Transformational Innovation: Reflections on How to Foster it in Engineering Education Systems*

ROGER BURTON
SUSTAIN Learning Initiative, California Polytechnic State University, San Luis Obispo, CA 93407, USA.
E-mail: rburton@calpoly.edu

LIZABETH SCHLEMER
Industrial and Manufacturing Engineering, California Polytechnic State University, San Luis Obispo, CA 93407, USA.
E-mail: lschleme@calpoly.edu

LINDA VANASUPA
Materials Engineering Department, California Polytechnic State University, San Luis Obispo, CA 93407, USA.
E-mail: lvanasup@calpoly.edu

This paper describes the educators' disposition that we believe is required for transformational innovation. Innovating in this domain relies on interrupting existing patterns. This interruption requires the conscious recognition of patterns through an active practice of self observation. Though self observation does not necessarily need a collective process, it is served by encountering the diversity of views present in groups. Innovation in this sense consists of a fundamental identity shift in the human system and the innovators themselves. Unlike the processes of problem solving and process improvement, transformational innovation requires insight into the individual and collective attention of the designers. It also allows access to unexamined mental models and apparent cause and effect relationships. The praxis of transformational innovation within organizations looks like an active practice of reflection, experimentation and learning within the human system. We explain the theoretical perspective, suggest a protocol to begin experimenting with self observation for the purpose of pattern interruption, summarize preliminary results from a year-long process of action research involving over 25 university agents in such a change process, and comment on the limitations and risks in the protocol.

Keywords: innovation; disruptive innovation; transformational innovation

1. Introduction

The authors would like to offer an apology in the traditional sense. We are aware that readers expecting a traditional case study may find our work confusing. The purpose of this apology is to briefly make clear the nature of our own methodological bias, with the hope that this will allow readers more successful access to the ideas presented here. The fundamental premise of this paper is that innovation within the dynamic, human systems of engineering education requires methodology and practices that radically differ from the empirical approaches traditionally used in engineering, which are often thought of as 'objective.' The usefulness of empirical approaches is the predictable manipulation of objects, taken as separate from the subject or observer. We hope it is evident to the reader why we might feel that this approach is inappropriate for the consideration of innovation in human systems. We instead chose to use a methodology, action research, which includes the researcher themselves as part of the human system of study. The value of this phenomenological approach is the derivation of meaning and meaningfully correlated action within a system that is understood as a dynamic whole. Practicing this type of research focuses on ideographic data (i.e., information derived from the researcher's experience).

In the absence of some understanding that we are employing a specific methodological bias that is distinct from the empirical bias one might anticipate, we feel that our paper might be confusing. We also note that the way the paper is presented is not based on a lack of knowledge on our part with regard to case studies, or an empirical approach. It is a very intentional choice we have made because we are considering innovation in human systems, which are not similar to mechanistic objects in their behavior. We recognize that this distinction is quite complex and has been the subject of philosophical and practical debate in different forms for some centuries now and it is in no way our intent to pretend to resolve or even address something about that. The full explication of that debate, the deconstruction of modern causality and such, are not rightfully within the domain of this paper. We simply ask that readers encountering methodological concerns recall the nature of this apology and consider setting them briefly aside.

* Accepted 20 August 2011.

Innovation has many meanings [1, 2]. It often denotes a process of ideation that produces products, processes, and services or the goods that result from such a process. One of the underlying assumptions is that innovation yields some kind of economic value [3, 4]. However, we are broadly considering innovation to mean designing anew; the 'new level of thinking' required by Einstein when he suggested that one cannot overcome problems at the same level of thinking used to create the problem. Much has been written about this type of creativity in terms of design team heuristics [5, 6] and cognitive processes [7–10]. However, these viewpoints focus on the ecological conditions or analysis of highly-functioning teams. This paper is about the designers' basic disposition for making changes to established ideas–*innovating*.

Within this definition of innovation, we differentiate between mechanistic, prescriptive approaches and intentionally emergent approaches. Evaluating innovation across this spectrum generates three distinctive domains of innovation, each with its own practices and process.

1. *Problem Solving*—The first domain is innovation within the bounds of a specified process or set of processes. Typically this looks like solving some problem by doing more of what is already being done, with perhaps additional efficiency, resources, speed or scale. Problem solving usually results in incremental changes to existing designs.
2. *Process Improvement*—The second domain is innovation arising from examining the process of problem solving. Process improvement requires an aggregated view of events over time, such that trends and patterns are revealed. Process improvement has the potential for designs of larger impact, since the boundaries of consideration now include incremental and systemic improvements.
3. *Transformation*—The third domain is transformational by nature and requires or inspires a fundamental identity shift in the both the system and the innovators. In this third domain the deep structures and patterns of thought, habit, and way of being are addressed. This domain creates a context for profound change in the other two domains.

This paper explores the third domain—*Transformation*. We assert that intentional, transformational innovation necessitates an identity shift in the innovators themselves, individually and collectively. In the absence of this shift, much innovation is more a sort of adaptation where the transformative qualities are limited by the assumptions embedded in the original design (i.e., Einstein's 'same level of thinking' that created the problem). Such adaptation is necessary and useful. It is merely our aim to begin to distinguish between such *associative* activities that closely connect to existing designs (domains 1 and 2) and more *generative* activities that would be considered transformational (domain 3). In our model, the first and second types of innovation are associative, because they are associated with historical patterns; the third type is generative because it requires the interruption of past patterns and creating anew.

