learning.

Through the metaphor of complex systems, learning itself can be viewed as an emergent property of the learning community, rather than something that is "controlled" into existence through the application of prescriptive order or processes. Incidentally, emergence does not imply "anything goes"; it involves a great deal of design and conscious participation through which one hopes to influence its

directional probability of occurring. Adaptive learning is analogous to weak emergence, where the phenomenon can be predicted on the basis of the properties of the parts. It is somewhat predictable that participants would learn from one another in the conventional sense by participating in the overall learning community. On the other hand, the emergence of existential crisis was entirely unpredictable on the basis of the constituent parts. We considered this phenomenon analogous to strong emergence.

Without the adoption of complexity metaphors, one would experience the dialogues through the industrial era paradigms; inefficient. Using the metaphor of complex systems, the dialogues were seen as a way of empowering interconnectivity and fostering the conditions for self-organization. Emotional content and processes would be experienced as something to be managed in order to make progress using the productivity metaphor; through complexity, emotional processes and content were part of the expected chaos and non-linear behavior of the system.

Figure 4. Proposed model of transformative learning as a complex system.

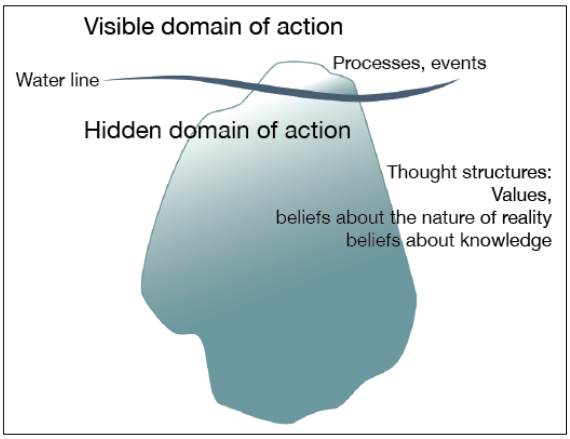


Existential crisis from an efficiency standpoint is an unwelcomed disruption in productivity; it is unlikely that one encounters existential crisis in lists of course learning objectives. However, these crises can be very useful in transdisciplinarity. According to Lele and Norgaard [58], conflict in transdisciplinary research is caused by differences in value structures (e.g., incentives for participation), mental models about reality (ontology) and beliefs about what constitutes valid knowledge and valid ways of knowing (epistemology). One can see these three conflicts in the list of "challenges" in transdisciplinarity derived from case studies [15] (p. 33). The anthropologist Edward Hall, proposed that these aspects of culture are invisibly and internally-held within the members, yet determine the visible actions within a culture [59]. Hall represented the relationship as that of the visible tip of the iceberg (actions) to that of its roughly 90% mass that lies beneath the surface, but creates the tip (beliefs, values, paradigms), Figure 5. We note that removing the tip of an iceberg (*i.e.*, addressing symptomatic behaviors or processes) will result in the tip being recreated through buoyancy forces of the thought structures beneath the surface. The dilemma is that the transformational agenda of sustainability science requires interruption in the invisible thought structures that are giving rise to visible historical systemic patterns of behavior, yet the nature of these thought structures is that direct intervention occurs as threatening and is therefore resisted.

Existential crisis, if skillfully negotiated, does in fact disrupt habitual patterns of thought; like strong emergence in complex mathematical systems, this novel state seemed to naturally emerge from the systemic conditions in our research context, rather than from any direct action on our part. It was not predictable from the combination of the participants in the learning system, nor was it occurring

within the participants ("parts") themselves, prior to their participation in the transdisciplinary research. However, based on the behavior of complex systems, we believe that there are specific properties and conditions of the transdisciplinary research which fostered the emergence of existential crisis, which was the doorway to transformative learning. These conditions are described in the following section.

Figure 5. Iceberg analog that depicts the conceptual relationship between the visible actions and the invisible causes in a human system (adapted from Hall [59], with additions from Lele and Norgaard [58]).



