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Donald L. Gilstrap

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**Critical Reflection as an Irreversible Process: Epicurus, the Arrow of Time, an Ontology for Organizational Learning Phenomena**

Donald L. Gilstrap  
*Wichita State University*

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has traditionally paid little attention to time as a construct (Blount, 2004) and has focused more fully on the linearity of time to improve efficiencies. The purpose of this article is to extend this research through an interdisciplinary framework of philosophy, science, and organizational learning by focusing specifically on critical reflection as an irreversible process. Returning to Epicurus's original investigation of time, this paper argues for an ontology that links irreversible processes with Prigogine's (1996; Prigogine & Stengers, 1984) *Arrow of Time*. Furthermore, defining critical reflection as an irreversible process then leads to an epistemological framework that helps describe change over time during organizational learning processes.

## **Epicurus And The Atomists' Perceptions Of Time**

*We should investigate the causes of all celestial and nonperceptible phenomena by making a comparison of these with the various ways in which an analogous phenomenon takes place in our own experience (Epicurus, Letter to Herodotus; Strodtach, 1963: 44).*

The theoretical construct and ontology of time have been debated for thousands of years. Certainly, conversations have ranged from whimsical parlor discussions to intense scholarly investigations among the scientific and philosophical communities. A resurgent interest in the questions of time and space emerged during the Middle Ages with the widest recognition given to the works of Aristotle by medieval philosophers. And, during the Enlightenment period, this mode of inquiry returned to the more specific classic debate over Stoic and Atomist philosophies of science with philosophers such as Francesco Patrizi favoring the former, Giordano Bruno arguing for the latter, and Pierre Gassendi embracing the strengths of both (Bernier, 1684; Bollack & Laks, 1977; Grant, 1981). Moreover, it is this discussion of reversibility during the Enlightenment in which the philosophical roots of positivism can be found today. I will not be so bold as to attempt to resolve theories of time with a panacea of utilitarianism. However, it is important to draw attention to the place of time in current scientific debate and, like our philosophers of science throughout history, recursively return to some of the original debates in ancient Greek philosophy.

## **Time Is Reversible, And, Therefore, Time Is An Illusion**

To understand how this construct has come into existence, we must look closely at the universal laws of classical mechanics. It is interesting to note here, that Isaac Newton himself had been influenced early on by Epicurean philosophy. Although Epicurus's writings arrived much later in England than in France, early in his career Newton struggled with questions concerning the void in atomic theory in ways that were similar to Epicurus. Although Newton would later change his stance on universal attraction, this Epicurean philosophy served as a basin of attraction for much of Newton's early life, primarily through his study

of Pierre Gassendi (Guerlac, 1963). In linear determinism in physical systems, variables input into a systemic process are constructed theoretically in such a way that the ending result can be reduced in a time-reversible method, arriving at the original system components.

This concept of reversibility in time is critical to the foundation of positivist philosophies. Laplace's Demon, as it has come to be known, suggests that if all possible variables are known in advance, we can predict the future with certainty. This phantom of omniscience would allow us to arrive at the border of what Stephen Hawking (1998) described as the very end of our quest for a theory of everything. In similar fashion, string theory has struggled to arrive at a similar juncture, yet it has been unable to prove the existence of the Higgs Boson, accounting for dark matter and energy. However, more than 30 years have passed without resolution or advancement in a more unifying string theory, and Hawking's prediction of a theory of everything has come little farther than his original prolepsis for the scientific community. Moreover, this framework is firmly rooted in the linear determinism of the modernist world. Certainly attempting to understand time from more than a basic construct as a unit of measurement has confounded most who enter into this investigation, including Epicurus.

## Theoretical Framework

### Epicurean Time

**E**picurus lived from 341-270 BCE and was born on the island of Samos. After becoming an Athenian citizen through the takeover of Samos by the Greek patriarchy, Epicurus' philosophy evolved as he moved throughout Asia Minor, establishing schools until finally settling at his renowned Garden school in Athens. The majority of historical analyses on Epicurean scientific philosophy comes from two of his works, *Letter to Herodotus* and *Letter to Pythocles* (Festugière, 1946). It is common to see Epicurus cited as a student of Democritus, but from his writing, Epicurus had few complementary statements attributed to him (Jones, 1989), and some might argue Epicurus was openly hostile toward Democritean philosophy (de Gandt & Souffran, 1991). Needless to say, Epicurus and the followers of Democritus shared in their philosophy of Atomism, breaking from the Stoic and Aristotelian traditions of the ancient Greek world and their own conceptions of time and matter in the universe in spirited yet primarily collegial dialogues. Certainly Epicurus, as well as Aristotle, were limited in their abilities to perform scientific experiments with atomic microscopes or computer processors easily able to compute atomic trajectories at the  $10^{10}$  decimal place. As a result, their scientific theories lack key components that are well understood in the scientific community today. But perhaps we should remark on how astounding and complex their theories were, given limited instrumentation while relying on their philosophy of experience of the world around them. And these concepts to this day are used as a basis for deep investigations of dif-

ficult theoretical constructs such as the role of time in the universe.

In her well-known work on Epicurean science, Asmis (1984) summarizes Epicurus' Dilemma of exploring time which Prigogine (1996) would later reinvestigate.

*Epicurus points out that time is not to be investigated like other properties of bodies by being referred to a presumption. Instead we must compare the evident occurrence [ἐνάργημα]<sup>1</sup> with other evident occurrences of the same type... These concepts permit us to investigate time, even though we do not have a presumption of time itself; for time is nothing but the relative duration of properties (Asmis, 1984: 33).*

There is no question that Epicurus missed the mark on his understanding of the atomic and subatomic levels of the universe. And it is this dilemma in describing atoms that leads to his further extrapolation of time. In Epicurus' *Letter to Herodotus*, he describes atoms as those entities that move in perfect parallel trajectories in a continual downward motion. Although conflation, it is interesting to note that Epicurus was alluding to laws of gravity through this downward atomic motion. However, Epicurus could not overcome his own paradox of explaining parallelism with the atomic collisions that drive the universe [*clinamen*] and, therefore, conceded to the idea of derivations in atomic trajectories. As an illustrative analogy, Prigogine (1996) presents these types of motion as stable and unstable system trajectories (Figures 1 and 2). Moreover, Konstan (1979) has shown, in Epicurean theory, there is "no way to define the difference between collision and mere contiguity of atoms" (p. 395). Consequently, this is the very essence of the importance of Epicurean theory to complexivists: that at a certain level, issues become less about absolutes, become more about description, and, perhaps more so, highlight the importance of metaphorical significance in the bridge between scientific thinking and philosophy.