While transformational innovation can occur in any circumstance, we contend that without an intentional identity shift in the human system, transformational innovation occurs more or less accidentally. Furthermore, we believe that the global societal challenges we face require transformational innovation. In this paper, we unpack the structural elements in the human system that we believe to foster transformational innovation, suggest a protocol with which one might experiment, provide preliminary results on a year-long experiment involving over 25 university agents, and offer thoughts on limitations of the approach. This paper is a reflective piece on the process of change where the authors position themselves within the education system being studied. Their shift in identity is from that of objective researcher, typical of case studies and objective experimentation, to that of research subject, as consistent with the social science action research methodology [11].

2. Theoretical grounding: structure of dynamic human systems

As stated, we consider innovation as a phenomenon that occurs within a dynamic human system. One of the fundamental principles of dynamic systems is that the outcome or behavior of the system is conditioned by the structure of the system [12, 13]; that is, structure determines behavior and outcomes. Or, as posited by Schein in his study of organizations, institutional agents perpetuate their own cultures via practices such as the institutional structures and policies they create through shared paradigms [14]. Therefore, any desire to foster capacities of transformational innovation in students must include a reflection on the education systems in which those students are enculturated.

A specific example of how structure determines outcome comes from the current state of higher education in industrialized economies: a physically and organizationally siloed research and education system will tend to produce equally siloed results. Research produced by such a system is likely to exhibit deep disciplinary grounding from within the silo in question, unencumbered (or unenriched) by

epistemologies or methodologies indigenous to other disciplinary silos. Students educated in such a system are likely to replicate the values inherent to their silo of study, since the process of acquiring a disciplinary viewpoint is in fact a process of enculturation, where one arrives at a way of thinking and seeing the world defined by the discipline [15–19]. The dynamism here is self reinforcing of the silos. We can innovate to some extent within the silo, but innovations that themselves cross the conservative boundaries of such silos are perceived as a threat by those in the existing system that are attentive to historical behavioral and success criteria. For depth of understanding, these divided and specialized systems of learning are highly efficient. Their consequence, however, is to create habits of mind, or 'patterns,' based on historically tested and utilized disciplinary standards. In other words, the historical organizational structure replicates itself within the cognitive framework of the designer. The designer is then biased through 'habits of mind' toward the more limited types of innovation of problem solving and process improvement (innovation domains one and two).

Often there is confusion between 'problem solving' and innovation. Typically the phenomena arising and understood as problems within the action of a human system are produced by that system functioning perfectly. All directly participate in the 'problems' themselves through the deep structures, assumptions, and lived metaphors of the human system. Senge illustrates these relationships between organizational structure, patterns and events using the analogy of an iceberg [13]. The tip of the iceberg simply represents the visible 10% of the larger system seen as the 'problem.' Beneath the tip are the patterns of behavior that produce the problematic symptoms. Beneath these patterns are the structures of the system that produce the patterns. These structures are both external, such as siloed departments, and internal, such as a shared preference for individuated, disciplinary expertise.

Over time these structures become procedural, habitual, legal; preserving them becomes a moral endeavor. For example, in higher education, the suggestion of change to the system of disciplinary departments becomes a threat to the metaphorical survival of faculty members. With respect to design for engineering education, the 'problem' of diminished capacity for innovation results from unexamined professional habits originally intended to preserve and advance the engineering professional enterprise; the profession and its attendant characteristics are self-replicated by societal and institutional structures. We assert that without a thorough understanding of this web of habit and deep structure, innovation is more or less severely limited.

The fundamental issue we want to highlight is the dynamic relationship between the forces of conservation and the forces of innovation within the engineering education learning environment. In conservation, say, for the purposes of preserving the integrity of the engineering professional standards, we are asking the question 'What should we conserve?' By contrast, forces of innovation are fundamentally mutative and transformational. To the extent we become self identified, and so politicized, with the form or expression of such forces, conservation and mutation seem in direct conflict.

If we interpret the human system of education for instance, as if it were mechanistic, our efforts at change, innovation and transformation, we unconsciously manipulate the human system as if it were a mechanistic, inanimate object. For example, we unilaterally decide on curricular changes to compensate for some 'missing' education element, such as requiring a course in 'ethics' to make up for an apparent educational deficiency. The positive benefit of this is that the results are seemingly predictable. Such predictable results though are themselves most suited for preserving the status quo, i.e. conservation of what is already known. Such an approach can lead to innovation within some defined process for the sake of efficiency or some other variable within a bounded system. This can be useful for optimizing the efficiency of processes or some aspect of a system understood as mechanistic, but of course has many unintended consequences for the human beings in such a system. However, these types of changes do not fundamentally transform the system that created the problem in the first place. Rather, they continue what is already known through applying historical practices. An entirely different process is required for transformational innovation, the results of which is fundamentally emergent and therefore seem unpredictable from the mechanistic point of view. This process often feels threatening by those who hold a positive intent of conserving something.

Presuming that preserving the engineering profession is beneficial, the operational question then becomes 'How do we work with ourselves, individually and collectively, to understand and make choices about these structures and the context for possible transformational innovation?' How do we even come to see such structures? For the most part, what we see is symptomatic, such as claims that the United States of America (US) is 'falling behind' of its 'global leadership' in innovation [20]. We typically interact with these symptoms at a superficial level where our attempts to change these symptoms are limited to assumed cause and effect relationships. As an example, the US national alarm over plummeting indicators of test scores by elementary

science and math students has spawned a concerted effort to increase science and math exposure at these levels, rather than consider deeper systemic and/or cultural forces that are producing these patterns and symptoms.