6.3. Systemic Conditions Supporting the Emergence of the Transformative Learning Opportunity

Because we considered existential crisis and transformative learning metaphorically similar to strong emergence, we also considered how strong emergence occurs in complex mathematical systems of numbers; doing so allowed us to see the patterns through a different ontological lens. Complexity theory suggests that the conditions for strong emergence are the following: a requisite variety or diversity within the system; a global constraint within the system; a high degree of interconnectivity amongst the parts of the system; and freedom of parts to reconfigure [28]. We believe that these conditions were met in our learning system. Table 7 provides a summary of the ways and the following sections describe details.

Table 7. Conditions for strong emergence in complex systems and how these were met.

System Condition	How this was met in our SUSTAIN learning system
Requisite diversity	Student, faculty and community partner of interests and disciplinary homes that spanned critical, social and natural sciences. Representative colleges: architecture, agriculture, liberal arts, science and math, engineering, business.
High degree of interconnectivity	Daily and weekly interactions supported through course meeting structure and team projects; instantaneous communication through social media.
Freedom to self-organize	Communication and self-organization facilitated through transparency of information and use of social networking tools.
Global constraint	Teams formed on the basis of autonomously choosing projects that were intrinsically motivating while ensuring that all partners were served with a team of a minimum size of three.

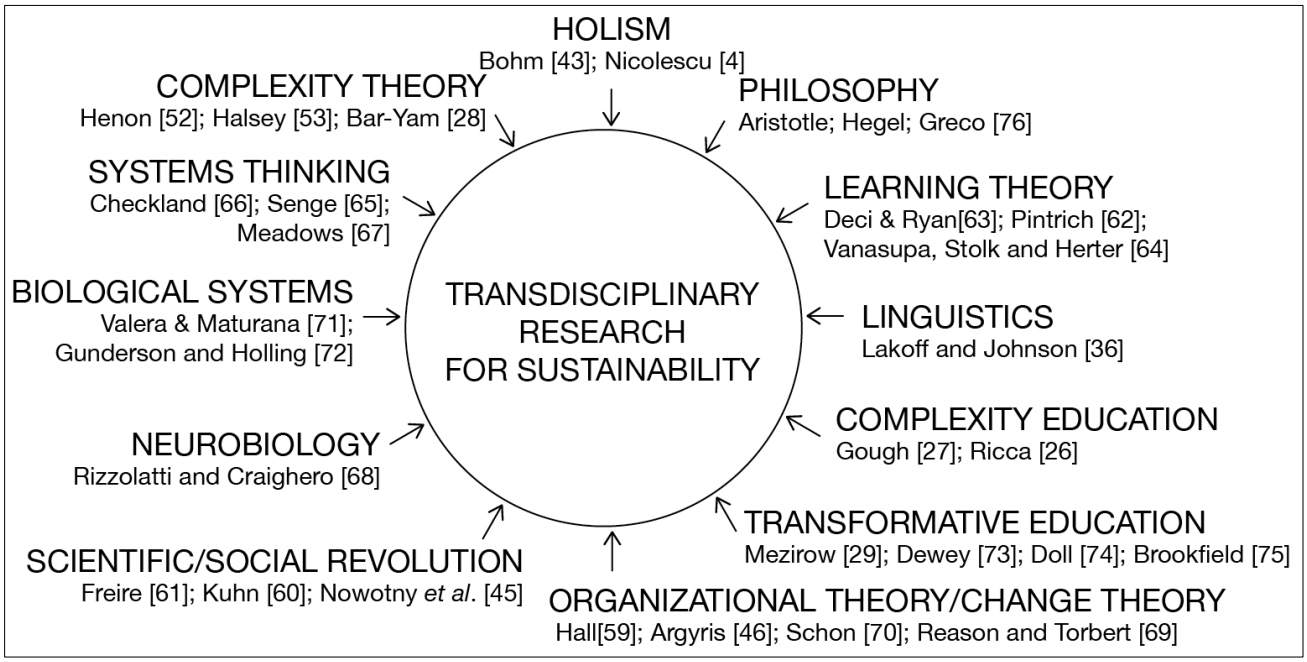
6.3.1. A Requisite Variety within the System (Diversity)