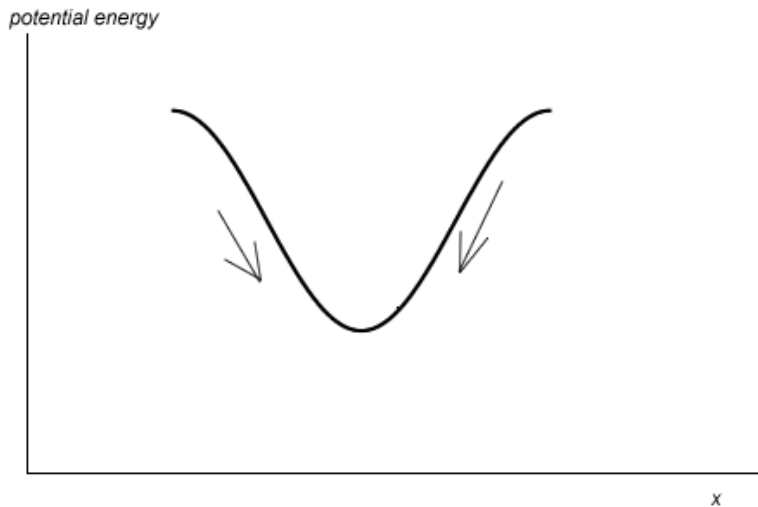
In his seminal work, Morel (2002) presents the challenges of the Epicurean development of time in this metaphorical framework:

1. Is time external and objective or intimate and subjective?
2. How does one know time?
3. Is time grasped by reason and can the multiplicity of imperceptible time be formed, like an aggregation, as a unique time (p. 195-196, translated by author).

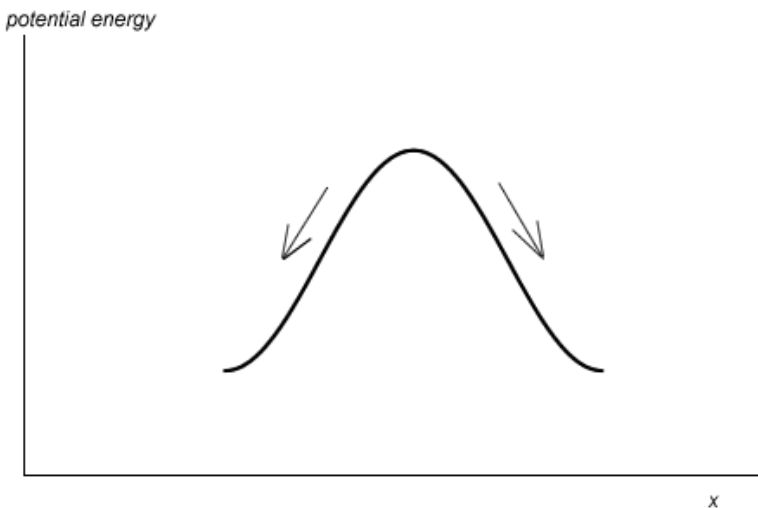
Borrowing from Sextus Empiricus, time is an "accident of accidents... its existence is [not] in doubt, but that it bears a relationship of properties that are themselves accidents" (p. 199). As a result of time being a measure of movement in the atomic world of Epicurus, Morel (2002) goes on to argue that, in effect, "time is not an accident but a property of accidents" (p. 200). To Epicurus it was

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1. ἐνάργημα is translated by Asmis as evident occurrence. It can also be translated as manifestation, implying the outcome of emergence.



**Figure 1** *Stable System Trajectories* (Adapted from Prigogine, 1996)



**Figure 2** *Unstable System Trajectories* (Adapted from Prigogine, 1996)

in our inability to deal with the paradoxes imposed by time that causes us to deny its existence. "Time is therefore not the movement of the universe, not only because it does not exist by itself, but also because it must be defined by the information of the representation that we have of it" (p. 201). The theoretical construct of the arrow of time, therefore, proved to be the Epicurean dilemma, as the Atomists felt they had originally solved this problem. The Epicureans conceded this paradox must be addressed through description in language, since in their belief the movement of the atom was the illusion, rather than time being an illusion:

It now makes perfect sense to say that at any moment an atom is not moving... yet over successive instants it does move... the problem

becomes this: what is it that distinguishes a moving atom at a given moment from a stationary one?... *It is essential to take into account the previous history of an atom in describing it at any given moment* (Konstan, 1979: 396, emphasis added by author).

In effect, Epicurus had identified metaphorically upon what is now known as the phenomenon of self-referencing inherent in complex systems.

Along this same line of reasoning, Epicurean philosophy also challenges the concept of the physical vacuum, describing atomic structures being surrounded by space rather than matter (Konstan, 1979). The metaphorical significance of this idea relates uniquely to the strange attractor patterns found in chaotic systems, where iterative movements do not follow linear and deterministic paths but are still bounded by system parameters. The basin of attraction is the magnetic resonance of the chaotic system, and these system boundaries are, in similar fashion, not matter but rather space. The importance of this proposition relates to the current debate in quantum physics in which a quantum vacuum not only suggests the absence of matter but also the absence of time (Rovelli, 2004). Aristotle had originally suggested the possibility of quantum motion to Epicurus, but even Aristotle did not go so far as to argue—given the descriptions inherently different in what are now known as classical and quantum physics—that an atom can ever be described as moving (Konstan, 1979).

Epicurus could not reconcile the concept of how energy is transferred between atoms as a result of his theory of *minima*, which contrasts with the key component of thermodynamic exchange in dissipative structures. However, as Konstan (1979) reminds us:

*His principle of uniform atomic motion is, like the conservation of energy, a bastion against entropy, the final degeneration of all motions as a result of innumerable collisions* (Konstan, 1979: 398).