To see into the deeper structures of dynamic human systems which create our institutional structures, we consider the insights from organizational behavior researchers. With reference to the iceberg analogy of Senge [13], the institutional structures themselves derive from the frame of action held by those who create and perpetuate the structures [14, 21, 22]. The frame itself arises from a deeper human structure of attention [22, 23]. The relationship of these perspectives to one another is depicted in Fig. 1.

Figure 1 illustrates the structure of action: One's actions proceed from a frame of reference which is itself a product of one's attention. One's awareness and perspective, represented by the location of the observer in the figure, defines the scope of changes from which innovation can emerge. That is, the limits of one's attentional perspective create the limits of the innovation.

For example, one can respond within an assumed cause and effect relationship to an event. This is the first loop or physical domain of action and occurs in what Torbert calls 'durational time.' For example, in response to the industrial pollution of lakes and rivers, methods are developed to clean up the pollution or filter out the toxins before they enter the environment. From the perspective of the action (Fig. 1: single loop), there is a direct causal relationship between the 'event' of polluted water and the 'action' of mitigating the polluting process. However, the insights from the other domains are largely invisible to one at this level of perspective, since the frame of action and the attentional focus within that frame is largely unexamined–figuratively outside the peripheral vision of the designers. The dynamic is initially paradoxical: the self limiting point of view is also experienced as the means of functionality. And from this view, a correlation of action and event occurs as an exhaustive understanding of the phenomena. In the face of such an apparent paradox we are often left with the impression of an insoluble problem, in which there are no meaningful alternatives. This can be considered a type of structural trap.

If one were to consider the cognitive frame of the action, they may begin to see that the initial action left unexamined the underlying assumptions that lead to the polluted waterways. This requires one to view aggregated events over time (Torbert's 'eternal now') as well as paradigms directly producing those events. From this frame (Fig. 1: double loop), one might begin to ask: What are we assuming about the cause of the pollution? Is it necessary for the industrial process in question to function as it does? Why? What are inherently benign alternatives? What other societal processes are involved in creating this outcome? One has a double loop of learning available to them because they can see both the physical domain (action) and the cognitive domain (frame) that is causing the action. The cognitive frame itself has a structure. From within the processes and reflections associated with a second order learning loop, these structures may themselves be opaque, and so related to as if having a fixed value (i.e., they have the unquestioned status of truth).

The third perspective is that of attention, where triple loop learning is possible, as the designer can see into all three domains. The attention domain is transpersonal and is typically the domain of organizational visioning exercises (Torbert's 'volume of infinite possibilities'). Working in this third domain is challenging in a variety of ways. It is often counter intuitive since the areas of inquiry are the habits and patterns that create our ability to function. With respect to our pollution example, the inquiry may revolve around seeing into where the designers' attention resides (or doesn't reside). Where was our attention in the initial solution when a system

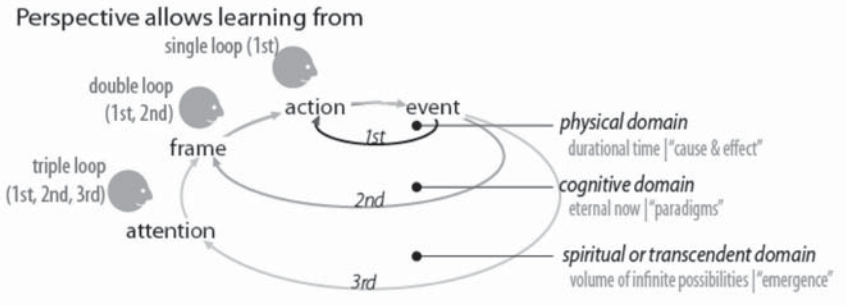

Fig. 1. The structure of action. Adapted from Torbert [26]. Used with permission.

emitting constant streams of toxins into the air, land and water of the surrounding community occurred to us as 'solving a problem?' Who are we, the designers, in that system? What were we envisioning? What are the areas of assumption, now viewed in the action of the system as established truth? These are places where attention has become individually or collectively fixed. We are literally unable to perceive our own action, presuppositions and assumptions in this area; in fact relegating these actions to 'automatic' enables us to improve our functionality or productivity. In this particular case examples might be acculturated or socialized truths such as 'all life produces waste' or 'waste is necessary for growth.' We will often discover the assertion of some necessity in the process of reflection (e.g., 'Growth is necessary.')

This process is served by a diversity of views, since the asserted necessity, often taken as apodictic, reveals itself in the conflict that arises from such diversity. The conflict itself then becomes one of the means for innovation, since it reveals the hidden structures of cognitive frame and attention such that we can actively work with them. This implies that the dialectic and reflective capacity, both within the individual and the group are important capacities for meaningful innovation. (Note: The siloed system paradoxically eliminates the possibility of such processes for effectively revealing and working with such conflict; it also tends to heighten positional conflict).

3. Suggested protocol for transformational innovation: self-observation & pattern interruption

We have suggested that there is typically an unexamined, systemic relationship between the source of our functionality and the phenomena we experience as problems. For engineering educators, one might say the following: educating engineers who are successfully employed in the current industrialized system is systemically linked to what we experience as engineering graduates with a diminished capacity to innovate. If it is our hope to have a different educational outcome, we must first recognize these existing patterns and habits of functionality and begin working with them. This is the work of the transformational, attentional domain (triple-loop, Fig. 1: The structure of action).