Industrial era manufacturing methods attempt to minimize diversity and its sources through quality control. In these metaphors, profit is assumed to be maximized through economies of scale, where variation accrues as a loss in profit. This dynamic expresses itself in a human system through efforts to assert a single "truth" and eliminate alternatives as "wrong"; domination by expert perspectives in transdisciplinarity is a known challenge [15]. Using the metaphor of complex systems instead opens possibilities for a plurality of valid "truths" to simultaneously exist, since the underlying premise is that systems are more than the sum of their parts [12]; in this case, socially-constructed disciplinary views would represent a part or partial "truth". This does not mean that disciplinary knowledge, such as physical laws of classical mechanics, are less "valid"; it does mean that in the process of transdisciplinary research, one would inquire into the limits of the validity to find where the "laws" break down or no longer apply. That is, complexity can include positivist frames and understanding as needed.

Because complex systems require a sufficient diversity for strong emergence of novel states, their metaphors promote the inclusion of differing views, a foundational premise of transdisciplinarity. Figure 6 illustrates some of the lenses we have used to interpret and find meaning in our transdisciplinary research activities: holism [4,43]; complexity theory [28,52,53]; linguistics [36]; scientific/social revolution [45,60,61]; learning theory [62–64]; systems thinking [65–67]; neurobiology [68]; complexity education [26,27]; organizational and change theory [46,59,69,70]; biological systems [71,72]; transformative education [29,73–75]; philosophy [76]. Complex systems metaphors support the validity of interpretations that transgress disciplinary boundaries, rather than consider these interpretations invalid because they are transgressive by socially-constructed disciplinary standards.

The prioritization of the whole that comes from complexity metaphors allowed us to at least espouse an egalitarian point of view with respect to different perspectives. In all SUSTAIN cohorts, faculty and students together represented a diverse set of natural interests, identities, expertise and world views. Additionally, students and faculty were also participating simultaneously in regular university courses, which provided contrasting learning experiences. These differences created the basis for conflict, which served as a point of inquiry within the learning community. We point out the necessity of the safe and caring community, however. These conflicts normally exist in university systems as private, isolated complaints. The safe and caring community empowered the students to speak to the faculty about their experience. We welcomed conflict as the visible evidence of different mental models and an opportunity to inquire into them for better understanding. Our base assumption for conflict was that we were committed to shared outcomes, but had different mental models of how we were envisioning achieving the outcomes. We note that amongst the faculty, student and community participants (65–85 people during any of the three cohorts), at least one person (Burton) was deeply skilled in the practice of change management, and at least five people had been intentionally building the capacity for change for two and a half years prior to the start of the courses in the first student cohort. We expected conflict from diversity and were learning the skillful means to constructively work with conflict toward shared aims.

Figure 6. Multiple lenses through which transdisciplinarity can be viewed. The references in the figure represent some of our theoretical and empirical grounding for our work.



Importantly, the lack of diversity that one might get if all agents were from the disciplines that shared values systems, ontological and epistemic frames is less likely to result in conflict and the critical thinking that conflict can catalyze. One of the authors was involved in a previous transdisciplinary project that failed to produce transformative outcomes [30]; in retrospect, the previous failed project did not sufficiently include critical science perspectives. We suspect that the wide disciplinary nature—natural, social and critical sciences—of the faculty cohorts in SUSTAIN created a critical threshold level of diverse disciplinary perspectives.

6.3.2. A Global Constraint within the System (Project Group Formation)

For all agents, the duration of each cohort's participation was bounded by a six-month period that spanned two university quarters. This constraint created a global boundary that was shared across the system and included community partners for each cohort of students. We were also required by the provost to "do no harm" with respect to the students' normal matriculation, which created an additional constraint around the courses. An additional constraint was our intent to serve all community partners with a minimum of three co-learners per project team, where the project teams were self-selected on the basis of one's intrinsic motivation for the community partner's aspirations. In practice, the project selection process resulted in some individuals choosing projects as a non-optimal personal choice. This possibly created a useful source of discontent for student participants, which may have contributed to existential crisis for some (e.g., "Why am I doing this?").