Consequently, Epicurus recognized that the universe was not linear and deterministic in its response to entropy production. In Epicurus's view, the world would not exhibit the metaphorical characteristics of Laplace's clock-like universe where continual increases in entropy would cause the clock to wind down in eventual self-destruction. Epicurus's philosophy of *minima* implies that, instead of focusing on the absolutes of micro-atomic system states currently debated in classical mechanics, "the doctrine of minima, on the other hand, was addressed to rather different considerations, such as the discontinuous nature of space, time, and motion" (Konstan, 1979: 400). And this discontinuity equally begs for a further operational definition of Epicurean philosophy, including the concept of irreversibility.

In spite of Epicurean failures in relation to our current knowledge of atomic science,

*The problems with which Epicurus wrestled, and the solutions which he propounded, were not inherently absurd. As it happens, Epicurus's theory does not describe satisfactorily any class of particles that are significant in nature, nor we may add, is it likely to. But for its subtlety, sophistication, and boldness, it represents a major achievement in the history of mechanistic world models... it may be said that Epicurus's theory is the first such model we can satisfactorily identify and describe. It has yet to claim its rightful place in the history of science (Konstan, 1979: 418).*

Epicurus was never able to resolve this dilemma of time and motion, and he seemed to fall comfortably back on the mechanistic worldview. It is for this reason that Prigogine returns to the place where Epicurus left off given contemporary scientific knowledge.

### **Complexity Science And Our Views Of Time**

*To Einstein, [ignoring the arrow of time] appeared to be the only position compatible with the achievements of science. But this conclusion is as difficult to accept now as it was to Epicurus. Time is our basic existential dimension... For philosophers, it remains the central question of ontology, at the very basis of the meaning of human existence... What is the purpose of science if it cannot incorporate some of the basic aspects of human experience? (Prigogine, 1996: 13-14).*

As stated previously, according to classical mechanics, irreversible processes are an illusion, and, therefore, time is equally an illusion. There are several contemporary cosmologists who address the concept of the arrow time: most famously Hawking's exploration of the reversibility and the illusion of the arrow of time (1998); Price (1997) who finds parallels to the outer dimension view of time of Archimedes; and Gould's (1988) investigation of geological time and its subsequent cyclic interpretation. These works have contributed greatly to the recent explosion of research on the subject, yet it is impossible to include a detailed analysis in the confines of this article. My intent is to focus on Prigogine (1996) who draws from Epicurean perceptions of time to formulate a framework in which complexity theory, and more specifically dissipative structures, can reintroduce this debate. In Prigogine's (1996) view, it was Boltzmann's nineteenth century attempt to apply Darwin's work in biology to the field of physics that the time paradox which Epicurus and his contemporaries debated was rediscovered. However, "Boltzmann is now associated with a conclusion quite opposite that of Darwin; he is credited with having shown that irreversibility is only an illusion. It was Boltzmann's tragedy to have attempted in physics what Darwin had accomplished in biology--only to reach an impasse" (Prigogine, 1996: 19). Prigogine himself struggled with this concept and that, like the deductive reasoning forced on thermodynamics, physics would also be forcing reductionism on biology in discussing biological concepts in nature through physical laws.



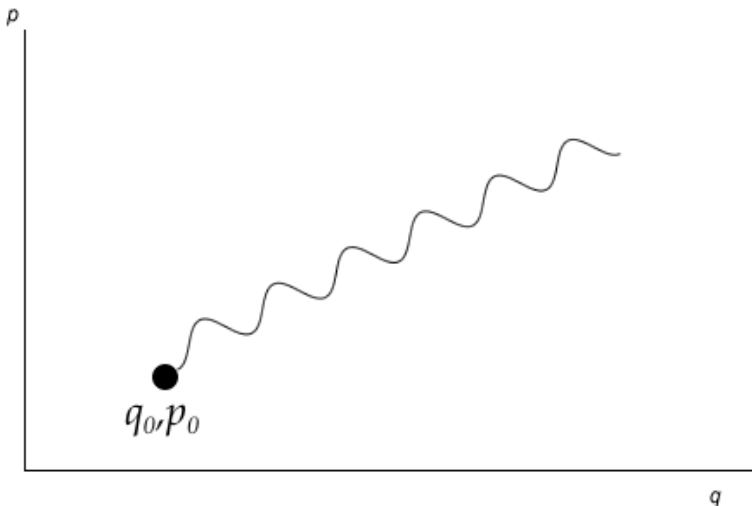
But ultimately, Prigogine concluded that:

*The laws of physics, as formulated in the traditional way, describe an idealized, stable world that is quite different from the unstable, evolving world in which we live. The main reason to discard the banalization of irreversibility is that we can no longer associate the arrow of time only with an increase in disorder* (Prigogine, 1996: 26).

Over a century has passed since Boltzmann's original experiments, and ensuing debates have taken place as to the roles and illusions of time. However, I argue that an emergent view of time--and more specifically new dialogue among complexity scientists on the theoretical construct of the arrow of time--is critical to understanding human processes in the framework of research on complexity theory.

### The Arrow Of Time

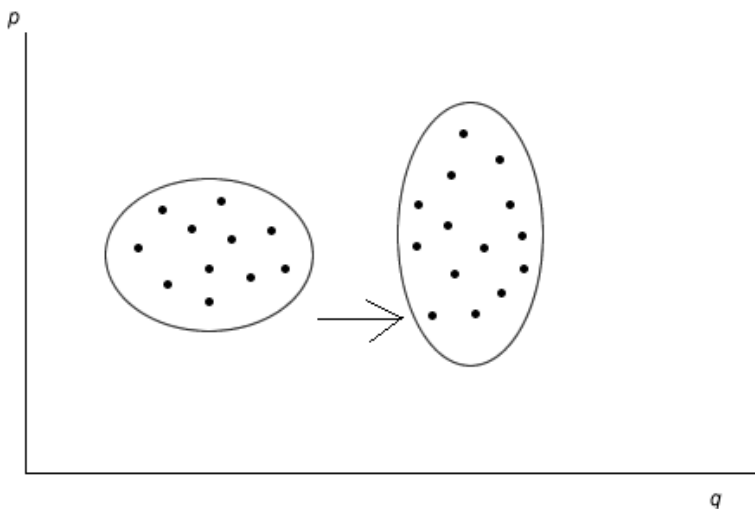
Casual readers may find themselves equating linearity with the arrow of time. However, these are two quite juxtaposed terms in their scientific sense. If we subscribe to the theoretical construct that "life is possible only in a nonequilibrium universe" (Prigogine, 1996: 27), then we are able to estimate phase spaces through dynamical system states. For the purposes of this article, phase space refers to the modular coordinates of systemic structure that are necessary to describe more fully the system in its entirety or over time. Where  $q_0$  is associated with positions and  $p_0$  represents momentum, we have a basic understanding of coordinates within phase space following deterministic chaos (Figure 3).