It is then necessary first to see and understand the nature of those deep structures and make choices about them that nurture, allow and enable the entire creative process. Such practice involves a fair amount of tension or conflict within the system. If we seek to eliminate this tension, experiencing it as a problem in and of itself, then we also greatly reduce our ability to work consciously with the entire process of transformational innovation.

Instead we can consider tension the nature of the 'human container' for the innovation. That is, within the social fabric created by ourselves, communities and organizations, the capacities and practices that allow us to work with these deeper structures are:

- *Seeing*: The ability to recognize and constructively hold tension where it is arising, even when it occurs as conflict and politicization;
- *Connecting*: The ability to consistently observe ourselves in action and reflect on the frames of those actions in our lives;
- *Experimenting*: The willingness to experiment and 'interrupt' patterns of thought, habit, and action in order to learn.

We suggest the following praxis for cultivating the capacity for transformative innovation, which is graphically depicted in Fig. 2.

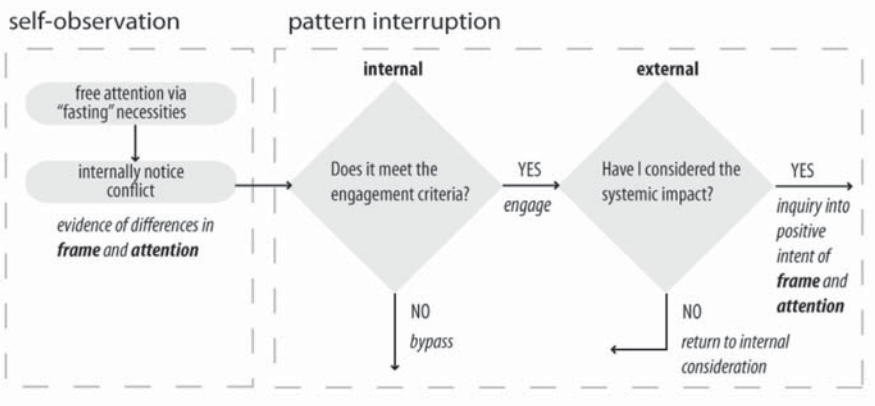

Fig. 2. One potential innovation protocol.

3.1 Foundation: creating 'free attention' through self-observation

One of the primary reasons we simply fail to be innovative individually and collective is due to the lack of resilience in our lives and lived systems. In the attempt to maximize unexamined values and necessities, (e.g. efficiency, utility, impact, etc.) we tend to remove all resilience from our lives. This then becomes a 'problem' for us which we tend to solve from within the context of those same unexamined values and asserted necessities. We actively create an environment in which we have no free attention or energy. As a result our lives become brittle and mechanistic, rather than pliable and emergent. Often this is simply done out of fear and a confusion between our literal survival and the survival of some metaphorical and extended sense of identity. The inquiry into such asserted value and necessities is itself a practice that begins to free attention in our lives. This often seems as if it creates conflict, when it is much more likely it is simply revealing structural incongruence and existing conflict with which we have been coping. It is in great part this strategic coping that takes up all the space within our lives. Reflective observation of such a dynamic is itself an initial form of pattern interruption.

Paradoxically of course this means that we must find some free attention to look into these underlying conditions. How do we do that? Typically we are inspired to take such action in the face of crisis. The difficulty is that in the absence of crisis, which frees attention in the system by forcibly eliminating complexity, we cease to act in a way that addresses these deep structures of necessity and habit. We may even develop a habit of moving from crisis to crisis as a way of emulating innovation. Often we will celebrate the heroic efforts and creative solutions to address the crisis and this becomes the valued aspect of our culture, reinforcing the need for crisis. Many of the crises themselves are the direct result of a closely held and unexamined assertion of some necessity or model. There are several ways to begin to free attention and energy in our lives from where it may have become fixed and habituated.

Self-observation serves as the starting point. Pattern recognition in our lives becomes critical, but is not sufficient. We must become present to the activity of patterning itself. How are we participating in the recognized patterns? What is our role in the enactment of such patterns? What is our strategic interest in the existence or perpetuation of such patterns? All of this must be looked into within the living experience and action of the innovator. Once we see something about this one of the simplest ways of understanding the deeper structures leading to the pattern is to consciously 'fast' our participation in the pattern and observe what arises. Remember, we are talking about the process of freeing attention and energy in ourselves and within the lived system as a basis for innovation. Fasting is one way of beginning to make apparent the places where attention and energy have become fixed and examine the asserted structure of necessity and utility upon which the fixation based.

For instance, withhold telling students 'the solution' in a design team. What happens? What do you notice? Where did you feel it necessary for you to tell them what you believe is the solution, what did you do? What was the basis of that asserted necessity to tell them the 'answer' or to prioritize your 'answer?' You can see from this simple, simple example that the work to not only reveal, but actively work with such structure can be very challenging. Imagine an analog within an organization. Perhaps there is curricular dispute that has been habituated and occurring for some years, such as a standing and habituated conflict between the 'STEM' and Humanities colleges of your university. It has been going on long enough that is now the status quo. The conflict is the normal condition, so thoroughly so that it is not even consciously felt, but rather professionally coped with and actively un-felt. A starting point can be noticing and 'fasting' the ways in which you personally participate in the dynamic.