6.3.3. A High Degree of Interconnectivity amongst the Parts of the System (Transparency and Community)

Interconnectivity within the learning community came through removing the boundaries that normally exist between classes. In normal university experiences in the United States, there are not

clear channels of communication between student or faculty in separate classes. In our situation, faculty members were communicating with one another across course boundaries, as were students. With respect to the complex systems metaphors, this can be seen as interactions across scales. The level of safety felt by many students empowered them to express to the faculty experiences that are usually hidden, such as oppressive classroom dynamics. Our commitment to transparency also meant that we faculty members openly shared information about our own learning journey with one another and other participants. At times, this included our own sense of failure to create our idealized, integrated learning experience. As suggested by Meadows, making information transparent within a system is a fairly high-leverage systems intervention that can catalyze significant systemic changes [67]. It was our experience that the transparency across the communities contributed to choices that we would not otherwise make. An example is that students in a particular course were growing increasingly disgruntled regarding what occurred to them as an unreasonable level of demand. This caused the faculty member to invite into her classroom a mediator to negotiate the conflict. She also made other choices to moderate the workload in a way that honored her and the student experience. Students reported that the increased level of vulnerability by the faculty member caused them to feel less oppositional. Importantly, the transparency also involves a quality of vulnerability. The opposite—a closed system—can be considered "defended". Systems that value transparency require not only an enacted vulnerability, but also call for an increased level of sensitivity—the ability to sense what is occurring between and at scales that might be imperceptible in the posited, closed system.

6.3.4. Freedom of Agents within the System to Reconfigure (Self-Organization)

Some of the faculty members in SUSTAIN were very intentional about dissolving the hierarchical power relationship in the classrooms between teacher and student (although variably successful). The SUSTAIN learning community espoused self-organization and peer-to-peer learning as a value. Many of the courses were structured to support this value. In one case, students felt so empowered as citizens yet discouraged by their learning experience that they self-organized a kind of mutiny and created their own tutoring sessions to teach one another the material. In another course of the same subject (physics), students spontaneously organized into self-selected pairs and teams when asked to work with new concepts; this was supported by the faculty members by creating open, student-centered learning spaces.

6.4. Conditions for the Success of Faculty Members in the Transdisciplinary Research System

It is our experience that creating the conditions for transformative learning is not simply a matter of form. That is, we can include all the elements of transdisciplinarity and still not experience a transcendence of our habitual patterns of thought and behavior. There is a considerable gap between a conceptual understanding of transformative learning and the situated experience for all participants. Within our transdisciplinary research activities, we have seen cases where faculty have been very willing and very thoughtful about class design, but struggled to negotiate the emergent existential crisis in a way that was life giving for themselves or their learning partners (students and community members).

This has caused us to consider the nature of that struggle and what might actually be required beyond willingness to undergo such a shift in personal worldview. The first, we believe, is an understanding of the assumptions about student, faculty and learning that underpin a more traditional teaching model. Sometimes subtly and sometimes overtly, faculty will assume that they must control the classroom. They assume the students do not want to learn and must be made to learn.

This is often accompanied by negative assumptions about students, as a category, including attributions such as laziness. This also requires assumptions about the faculty as the controller and a disposition of "I know and you don't" in which the students are objectified. This objectification is part of the control mechanism with the intent to produce predictable outcomes. That in turn is often based on the institutional demand to produce such predictable outcomes, not directly about learning, but associated with the metrics of the university about such things as matriculation rates, financial and growth models. These business metaphors, larger structures and the prescriptive process associated with them reach down into the learning experience with unintended negative consequences.

One of our premises is that human systems are by nature complex. Part of what is meant by "complex" in transdisciplinarity is that there are a multitude of interconnected factors that actually influence the outcome, such that one cannot actually predict or control to a particular outcome (teacher: beliefs, disposition, assumptions, behavior, actions; student: history, beliefs, assumptions, behavior, emotional landscape; environmental: mix of students, historical social factors, power dynamics, economic factors; community partners: value propositions, motivations, organizational needs, time constraints, expectations). We assume the classroom and overall transdisciplinary research are examples of such complex human systems.