**Figure 3** Trajectory In Phase Space  
(Adapted from Prigogine, 1996)

However, if we consider population dynamics in less deterministic human settings, as has been performed by Gibbs, an ensemble of coordinates is repre-

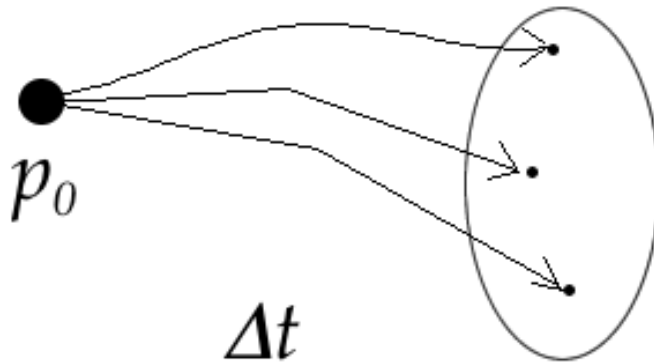
sented as a cloud within this phase space where  $t=$ time is now introduced into the equation. "The probability of finding a time  $t$ , a point in the small region of phase space around the point  $q,p$ . A trajectory corresponds to a special case in which  $p$  is vanishing everywhere except at the point  $q_0,p_0$ " (Figures 4 and 5) (Gibbs, 1902; Prigogine, 1996: 33).



**Figure 4** *Ensembles In Phase Space*  
(Adapted from Prigogine, 1996)

Both a micro and a macroscopic level of description at the individual and the ensemble levels emerges in this phase space. It is also important to note that we now have a geometric description of this phase state that might be inferred to be fractal in nature with scale independence between levels. But when this construct is applied to far-from-equilibrium systems, as is the case in population dynamics, the "trajectories now become idealizations. We can no longer prepare a single trajectory, as this would imply infinite precision" (Figure 5) (Prigogine, 1996: 37).

In studies of time in workgroups in the social and behavioral sciences, Bluedorn and Jaussi (2007) have drawn attention to the construct of polychronicity. At the individual level, this implies preference toward working on multiple tasks at once. At the group level, however, a dimensional aspect is factored into the phenomenon. Those that cross organizational boundaries, as is the case with cross functional teams, typically work on more projects with more productivity over a time series. Moreover, in organizations where specialization at the individual level is avoided, and where the size of the organization is small enough to discourage formal departmental boundaries, polychronicity emerges at a higher level (Bluedorn & Jaussi, 2007). Furthermore, groups that exhibit polychronicity typically share "temporal schemas" that are characteristic of each independent group (p. 195). In effect, the construct of polychronicity exemplifies the class-



**Figure 5** Diffusive Motion Over Time  
(Adapted from Prigogine, 1996)

room setting and adds credibility to the dimensional aspects of individuals interacting in groups over time.

Equally, the concept of temporal depth is affected by dimensional aspects of polychronicity in group dynamics. Drawing parallels to Prigogine's (1996) argument for both micro and macroscopic levels of description, "as with other temporal variables, past and future temporal depths have been found to be significantly correlated at both the individual and organizational levels of analysis" (Bluedorn & Jaussi, 2007: 206). In a systems dynamics framework, Broberg *et al.* (2007) expands on this type of phenomenon by integrating multiple dimensions of observation with temporality, described as a *timescape*.

Reflecting current and ancient debates in physics about the role of time, Prigogine (1996) argues that it is this lack of ability to perform infinite precision that prevents Laplace's demon from ever being realized. In effect, utilizing the construct of the arrow of time breaks the entire concept of time-symmetry which is integral to reversible processes. The past and the future, subsequently, take on new philosophical forms, and these new forms "require an extended functional space... which uses generalized functions or fractals" (Prigogine, 1996: 38). In Prigogine's view, therefore, human interactions require resonances in phase transitions which are by definition emergent. "At the level of populations, the symmetry between past and future is broken, and science can recognize the flow of time" (Figure 5) (Prigogine, 1996: 45).

## The Arrow Of Time And Irreversibility In Critical Reflection

*Everywhere around us we see the emergence of structures that bear witness to the "creativity of nature," to use Whitehead's term. I have always felt that this creativity had to be connected in some way to the distance from equilibrium, and was thus the result of irreversible processes (Prigogine, 1996: 67).*

Now that the framework for understanding time has been developed in this paper, we can move toward critical reflection and its metaphorical significance as a phenomenon encapsulated within a snapshot of the arrow of time. Several researchers have focused on the roles of critical reflection and reflective learning in group processes from a complex systems framework (Aram & Noble, 1999; Smith & Comber, 1994; Stacey, 2003). Brookfield (1995) has investigated the symbiotic relationship between student reflections on learning and teacher reflections on practice in a critical framework. Doll (1993) has argued for reflective learning as a distinguishing characteristic of the complex classroom. And Fleener (2002) has shown how the use of generative metaphors and curriculum dynamics influence much deeper explorations of classroom content and personal reflection on learning.