3.2 Detection: welcoming conflict as the visible source of structural tension

Working in the transformational domain is often experienced as a crisis or series of crises because it is almost always politicized. These crises arise as conflict within the system. In the politicized conflict that debates which is right and which is wrong (and therefore who is right and who is wrong) we entirely miss the opportunity for profound transformation and innovation. The conflict itself is one of the primary sources for working with innovation in this transformational domain.

Conflict is the means by which differences in the otherwise invisible or unexamined habits and patterns (frames and attention, Fig. 1: The structure of action) become visible and the system can become aware of them. That is, conflict reveals tension in the structure, such as different assumptions and mental models (frames) or places where attention is contracted (attention). Innovation of the third domain can only occur if we do not seek to suppress the conflict as it arises, but understand conflict as evidence of structural tension and a moment of reflection and learning.

3.3 Assessing: choosing to engage or by-pass the conflict

As such patterns become visible through conflict, it is important to recognize that the enacted patterns and habits, which are themselves the source of the problematized phenomena, are historically grounded in a positive intent. It is this disposition of assuming positive intent which allows us to begin to inquire of one another. A disposition other than assuming positive intent creates the feeling of interrogation and defense rather than that of an open inquiry.

In the moment of conflict, then, one has the opportunity to make responsible choices about whether to engage or bypass the conflict, rather than reacting out of habit. Bypass is equivalent to noticing it and choosing to let it go. Engaging it takes the form of an inquiry into the frame or attentional place where the viewpoints diverge. The choice of whether to bypass or engage the conflict depends on one's personal or organizational 'mandate' for doing so. In the process of making such a choice we make explicit the context of service in which we are operating, rather than holding it as an implicit assumption.

3.4 Interrupting: making visible the background conversation

The first level of external intervention in the system is making the 'background conversation' explicit–revealing the invisible thoughts or collective organizational rumor. Oftentimes that lived or enacted values of a design team (or other human system) are in direct conflict with the espoused values. This is evidenced by private conversations that take the form of complaints. It is the private nature, either within an individual or between a subset of the design team, that keeps the team functioning incongruently with respect to its espoused values. In this way, those who withhold their awareness of the incongruence are directly participating in it. Beginning to reveal this structure is itself interventionist and has consequences. True innovation has consequences. We must be very clear about that before undertaking any transformational endeavors. We must ask 'What do we want to conserve?,' and be very clear about this. We must deeply explore the consequences of successful as well as failed innovation prior to entering into it.

3.5 Learning: validating theories through action

Transformational innovation occurs when new models altogether are created and carried through to practice in such a way that they can be socialized. Without some form of collaborative practice and socialization process these new models and theories are simply abstract and conceptual. It is therefore necessary to validate such contextual shifts, not with respect to some third model held as objective and authorized, but rather with respect to the lived reality of the people involved. In essence this looks like an active practice of experimentation, reflection, and learning within the human system. Such a practice itself typically requires a contextual shift—the first area of innovation. In other words, transformational innovation is cultural phenomena. The possibility of any consistent innovation emerges not from prescriptive or proscriptive practice and technical understanding of any sort, but rather from the deep structure of the human system. This deep structure may not be initially evident as such, but is evident in the behaviors of the system. One implication of innovation as a cultural phenomenon is that the capacity for innovation itself is preserved and promoted through the lived stories, or narrative of the system.

If we imagine any sort of consistent innovation, as a result of a culture that structurally allows and enables innovation, we must be inquiring into these sorts of questions, not as if they were outside of us, but rather as if we were living and even lived by, such structural conditions. In the absence of such an undertaking of conscious inquiry, we see the attempt to solve a lack of innovation through 'best practice', the transformational qualities of which we believe are accidental.

4. Preliminary results from a year-long change process

We have initiated a process of transformational innovation, hosting weekly workshops on capacity building. These workshops were offered through the Center For Teaching and Learning (CTL) on Cal Poly's campus. While open to all, they were primarily attended by faculty and staff. It's our bias that faculty and staff (i.e., ourselves) are critical actors within higher education cultures, so we considered this collaborative practice of learning together as preliminary to changing educational practices.

The workshops met each week for two hours, usually on Friday morning. These workshops were guided by Roger Burton, who frequently drew upon emergent issues within the group. The appendix contains an example of some of the content that was addressed. While the content supported the process, we believe that other institutions can use different content while practicing the suggested protocol of pattern interruption. The focus of the workshops was the practice of change, situated in one's own lives. The process of pattern interruption was a consistent theme of practice.

Near the end of each of the three 10-week long

workshops individuals were queried about the benefits of the workshop. Participation in the workshop was completely voluntary and thus attendance varied from week to week. Generally 15 to 20 faculty and staff attended each week. Students participated at a much lower level (sometimes 1–2 students per workshop). The first survey was sent to 30 people, the second was sent to 19 people, and the third was sent to 45 people. Some individuals participated in several workshops and thus may have responded to the survey more than once. A total of 44 individuals responded to the open-ended question: 'What benefits are you personally gaining through your involvement in the workshop?'