Traditional pedagogy tends to treat the system of a classroom as a simple mechanistic system; this can be more comforting in a certain way since it lets us live within the illusion of control and predictable outcomes. One consequence of this reduction of complexity is that since the system is actually complex, functionally relating to it as if it were simple (or even complicated, but reducible to set of key factors) requires a great deal of force exercised through the application of prescriptive order and process in a way that treats students as objects and ignores their human needs for autonomy, respect and meaning. This is a recipe for suffering. Additionally, all the "problems" arising from such an approach are not understood as being produced by the approach itself, but are instead viewed as if a result of insufficient control. Of course a common result of this is to attempt to increase control, which results in amplifying the problematized phenomena.

Another way to understand the systematized suffering is to consider what is being asserted as necessary. Typically this level of assertion is unconscious and only visible when it feels threatened or violated. "Students must learn." "Students must graduate according to the schedule of the university." "The university must be profitable and grow." "The university must exist." "Faculty must publish research." "The university must produce graduates and research consistent with the economic and growth models of the social contract in which it is situated." None of these assertions are actually true in any self-evident way; relating to them as if they were unconsciously conditions our behavior in unintended ways.

Take, for example, "The university must exist." Once we make this sort of assertion there are many consequences that follow. We may have some deeply held commitment based upon wanting the institution to exist and persist, but we do not typically relate to the asserted necessity in this critical

fashion. It is just self-evident to us that the existence of the institution is a good thing and if it went out of existence that would be a bad thing. Our actions, collectively and individually, become more correlated with maintaining such an assertion and an attachment to specific form than with living in a way that might be consistent with the commitment(s) that gave rise to the form in the first place. In the case of a university, commitments to serve the well-being of society at large are often displaced by the need to keep the university in existence.

This carries through to the level of individual faculty and is one of the ways the expert model is produced and maintained. We begin to imagine the university as a necessary component to our survival in a very immediate and personal way. That is, our identity as "experts" is validated and maintained through the institutionalized "disciplines" of universities. Arguments for the necessity of the university itself become conflated with this immediate feeling of necessity and individual (metaphorical) survival. One result of this is that if something occurs that we, as faculty members, might view as threatening our expertise or the category of an expert-based system, we feel that as a personal threat to our own survival. For example, if a program were to allow students to graduate without taking courses in our field, we might feel a sense of personal threat. In many cases our expertise is subtly based on assertions about the incompetence of some "other" (such as students) such that empowering that category of people as human beings itself becomes a threat to our survival. This is the dynamic of domination.

Of course it is neither easy nor comfortable in most cases to confront these things. It is often the case that one of the dynamics within a survival-based system is that transparency is encountered as threatening. The point of such an encounter is not to destroy the pre-existing system. Instead we wish to illuminate the dynamics and make conscious choices with as much awareness about consequences as possible. To do so, we have found, requires the qualities within the faculty member of authenticity, presence, vulnerability to one's own status as a learner and a threshold level of satiation with the human need for respect. We have also experienced the need for skillful means so that these profound internal shifts of transformation can be successfully negotiated. These qualities are summarized in Table 8.

Table 8. Qualities needed in the faculty members in order to successfully negotiate transformational learning.

Qualities	Description
Authenticity	Living in an emotionally appropriate, significant, purposive and responsible way that is congruent with espoused values
Presence	A quality of being that is emotionally open and attentive to what arises in the present moment
Satiation with the human need of respect	Sense of having their human need for respect generally satisfied
Vulnerability to one's own state as a learner	Willingness to acknowledge one's lack of understanding, limits of understanding and the possibility of learning from anyone.
Skillful means	Ability to manage one's attention; bodily sense one's affective state; suspend one's hostile assumptions about "other"; enact a model of unity in the presence of conflict; consciously hold a paradox

6.5. Negotiating the Existential Crisis: The Necessity of the "Strange Attractor"

In the above sections, we described the systemic conditions and the qualities of the faculty that we believe to have increased the probability of transformative learning. Up to this point, we have said very little about the ecological conditions that need to be in place for successfully navigating the existential crisis to a transformative place. In an existential crisis, one comes into conscious contact with the previously hidden assumptions that they are enacting in their worldview; they question the basis of their own identity and purpose in life. This state of existential crisis was useful in interrupting the tacit, habitual patterns and structure of thought, represented conceptually in Figure 2. Our transdisciplinary research activities have included mostly experiences of successfully negotiating the crisis, with a result of transformative learning. However, we also had cases where, in the face of the emergent crisis, people decided to retreat to known and apparently safe emotional territory. Faculty members who did not experience transformation, could be said to have only two or three of the five attributes listed in Table 8. Another way saying this is that the historical and present systemic conditions contributed to individual faculty's depletion of resilient qualities listed in Table 8.