Although semantics might certainly come into play in the use of the term *critical reflection*, Doll (1993) defines this theoretical construct as:

*The vehicle by which transformation occurs... Reflection is taking experience and looking at it critically, variously, publicly: that is, connecting our experiences with others' experiences, building a network of experiences wherein past, present, and future are interrelated. Reflection steps back and examines past experiences in the light of other connections and alternatives. It is a reconstruction of actions taken; it is a re-look at meanings made (Doll, 1993: 138, 141).*

In Doll's description, we find similarity to Prigogine's concept of the arrow of time. Once this concept is introduced, past and future are no longer irrelevant, as in reversible systems, but rather now the past and future play key roles in our reflection on learning. In a similar vein, *critical reflection* as a theoretical construct extends the etymology of critical thinking, entailing a journey which simultaneously challenges and expands upon our previous thinking. At the same time this implies that, when critical reflection takes place in the learning process, it is difficult to go back to the epistemological framework from which we started.

Metaphorically, we can see a close connection between critical reflection and phenomena that emerge in the physical sciences. As Prigogine has noted:

*Nature involves both time-reversible and time-irreversible processes, but it is fair to say that irreversible processes are the rule and reversible processes are the exception (Prigogine, 1996: 18).*

In describing the Second Law of Thermodynamics, Prigogine and Stengers (1984) introduced the arrow of time, where irreversibility and chaos present us with a juxtaposition of previous scientific thought. In biology, higher-level species emerge from lower-level organisms, and, in the physical sciences, the generation of entropy leads the universe from simple to complex forms during infinite, iterative processes. Subsequently, this creation of further complexity generates irreversible conditions, suggests that the arrow of time does exist, that the universe is not reversible, and that "it is only when the classical point of view is lost... that we can speak of 'intrinsic randomness' and 'intrinsic irreversibility'" (p. 289).

In similar fashion, the incorporation of this perspective of time implies that system processes lead to further entropy production in one direction,

*Which is by definition the future... Why is the arrow of time always pointed in the same direction? This can only mean that our universe forms a whole. It has a common origin that already implied time-symmetry breaking*  
(Prigogine, 1996: 102, 162).

Likewise, when exploring critical reflection in the classroom, these concepts of the arrow of time and irreversibility call into question discrete or reductionist analyses of observations and interactions between learners and teachers over time. Therefore, my purposes in the analysis of this research are to present an epistemological framework for the metaphorical connection between critical reflection and irreversibility by providing examples of brief student narratives of critical reflection on classroom curriculum and learning.

## Method

**B**ased on research performed for a previous study (Gilstrap & Dupree, 2009a, 2009b), I found myself returning recursively to the concept of critical reflection as an irreversible process. In this article, I use a complexity-based interpretive mode of inquiry and design, relying primarily on the works of Prigogine (1996) in relation to contemporary complexivists in the social and behavioral sciences. Over the course of a year, students were given Brookfield's (1995) Critical Incident Questionnaire (CIQ) to complete at the end of each of four consecutive information and computer literacy classes. Focusing on a particular curriculum section, the classroom learning environment integrated Doll's (1993) 4 Rs of emergent curriculum: rigor, richness, recursion, and relations. Rigor served as an integral component of the curriculum through the use of the questionnaires and classroom discussions, where students were "purposely looking for different alternatives, relations, connections... indeterminacy with interpretation" (p. 182, 183). Richness and relations were encouraged in the classroom through the integration of group activities that fostered additional questioning rather than pigeonholing group discovery into predetermined answers. The discussions that emerged during each class, in combination with the

responses on the questionnaires, were then interpreted to help generate new, unfolding, and unanticipated curriculum design during the next class. And a recursive dialogue which drew from the previous day's content and discussions were included at the beginning of each successive class in order to build upon the previous class while creating curriculum beyond the day's basic lesson plan. This provided a metaphorical framework of a chaotic system folding in on itself with further emergence taking place at each iteration.

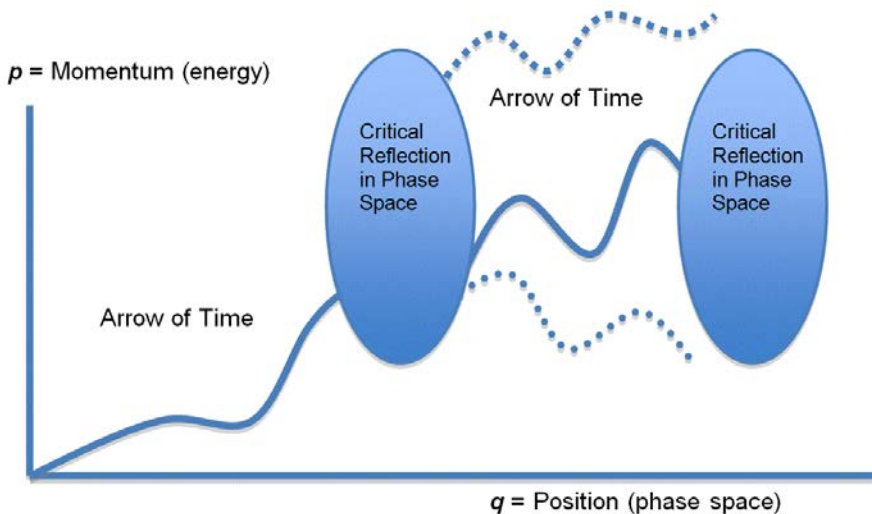
The data from individual responses were aggregated for the original sample in order to analyze and report the findings (Gilstrap & Dupree, 2009b, 2009b). However, as is the case with many large data sets, there are numerous possibilities for analysis and reporting of different findings in qualitative research (Denzin & Lincoln, 1994; Stake, 1995). I found myself returning to the original narratives generated by students to look at individual responses *over time*. In effect, this paper is an interpretive study which uses the collected data in ways very different from previously reported findings. Rather than focusing on the original sample from the population, *purposive sampling* has been used as a means to convey the rich descriptions of particular participants, and, moreover, to illustrate and problematize the concept of the arrow of time in complex studies of social and behavioral sciences research.