Although we are familiar with the standards (Bogdan & Biklen, 2006) of qualitative analysis of open ended comments from such a survey, we chose to analyze the responses in a way that recognized the researcher as a real participant in the process. We do not intend to assert that these results are generalizable to other campuses or groups, but to illustrate a process of innovation that led to self-reported, new ways of thinking. In this process we recognize the unique characteristics of not only the participants, but also the researchers (as participants), that contribute to the insights achieved. We believed that the comments would tell us something about our own experience in these workshops at this moment in time. Although the analysis procedure did not include multiple coders or cross referencing for inter-rater reliability, we suggest that the evidence of change has face validity through verbatim individually-reports of change. Of course we recognize that someone else might find a different pattern in the comments, but the pattern we identified has real meaning to us. We are not attempting to generalize these results to say that others who initiate these kinds of workshops, or even other workshop participants, would identify the same model. This is our experience and we believe that others will have different and equally valid experiences in this kind of exercise. Although we could have followed the appropriate protocols for this analysis, we purposely chose to describe one interpretation, not pretending it might be the same for someone else. Practically this meant that one of us performed the data analysis that consisted of parsing comments into sentences. Each sentence was counted as a separate thought. This resulted in 138 separate comments. These then were grouped into four categories. Taken together, they create a kind of picture of the process of building capacity for transformative innovation as shown in Fig. 3: Capacity building process. In this model, we have used the term *Awareness*, as a necessary but insufficient condition for the capacity of *Seeing* that was described above. *Seeing* includes both the recognition and the ability to tension between the reality of the current state of things and the envisioned state of things.

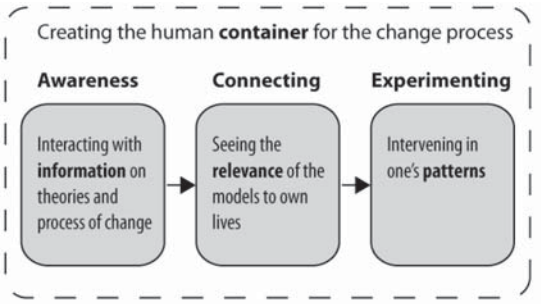

Fig. 3. Capacity building process.

Building Social Fabric: The first category of comments illustrates the appreciation for the human container of time, space and community established in the workshops. We believe this container is necessary for the change process. Almost 30% of the comments referred to the enjoyment, comfort or satisfaction individuals gained by participating in the workshops. Forty-one the 138 comments related to this support provided during the workshops. A few sample comments are listed below.

> I have especially found the insights and relationships of this faculty/staff/student community to be extremely useful for my sanity and well being as a person this quarter
>
> I feel uplifted and peaceful after the sessions.
>
> There is a sense of integration and wholeness; a fulsomeness to the meetings and the time the group gives to one another.
>
> The leadership workshop was like therapy for me this quarter.
>
> Having 2 hours per week to step away from my normal administrative duties and simply reflect on what the heck I'm doing is a real pleasure.
>
> A final personal benefit was that I enjoyed spending the time with the people in the workshop.
>
> It gives me time to think and contemplate, which is very difficult to do with all the other demands on my time.

Seeing: For many, the process of being able to notice and hold structural tension began with becoming aware of the possibility that it exists. Many respondents described that they were reaching a new level of awareness with the idea of change. This occurred through introducing change models, suggested readings, demonstrations by the facilitator, and projects. Twenty-Six of the 138 (19%) comments referred to the usefulness of information. Below are some samples of these comments.

> Reviewing the various change models and the readings that Roger has provided has given me some new resources I wouldn't have otherwise known about.
>
> Each meeting has informed my thinking.

I learned about the concept of dialogue and about formal change processes.

It's my first exposure to change as a discipline.

The major benefit for me was that this workshop provided the opportunity to intellectually think about and reflect upon the concept of leadership.

Connecting: Information is interesting and stimulating, but until the identification of the relevance of the information to our lives, no real change is possible. Forty-nine of the 138 comments referred to the realization that the information present had direct relevance to the individual or the organization. This self-reflection is important to developmental change.

The benefits for me have to do with recognition of where change needs to take place in my life personally and how I create barriers to keeping the status quo and not making changes that would ultimately benefit me.

It challenges me to consider alternative possibilities both personally and within my work life.

After the third meeting, I recognized a personal need to undo many of my assumptions about change and how change occurs, both personally and institutionally.

I began to see a broken mirror image of fragmented change and ineffectiveness, and how much more I wanted to learn about my own thought processes.

Our discussions helped me understand my personal life in a context I'd never considered before, and the homework exercises Roger assigned allowed me to test my perceptions and processes on a daily basis.

The workshops encourage personal development and building reflective capacity–essentials for quality of life, both personally and professionally.

Self-discovery and understanding of the world around me.

Experimenting: The last category of comments referred to real change that occurs in the lives of the participants. There were 20 comments that referred to concrete change. Samples of these comments are below.

The readings challenge my assumptions and more importantly, provide new ways to be in the world, to act on deliberately changing habits of mind, heart, and hand, with a goal of being a more effective person.

I am experiencing real personal transformation.

I am definitely empowered to make personal change and lasting change in my life–both professional and personal.

This mere thinking process often results in a positive experience leading to some kind of change in the consequence.

By suspending I can inquire into people's actual meaning, which then leads to a dramatically more positive outcome than what I am accustomed to.

I also learned about how to focus my attention and learn a lot about how to enable a discussion without really having a well-defined topic.

I have begun interrogating my own mental models and problem solving strengths.