Returning to the themes in the narratives, Table 4, we speculate that the presence of a safe and caring community is the property that supports one's successful navigation of existential crisis as in the model posited and depicted in Figure 4. Metaphorically speaking, we speculate that the safe and caring community is an indicator of an underlying "strange attractor", a quality of our transdisciplinary research effort that is reported as distinctive and often spontaneously named by participants as something that draws them to engage as a partner. Like the "strange attractor" of complex systems, the quality of safety and caring was fractal; it could be found at many scales within the learning community. As an example, in a physics course, an architecture student revealed that she had stayed up all night to complete a project. This revelation was not only met with sympathy, her twelve classmates enthusiastically asked to see the project and followed her after class along with the faculty to the project space. The 14 of us stood around her project, appreciating her accomplishment as a safe and caring community, while her non-SUSTAIN architecture student colleagues stood alone with their artifacts. This is a small example of the fractal nature of caring that is present as a "strange attractor" in the SUSTAIN transdisciplinary work.

Of the individuals who encountered but turned from the opportunity for transformative learning, all reported feeling a lack of safety at some level for various reasons or reported the experience of safety in the community, but felt insufficient threshold of the qualities for resilience listed in Table 8. In considering these experiences and data, it is perhaps a simple (and scientifically offensive) result that compassion and love are essentially in processes of benevolent, transformational change—the kind of change so desperately needed at this moment in our collective human history.

7. Conclusions

Participation in transdisciplinarity is facilitated through transformative learning, yet our industrial era paradigms could unconsciously cause us to unsuccessfully negotiate this important and—we would argue; necessary process. Viewing transdisciplinarity through the lens of complex systems metaphors enables us to welcome chaos (often superficially encountered as messiness or inefficiency with respect to some legacy model of efficiency) and the emergence of unexpected experiences as a natural part of

the process. In contrast to traditional forms of disciplinary learning, transformative learning interrupts habitual patterns of thought: what one thinks of as "self"; what one believes to be the nature of reality and the nature of knowing. The opportunity for transformative learning can emerge as existential crisis, as was the case within our three cohorts. Reconstituting one's identity in an existential crisis can be profoundly disorienting and is not without emotional processes and content, which is inherent to the change process, rather than something in the way of changing. Faculty members who subsequently negotiated the crisis were those that experienced the learning system as safe and caring; they also displayed the qualities that gave them resilience in the process—authenticity, presence, satiation with the human need for respect, vulnerability to one's own state as a learner and the skillful means to work with one's own change process. We found the process of developing these skillful means to be (a somewhat slow and organic) practice of recursively applying theories in the action in one's own life and reflecting on the results. This praxis was facilitated by a community of practice that embodied the "strange attractor" of compassion and love.

A plausible model for transformative learning is that it emerges from a complex learning system where the system chaotically cycles. From these cycles emerge patterns of conflict, existential crisis, transformational learning and vitality; all within the context of a necessarily safe and caring community. Within the dynamic complex human system of learning represented by our transdisciplinary research, the systemic conditions that foster the opportunity for transformative learning seemed to be: a wide diversity of perspectives within the human system; a high degree of interconnectivity between the agents; the ability to self-organize; and a global constraint experienced by all in the system. However, it is one of our working theories that situating our practices in alignment with transcendent aspirations is more important than the procedural or formal structure of transdisciplinarity. In this way, aspirational intents can function in a transdisciplinary system as a kind of fractal pattern that imbues the systemic activities in the small and large actions of the transdisciplinary system. It is our hope that illustrating how these complexity science metaphors apply to transdisciplinarity serves as socially robust knowledge for working with the phenomenon of transformative learning in transdisciplinary learning and research.