It should be noted that the purpose of this interpretive study is not to test hypotheses or provide generalizations about the processes that are experienced by all students during critical reflection. Rather, these narratives serve as examples of the critical reflection process over time and help to illustrate critical reflection as an irreversible process. It is assumed that, as in the natural world, any typical curriculum setting would contain both reversible and irreversible processes. Although several different arguments could be made, for the purposes of illustration, let us assume that those students who do not express critical reflection at high levels in their responses could be described as those susceptible to learning as a reversible process. After the learning process occurs, it is quite possible that their knowledge base or understanding of the world returns, regresses, or remains in a near-equilibrium setting. This would highlight the reversibility found in classical mechanical systems, and, subsequently, would suggest that time is indeed reversible. However, if we entertain the proposition that irreversibility exists in complex human systems—and that what distinguishes the phenomenon of critical reflection is the far-from-equilibrium and irreversible outcomes of the learning process—then this would suggest that the arrow of time might also accompany critical reflection in epistemological aspects of our curricula.

# Interpretation And Discussion

## Critical Reflection As An Irreversible Process

Using Prigogine's (1996) conceptual framework of the arrow of time, this researcher was able to generate interpretative analyses for students' narrative responses as emergent pictures of their own critical reflection. These generative metaphors highlight individual students' critical reflection along this arrow of time and range from subtle fluctuations that influence chaotic systems over time to perturbations that lead to both positive and negative bifurcations in critically reflective experiences (Figure 6). As one example, when responding to a question about understanding, one student's reflection on learning moved from an apparent lack of engagement in the classroom to being an active and critical participant when role-play was introduced, juxtaposing the roles of teacher and learner. She noted that the ability to ask questions about learning to the instructor—while framing questions as a teacher would do with her students—really challenged her to think more critically about what she was learning. For complexivists, this relates uniquely to Fleener's (2002) argument for the use of role play in emergent curriculum processes. And for this student, the introduction of role reversal served as a metaphorical bifurcation during learning, as she was thrust out of her near-equilibrium comfort zone of disengagement toward the far-from-equilibrium suddenness of taking on the role of the instructor.



**Figure 6** *Critical Reflection As An Irreversible Process Emerging Through The Arrow Of Time*

Other students became increasingly engaged in the critical reflection process over time. Several students noted the importance of recursive discussion at the beginning of each subsequent class as a way to build upon previous understanding, as well as developing emerging curricula. This supports Doll's (1993)

use of recursion in curriculum development, as each recursive review helped to guide the curriculum of the class beyond the basic lesson plan and toward group development and creation of learning processes in a critically reflective manner. This also highlights the systems dynamics of the learning organization (Senge, 1994) and the complex interactions of individuals acting collaboratively in groups (Stacey, 2003). As an example, one student noted his confusion after the first class period. Yet after recursive review during the second class, this student began to express further understanding of concepts that were previously confusing and how they fit with new knowledge. By the third class period, the student had integrated prior learning through recursive review and began to point out critical aspects of the research process. By the fourth class period, this same student had commented at a detailed level about the differences in research strategies, information resources, search structures, and the impact this had on his ability to continue to perform effective research after he graduated.

And when responding about their most rewarding experiences, many students appeared to be reflecting more critically on classroom content through the use of generative metaphors and graphical illustrations of difficult concepts, highlighting the disparate roles of metaphors discussed by Fleener (2002). Several students reflected on how their newly changed views of the classroom content would lead to life-long learning or social impact. One student in particular noted a transformational experience about not letting the fear of failure prevent her from seeking new knowledge in the future. In the case of this student, a metaphorical bifurcation took place that most likely caused the trajectory of the arrow of time in her critical reflection process to shift.

Here we find many similarities between the events that took place during curricula designed to be webs of complexity and the science of chaos and complexity theories. By focusing on the narratives of students, we catch a glimpse of the critical reflection process taking place. In the same way Prigogine (1996) suggests probability analyses in phase spaces in order to recognize the arrow of time, we are also able to make inferences about what relative points during the curriculum these processes took place and how they contributed to additional critical reflection. And, by the end of the study, it became clear that particular students had changed their foundational knowledge, how they learn how to learn, and their philosophical outlook toward the research process. Although possible, it is difficult to accept that these students would revert to their initial states of development prior to the study. It is also safe to say that we could never know the multi-dimensional layers of variables that contributed to critical reflection, to pinpoint exactly when and how these variables influenced the critical reflection process, and to determine with certainty when exactly the critical reflection process began and ended. This moves us closer to accepting, if only in an ontological framework, that the process of critical reflection must be irreversible, and this irreversibility distinguishes reflective learning from rote learning. In other words, it is impossible to reverse the process of critical reflection.

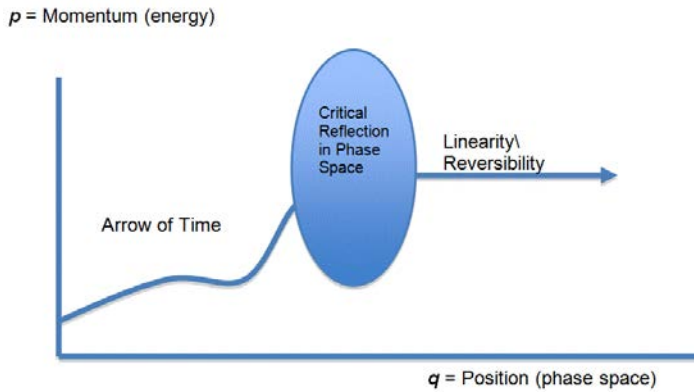


tion, as each of these factors would prevent us from reducing the process to its component parts.