5. Limitations of the protocol

In writing this piece, there is a risk that the codified process will itself become a 'best practice' that has the form but not the substance of transformational innovation. Until we develop a capacity with real self-reflection and the enactment of what we learn from that, activities of inquiry are extremely difficult. This not something inherent to such activities, but rather a lack of capacity that arises from the larger cultural and historical context in which our institutions exist. Furthermore, it is not possible to persuade someone that such reflective activity has any 'practical' purpose or use with respect to their existing models of necessity and utility. Such reflective practice cannot be forced. Such practice is not possible though manipulation. Furthermore, if you are not engaged in such practice yourself, in your own life and lived systems, it is difficult to meaningfully talk about. This means that such immediate self reflection and action are where we need to start in all cases. Most difficult about this is that if we are enacting it to solve a problem, it then becomes technique and is more or less self-defeating. The first act of reflection and inquiry is into the value of in inquiry and reflection. This will often initially look like encountering the assertions about why reflection and inquiry are not valuable or merely functional. In that moment it is possible to begin to look at the deep structure and frames that make that true and the consequences of frames.

Additionally, we have omitted the ethical component of innovation. Innovation is itself an intervention. Often it is for the sake of growth in some dimension or another. From a market point of view it is often framed in terms of profit. This ethical inquiry is an enquiry into the deep ecology of the human and natural systems in which any intended innovation will take place. There are several types of questions that we simply fail to ask with regard to innovation.

- What do we wish to preserve or conserve?
- What are the unintended consequences of the success or failure of the innovation?
- Who and what is included or excluded by the innovation?
- How does the innovation participate in interconnectedness?

The explicit purpose of the engineering profession, stated in professional society ethics codes, is to serve the well being of society. In the absence of a reflective capacity, we end up in the condition described the chairman of the Committee on Grand Engineering Challenges convened by the US National Academies: The engineering profession's greatest challenges in the twenty first century

are to solve the problems created by the professions' successful solutions in the twentieth century [27].

6. Conclusions

It is not simply the case that changing something because we can constitutes innovation. Changing something because we can, in the hope that it will create some return is accidental by nature. It assumes that with sufficient scale, trial and error, we will arrive at a meaningful innovation. Experimentation is necessary, but in the absence of a reflective context it does not constitute innovation. Moreover, in the accidental moment of apparent success, no capacity for innovation is built. What we build in this case is an exhausting, unsustainable mechanistic system. Innovation cannot be mechanized. However, the disposition for designers' innovation can be grown within the culture of a human system. Using the models of Torbert and Argyris, we have suggested that this process begins with freeing attention through self-observation. It requires welcoming conflict and assuming a positive intent of different viewpoints. Designers can then consciously decide to engage or bypass conflict through a responsible consideration of their role in doing so and the potential consequences. The validation of the capacity for transformational innovation is evidenced by experiments initiated and designed in the lives of the innovators themselves. Our year-long process of attempting to grow change in the human system of a university showed promise through the personal narratives of transformation. However, we fully acknowledge that the suggested protocol for growing the capacity for transformational change is simply an example, rather than a prescription. We have left unaddressed all the deeper ethical considerations inherent to the practice of innovating. That is, we've described the means of innovation without a thoughtful look at the ends. However, a reflective contemplation of the ends of innovation is perhaps even more important.

Acknowledgements—This work has been supported in part by grants from the National Science Foundation (NSF-DUE0717428, NSF-EEC1025265). The views expressed in this paper represent those of the authors and do not necessarily reflect those of the National Science Foundation.

References

1. I. AbuJarad and N. A. Yusof, Innovation creation and innovation adoption: a proposed matrix towards a better understanding. *International Journal of Organizational Innovation*, **3**(1), 2010, pp. 303–325.
2. A. Stone, S. Rose, B. Lal and S. Shipp, *Measuring Innovation and Intangibles: A Business Perspective.* Institute for Defense Analysis: Science and Technology Policy Institute, December, 2008, pp. 1–140.
3. ASTRA, *Defining Innovation: A New Framework to Aid Policy Makers*. Washington D.C.: The Alliance for Science and Technology Research in America, 2007.
4. S. Girma, Y. Gong and H. Görg, What Determines Innovation Activity in Chinese State-owned Enterprises? The Role of Foreign Direct Investment. *World Development*, **37**(4), 2009, pp. 866–873.
5. C. Heape, *The Design Space: The Design Process as the Construction, Exploration, and Expansion of a Conceptual Space*. University of Southern Denmark, 2007.
6. T. Kelley, *The Art of Innovation: Lessons in Creativity from IDEO, America's Leading Design Firm*, Doubleday Publishing. New York, NY, 2001.
7. D. Brandt, Creativity at the borders of engineering: Three personal accounts. *European Journal of Engineering Education*, **23**(2), 1998, p. 181.
8. A. W. Court, Improving creativity in engineering design education. *European Journal of Engineering Education*, **23**(2), 1998, p. 141.
9. S. C. Mu and D. R. Gnyawali, Developing Synergistic Knowledge in Student Groups. *Journal of Higher Education*, **74**(6), 2003, pp. 659–710.
10. B. Shneiderman, Creativity Support Tools: Accelerating Discovery and Innovation. *Communications of the ACM*, **50**(12), 2007, pp. 20–32.
11. W. R. Torbert, Why educational research has been so uneducational: the case for a new model of social science based on collaborative inquiry. In P. Reason & J. Rowan (Eds.), *Human Inquiry*. Boston: John Wiley and Sons, 1981.
12. D. Meadows, *Thinking in Systems: A Primer*. White River Junction, VT: Chelsea Green Publishing, 2008.
13. P. Senge, *The Fifth Discipline: The Art and Practice of the Learning Organization.* New York: Doubleday, 1990.
14. E. H. Schein, *Organizational Culture and Leadership* (3rd ed.). San Francisco, California: Jossey-Bass, 2004.
15. T. S. Kuhn, *The Structure of Scientific Revolutions* (2nd ed.). Chicago: Chicago University Press, 1970.
16. P. Dressel and D. Marcus, *Teaching and Learning in College*. San Francisco: Jossey-Bass, 1982.
17. J.-C. J. Jehng, S. D. Johnson and R. C. Anderson, Schooling and Students' Epistemological Beliefs about Learning.' *Contemporary Educational Psychology*, **18**(1), 1993, pp. 23–35.
18. B. K. Hofer, Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology*, **25**, 2000, pp. 378–405.
19. L. Lattuca, Learning interdisciplinarity: Sociocultural perspectives on academic work. *The Journal of Higher Education,* **73**, 2002, pp. 711–739.
20. N. Augustine, Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, DC: National Academy Press, 2005.
21. C. Argyris, *Reasoning, Learning and Action: Individual and Organizational*. San Francisco, CA: Jossey Bass, 1982.
22. C. Argyris, Actionable knowledge: Design causality in the service of consequential theory. *The Journal of Applied Behavioral Science*, **32**(4), 1996, pp. 390–406.
23. P. Reason and W. R. Torbert, The action turn: Toward a transformational social science. *Concepts and Transformation*, **6**(1), 2001, pp. 1–37.
24. R. C. Bogdan and S. Biklen, *Qualitative Research in Education. An Introduction to Theory and Methods. Fifth Edition.* Boston: Allyn & Bacon, 2006.
25. A. Starr and B. Torbert, Timely and transforming leadership inquiry and action: Toward triple-loop awareness. *Integral Review: A Transdisciplinary and Transcultural Journal for New Thought, Research and Praxis*, **1**, 2005, pp. 85–97.
26. W. R. Torbert, *Action Inquiry: The Secret of Timely and Transforming Leadership*. San Francisco, California: Berrett-Koehler Publishers, 2004.
27. Engineering's Grand Challenges, *Today in Engineering*, 2008, (Spring), 2.