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Author Contributions

All authors have been directly involved in the research and generated narratives on which the qualitative analysis was based. Courtney Brogno, Ginger Hendrix, and Neal MacDougall contributed editorial input. Burton, Schlemer and Vanasupa collaborated in the synthesis of the overall framework. Roger Burton grounded and integrated the conceptual frames and authored the section on conditions

for success. Lizabeth Schlemer lead the data analysis and authoring of the history and overview, methodology and results. Linda Vanasupa served as the primary author.

Appendix: SUSTAIN SLO Learning Initiative Details

There are three co-learner groups participating in SUSTAIN: students, faculty and community partners. A sampling of pertinent data regarding the participation of these groups is included in the tables below.

(1) Students

A self-selected group of students participate in the SUSTAIN learning initiative during winter and spring quarters of their freshman year as shown in Table A1. The students take linked general education courses that make up approximately half of their course load during these quarters.

Table A1. Details about the students involved in each case.

	Case 1 (2012)	**Case 2 (2013)**	**Case 3(2014)**
Number of students	42	43	63
Number of freshman at the university (fall)	4316	3701	4871
Number of different majors	29 (49% STEM*)	25 (28% STEM*)	30 (32% STEM*)
Percent female	57%	59%	65%
Average SUSTAIN course load as % of total course load	75%	50%	50%

Note: * STEM = Science, Technology, Engineering and Math.

(2) Faculty

The students choose two or three courses each quarter from a list of available courses taught by faculty who collaborate and attempt to integrate content. The details about the courses are shown in Table A2. Faculty generally teach at least one SUSTAIN section and one or more courses which are not part of the SUSTAIN course cluster.

Table A2. Details about the courses in each case.

	Case 1 (2012)	**Case 2 (2013)**	**Case 3 (2014)**
Number of faculty collaborators	9	12 (7 new)	9 (2 new)
Number of lecturers	2	6	4

Table A2. *Cont.*

	Case 1 (2012)	Case 2 (2013)	Case 3 (2014)
Courses offered by collaborating faculty	**Liberal Arts** History of Social Movements; Economics **Science/Engineering** Soil Science; Plant Diversity and Ecology; Project Management; Physics (calculus) I and II; Physics (algebra) I and II; Introductory Physics; Chemistry **Communications** Speech; Freshman Comp; Critical Thinking and Writing	**Liberal Arts** Music of the 60's; Ethnic Studies **Science/Engineering** Soil Science; Plant Diversity and Ecology; Project Management; Physics (calculus) I and II; Physics (algebra) I and II; Introductory Physics; Sustainability **Communications** Speech; Freshman Comp; Critical Thinking and Writing	**Liberal Arts** Music Appreciation; Food and Culture **Science/Engineering** Soil Science; Plant Diversity and Ecology; Project Management; Physics (calculus) I and II; Physics (algebra) I and II; Introductory Physics; Sustainability **Communications** Speech; Freshman Comp; Critical Thinking and Writing
Number of sections	18	19	17
Number of SUSTAIN only sections	16	3	6

(3) Community Partners

Community partners consist of non-profits, small businesses and community action groups; they are listed in Table A3. The participant groups listed hosted one group each year. The projects duration was approximately January through June of each year. Project partners usually met weekly with their student teams. Each partner had one main contact for the student groups, but students participated in the community in a complete way, generally interfacing with multiple individuals during the course of their projects.

Table A3. Details about the community partners involved in each case.

	Case 1 (2012)	Case 2 (2013)	Case 3 (2014)
Participating community partners	AIDS Support Network; SLO Creek Farms; United Way *; Food Bank; Oak Creek Commons *; Western Wildlife; Generations Waking Up; Master Gardeners *; Glean SLO *; Independent Living Resource Center *	Along Comes Hope *; United Way *; Oak Creek Commons *; Glean SLO *; Real Food Collaborative; Cal Poly Divest; WikiSLO; Laureate School *; One Cool Earth; Asset Development *; SLO Seed Exchange; Puppet Theatre	Along Comes Hope *; Laureate School *; Asset Development *; Creative Mediation; Independent Living Resource Center*; SLO MakerSpace; The Lavra; The Ranch; United Way *; Sustainable Living Research Ordinance
Number of projects	10	10	10
Team size	3–7	2–7	3–10

Note: * indicates multiple year participation.

Conflicts of Interest

The authors declare no conflict of interest.

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