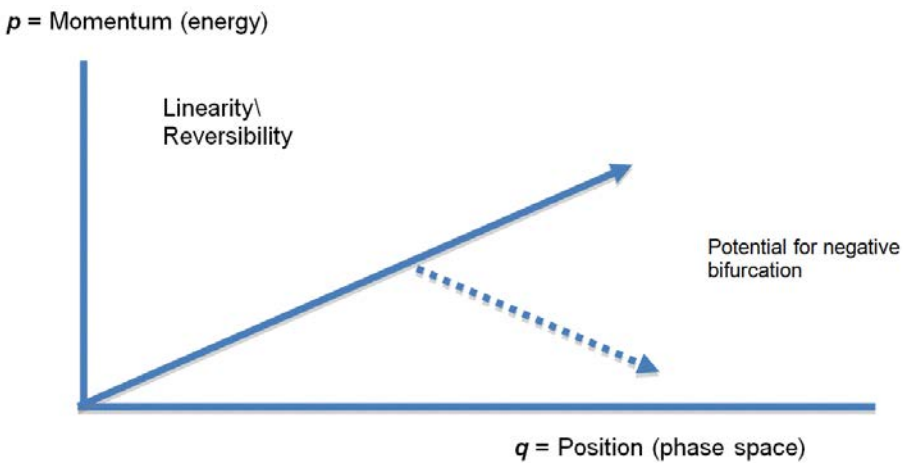
Conversely, other students reflected critically that a different arrow of time might be emerging. For these students, their classroom experiences generated negative feelings that continued to increase. As an example, one student responded over the course of four classes in a manner that reflected her disdain toward this type of curriculum approach. Albeit these types of responses are perhaps less enthusiastically received by teachers, they might reflect the criticality of entropy production in curriculum studies. On one hand, this response might be interpreted as a student who prefers the stability of linear and near-equilibrium pedagogy, and being "subjected" to a dynamic curriculum web led her to a closed-system perspective of critical reflection. On the other hand, Segal (1999) has noted that sometimes critical reflection occurs as a consequence of classroom dynamics perceived in a negative way. Both possible situations might highlight chaotic perturbations that manifest the negative consequences of classroom bifurcations or a return to near-equilibrium learning.

### **From Irreversible To Reversible**

Given the multi-dimensional possibilities following the arrow of time, it is proposed that critical reflection can move from an irreversible process to a reversible, near-equilibrium framework for curriculum theory. When we speak of irreversible processes in thermodynamic systems, it is quite reasonable to expect that if perturbations are not at a level of chaotic instability that initiate bifurcation, then the system can move back toward stability (Prigogine & Stengers, 1984). Likewise, one student's narratives seemed to infer that there was plateauing that had taken place in the critical reflection process (Figure 7). During the first class, the student seemed confused and overwhelmed by the content and amount of information that was being discussed. By the second and third classes, the same student noted how the recursive learning drawn from the previous classes was really helping him to understand the curriculum much better, identifying a sense of accomplishment and critical awareness of the research process. But by the fourth and fifth classes, the student commented that everything was clear now and he was no longer confused. Albeit, we might all like students to exhibit these types of confidence statements in assessments they make of our teaching, this also infers that the student from the beginning was more critical in nature about the class because of disorientation (Woods, 1993; Mezirow, 1991) or, rather, chaotic turbulence. After confusion subsided, it appeared that the critical reflection process did so also, since the student seemed to switch toward a rote learning process in the absence of chaotic activity.



**Figure 7** *From the Arrow of Time to Reversibility*



**Figure 8** *Reversibility In Classroom Dynamics*

### Reversibility In Classroom Learning

Reversibility in classroom learning was also observed. To many of us who teach, it is always nice to hear that our curriculum content is understood and that students think highly of our teaching methods. But we might also infer that, in some situations, these types of comments exemplify reversibility in teaching and learning processes. As an example, one student commented during the first class, how the content was understandable due to the instructor continuing to follow up on confusing subjects. By the last class, the student's comments included, "everything was presented very well," and "all the material was understandable." These are compliments indeed, but did critical reflection actually take place? We can never assume to know the answer to this question from this student's responses, but we might use this assessment as an illustration of reversibility in classroom settings (Figure 8). Literally from the first class, the student had a prescribed and linear understanding of what the curriculum would entail and had a good self-knowledge of when his own learning had reached the

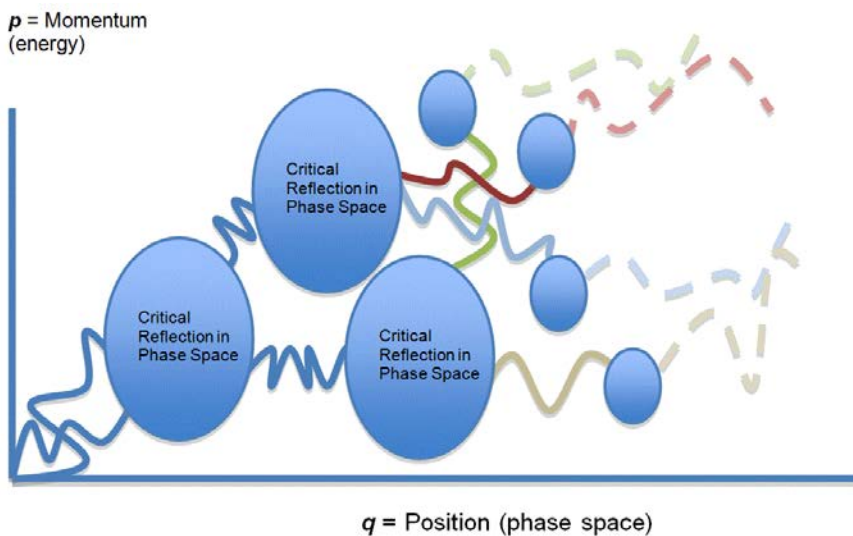
curriculum objectives. From the eyes of a student one might say, “the teacher teaches, I learn what I am supposed to learn, and if both the teaching and learning processes accomplish basic objectives, we have both succeeded.” In other words, the student has started at point A, accomplished that point, and then moves to point B and C with successive understanding.

## Implications and Conclusion

*What goes wrong with the usual reading of Epicurus, I believe, is that it construes him in the mold of later forms of empiricist theory, like them in conceiving the “data” of sense in the shallow terms dictated by assumptions about the receptive capacities (very limited) of our external sense-organs... Very much in Epicurus’s spirit, I believe, are some of Maurice Mandelbaum’s observations opposing an oversimplified “empiricism” by insisting upon “object character” or “reality character” as a phenomenological feature of perception” (Lee, 1978: 48).*