Appendix-Example workshop content

Change Models	Productive Dialogue Theory
Kantor's meta-model of change (Kantor, 1975)	Bohm's dialogue (Bohm, 1996)
Torbert's interpenetrating attention (Torbert, 1987)	Chomsky's transformational grammar (Chomsky, 1987)
Meadows systems interventions (Meadows, 2008)	Kuhn's structure of scientific revolutions (Kuhn, 1970)
Fritz's creative tension	Argyris's Ladder of inference (Argyris, 1982)
Teleologic change	The four-player model of healthy teams (Ancona & Isaacs, 2007).
Aristotle's cauality	

D. Ancona and W. Isaacs, Structural Balance in Teams. In *Exploring Positive Relationships At Work*, edited by J. E. Dutton & B. R. Ragins. Mahwah, New Jersey: Lawrence Erlbaum Associates, 2007.
C. Argyris, *Reasoning, Learning and Action: Individual and Organizational.* San Francisco, CA: Jossey Bass, 1982.
D. Bohm, *On Dialogue*. New York, NY: Routledge, 1996.
N. Chomsky, *Knowledge of language*. Westport, CT: Greenwood Publishing Group, 1987.
D. Kantor and W. Lehr, *Inside the Family*. San Francisco, California: Jossey-Bass, 1975.
T. S. Kuhn, *The structure of scientific revolutions* (2nd ed.). Chicago: Chicago University Press, 1970.
D. Meadows, *Thinking in Systems: A Primer.* White River Junction, VT: Chelsea Green, 2008.

Roger Burton. For the past 20 years Mr. Burton has been working as a systems change consultant and change catalyst with many of the world's largest corporations and organizations. His work has included the executive suite and the shop floor across a wide variety of industries and endeavors. Mr. Burton has worked or lived in over 40 countries to date. Examples of his work include: Designing and facilitating the research and learning process by which BP created their Alternative Energy Divisions; helping them work through the strategic and organizational difficulties of growing that organization over a period of 5 years; Initial responsibility for the cultural and leadership changes necessary for the United States Internal Revenue Service's shift from a police organization to a service culture when the U.S. Congress mandated its modernization; Assisting the creation of the initial Innovation Lab at BMW in Munich; Assisting them in making real the first- and second-person practices and processes needed for consistent innovation; working with a variety of large corporations on successfully dealing with the implications of merger and acquisition; designing the dialogue and capacity building processes for what have been considered breakthrough labor agreements and relations in Europe and Australia.

Lizabeth Schlemer is an associate professor at the California Polytechnic State University. She holds a Ph.D. in Education from the University of Santa Barbara, a master of business administration from the University of Southern California, a B.S. in industrial engineering from Cal Poly, San Luis Obispo, and a Professional Engineer's license. She has been teaching at Cal Poly for seventeen years. She is deeply practiced in project-based learning, having managed over 200 student projects during her teaching career. Her current interests include alternative pedagogies for learning engineering and action research as a means to foster authenticity, learning and greater wellbeing.

Linda Vanasupa is professor of materials engineering at the California Polytechnic State University and co-director of the Center for Sustainability in Engineering at Cal Poly. Following the leadership of a department curricular reform, she is currently collaborating with a group of faculty and community collaborators on new educational paradigms. Her recent focus is in developing the capacity to innovate, particularly with respect to greater holistic and societal benefits. She completed her Ph.D. and M.S. degrees in materials science and engineering at Stanford University. Her undergraduate work was in metallurgical engineering at the Michigan Technological University.