In this interpretive study of critical reflection in complexity theory, several key constructs have been proposed and discussed. Epicurean philosophy highlights the metaphorical significance of scientific thinking and our need as complexity researchers to return iteratively and continually to the dialogues of previous philosophers. Their works are rarely closed to interpretation, and each day we discover connections that manifest the self-referencing inherent in contemporary chaos and complexity research. Prigogine (1996) has performed this recursive investigation and has concluded that the arrow of time does indeed exist in irreversible processes. In similar fashion, studies utilizing complexity theories have shown the importance of critical reflection as a phenomenon that emerges when learning bifurcates to higher levels of individual and group development (Aram & Noble, 1999; Smith & Comer, 1994). Qualitative methods are used to collect and report data that highlight this phenomenon in the classroom setting. And propositions have been developed that show how critical reflection as a theoretical construct is an irreversible process and therefore subscribes to the arrow of time. Illustrative models are then presented to explore how learning over time at the individual level reflects irreversible, reversible, and a combination of these phenomena in the classroom. What is more, we have reached a point where the theoretical construct of time in group processes can no longer be ignored. As Reeves-Ellington (2007) has argued, “let us theory build rather than theorize... Theory building begins with a preliminary description based on observation (phenomena), progresses through classification (frameworks and typologies of phenomena), and ends by defining relationships (models that are statements of association)” (pp. 339, 341). In several ways, this article has intended to approach the theory building describing the emergence of critical reflection in learning settings, differentiating how critical reflection takes place over time, and developing parallels between critical reflection and irreversible processes.

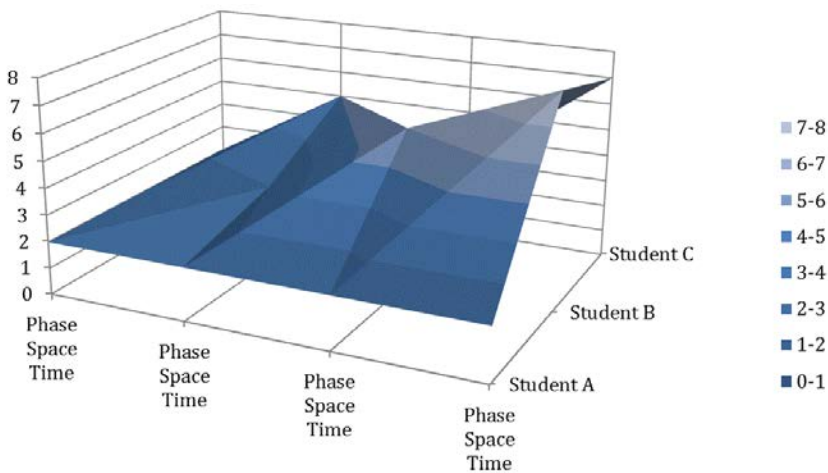
Borrowing from Epicurus, metaphorical description based on experience is critical to the advancement of scientific thinking (Lee, 1978). The potential for future discussions on critical reflection and the arrow of time are promising. They also open our dialogues to even more complex frameworks for understanding the learning process. In system dynamics studies of time in organizations, Broberg, Baily, and Hunt (2007) present a Multi-Level Timescape model where organizational hierarchies “introduce assumptions of nonlinearity into the model... that regulate the rate at which individuals flow in and out of specific timescapes” (p. 324). Expanding this concept, given that the arrow of time is a non-linear representation of phase spaces, multiple arrows of time within individual learning are most certainly a paradoxical aspect of our current thinking about our curricula and organizational development, as they suggest that the arrow of time is multi-dimensional (Figure 9). This is not to be confused with the multi-dimensionality of regressands that interact with each other and contribute to a process in the post-positivist sense; that would still imply linearity in thinking and observation. Rather, this framework for thinking incorporates an additional quantum dimensional layer of time in a complex web of organizational learning.



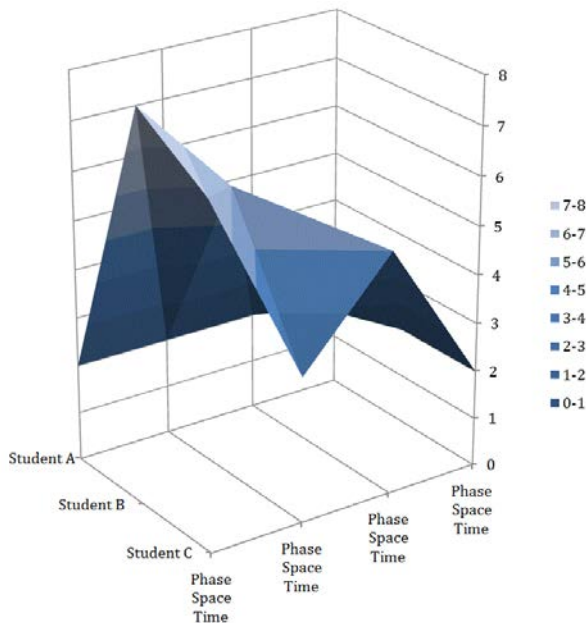
**Figure 9** *Critical Reflection As Multidimensional Through The Arrow Of Time*

This multi-dimensionality implies ever-expanding levels of phase spaces in describing individual development with the potential for several arrows of time to emerge at each critically reflective system state. At the same time, we see how the dynamics of group interaction contribute to critical reflection in even more multi-dimensional ways. As Medvec (2004) has contended, “groups will arrive at superior decisions when they seek information that disconfirms their initial opinions during the decision-making process” (p. 217). This suggests an abrupt shift *away* from linear decision-making models and movement towards critically reflective phase spaces. And when this takes place among several individuals

acting as collaborative agents, do the group dynamics involved in the critical reflection process contribute to an ever-expanding fabric of phase spaces during learning processes that manifests the presence of the arrow of time? (Figures 10 and 11). Zellmer-Bruhn *et al.* (2004) have argued that temporal entrainment “occurs when endogenous routines within teams become synchronized with external pacers” (p. 137). How then do the boundary conditions and external objectives that influence the development of our curricula expand upon the multidimensionality of time based phase spaces? These propositions challenge us to think in increasingly complex ways about the how we conceive of organizational learning and how we subsequently develop our curricula in the future.



**Figure 10** *Multidimensional Fabric Of Time I*



**Figure 11** *Multidimensional Fabric Of Time II*

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**Donald L. Gilstrap** is an Associate Professor and Associate Dean of Libraries at the University of Oklahoma, Norman, OK, USA. His research and scholarship includes complexity theory in leadership and management, research methods, and nonlinear dynamics and learning during organizational change. He can be reached at [gilstrap@ou.edu](mailto:gilstrap@ou.edu).



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