Chaos, Complexity, and Metapatterns in Discourse and Learning: A Perspective on Developing Complex Understandings

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The purpose of this paper is to explore how chaos, complexity, and metapattern theories inform our understandings of student cognition and student-to-student discourse. Using this theoretical framework as a foundation, a model for how students develop complex understandings will be developed. In the first part of this paper, the theoretical background in chaos and complexity theories and the related conceptual framework of metapatterns will be explored in considerable depth. Following this section, specific applications of these frameworks will be examined in terms of a student-controlled argument about density as an example of a chaotic and complex system. The next section will explore how chaos, complexity, and metapatterns can be used to model children's thinking by examining context maps and other student generated artifacts. In the last section, a model of curriculum that can support learning as a chaotic and complex system and other implications for learning and instruction will be discussed.

Theoretical Background

In looking for new paradigms to explain the kinds of phenomena apparent in studies of discourse and cognition, chaos and complexity theories and metapatterns offer viable alternatives. Metapatterns originated from the work of Gregory Bateson (1979, 1991). The "pattern which connects" and metapatterns served as the central notions for his quest of an ultimate unifying theory of everything. From his early work as a co-originator of cybernetics and open systems theory (Bateson, 1971, 1991), Bateson focused on trying to identify the patterns of patterns that help to broaden our understandings of the biological, physical, and social/mental worlds. He especially was concerned with mental processes, which he contended were at the core of all biological phenomena, including evolutionary patterns. Within this framework, Bateson identified several key components of what was later to be incorporated as fundamental principles of chaos and complexity theories. Such principles include:

a. stochastic processes, which involve random components with selective processes (random or chaotic systems with attractors)
b. cybernetic feedback loops or circular or more complex processes
c. context and ecological perspective on mind (recall his extensive sense of mental processes) (points to the notion of a web of relationships in chaotic and complex systems);
d. schismogenesis or divergent processes;
e. interaction (between parts of the mind) are set into motion by difference (equivalent to "far from equilibrium" in complexity theory;
f. stability as a continual process of change (similar to the notions of autopoiesis or self-maintaining systems).

Each of these principles is imbedded in current theories of chaos and complexity (Capra, 1996). At the same time, Bateson's notion of metapatterns has been extended in the work of his daughter, Mary Catherine Bateson (1994) and of Tyler Volk (1995). Metapatterns provide a descriptive approach to understanding phenomena. In contrast, chaos and complexity theories have a mathematical basis of description, even though most recent work in education and the social sciences adopt a metaphoric descriptive approach to using these theories.

In the following paragraphs, I will highlight the key principles of chaos and complexity theories as they apply to our social and psychological systems, and, at the same time, draw comparisons to metapatterns as described by Bateson (1979) and Volk (1995). In general and without getting into many of the current arguments, discriminating between chaos theories and complexity theories is somewhat difficult, since they appear to merge at several levels. However, for the sake of simplicity (no pun intended), chaos theories tend to be concerned with unpredictability and embedded or emergent patterns in seemingly chaotic or random phenomena. On the other hand, complexity theories are concerned with the complex relations within systems (chaotic systems) and the notion of autopoiesis (i.e., self-generating, self-amplifying, self-maintaining systems. Both of these theoretical perspectives involve a strong sense of the dynamics in systems. By contrast, metapatterns or patterns of patterns may seem to take a more static view, although such patterns are components of, have equivalence in, and are the results of chaotic and complex systems. In order to clarify these comparisons, we will examine the key principles in more detail (see Table 2 for a general comparison).

Metapatterns

Bateson's (1979) and Volk's (1995) treatments of metapatterns (see Table 1 for a list of Volk's metapatterns, along with descriptions and examples) focus on the notion of patterns of patterns that span conceptual contexts, disciplines, and worldviews. Metapatterns share common meanings across such contexts, even though they may have very different meanings at superficial levels or within specific cultural or disciplinary contexts. For example, a sphere in a biological context is significant in that it (a) minimizes the materials needed for construction; (b) reduces the surface area to volume ratio; (c) provides omni-directional strength against external forces; (d) acts as a container; (e) increases durability; and (f) minimizes environmental contact. From an architectural perspective, a sphere shares the same characteristics as in the biological context. In religious and cultural symbolism, where spheres may represent halos or mandalas and so forth, the specific context-bound meanings may differ greatly. However, at the core of all senses of sphere, the meanings of equanimity, strength, and omni-directionality are shared.

Specific metapatterns also may contain or interact with other metapatterns. A sheet, such as our skin, is made of layers. A sheet may make up layers, as well, such as, each layer of the Earth and its atmosphere is a sheet making up holarchic layers. Interacting metapatterns may involve arrows and cycles making up spirals. Spheres as cognitive schemata may contain other spheres (specific propositions) and centers (exemplars) connected by tubes (relations). Such dynamic interrelationships of metapatterns provide intriguing ways of modeling social and psychological systems, as well as intra- and cross-disciplinary conceptions. These types of models will be developed later in this paper to help elucidate student thinking and discourse.

Table 1. ***Volk's (1995) metapatterns with descriptions and examples.***

Metapatterns	Description	Examples
Spheres (Sphericity)	Maximizes strength and durability; deflects forces; equanimity; minimizes environmental contact; omni-directionality; simplification; container; reduced surface area to volume ratio.	Planets, stars, spores, domes, fruit, balls, eyeballs, cells, biosphere, bubbles, "sphere of influence," "sphere of consciousness," circles, etc.
Sheets	Maximizes possibility of transfer across surface; distribution throughout planar area; contact (increases exposure to environment); capture (transfer and/or capture materials, energy, or information); extension or growth two dimensionally; increased surface area to volume ratio.	Leaves, membranes, windows, parking lots, clothing, floors, layers of the Earth and atmosphere, paper, playing fields.
Tubes	Support; linearity; growth and extension along one dimension; provides for transfer or flow of energy, matter, and information; penetration; movement; reduced surface area to volume ratio.	Hair, fir tree needles, cilia, bones, canine teeth, tree trunks, light poles, nerves, muscles, blood vessels, tunnels, conceptual relations, spider webs (tubes making a sheet).

(Table continued)

(Table 1 continued)

Metapatterns	Description	Examples
Borders and Pores	Protection; separation of inside and outside; regulation (of information, energy, and material exchange); containment; borders made of repeating patterns of parts.	Walls with doors and windows; cell membranes; leaf and stomata; shells; skin and pores (many small, few large like eyes, ears, nose, etc.); fuzzy borders (e.g., clouds).
Binaries	Pairings; Perception—Difference; separation; unity; relationship; tension; duality; simplest complexity; most economical way to generate complex wholes with significant new properties; synergy between parts and wholes.	Positive-negative; form-function; all or nothing; distal-proximal; acid-base; inhale-exhale; space-time; DNA (double helix); report talk-rapport talk; mass-volume.
Centers	Center stabilization (stabilizing the whole); resistance to change; attraction; organizing; longevity and stability; radiating relations; centricity; importance or significance.	Government; nucleus; attractor; vortex; family; queen (bee, ant, human); CPU; fulcrum; dominant male in mammalian groups; altar; center of gravity; teacher.
Layers	Building up of order; stabilizing; provide structure; **hierarchies** (=sacred rule): whole cannot be seen until relations of parts are identified; stratified stability; information (or materials) moves up, control moves down (a flow binary); **holarchies** (pattern of concentric circles): nested parts in wholes; wholes evident even if parts are not.	Trophic layers; layers of the Earth; pyramids; rose; corporations; mandalas; Earth's atmosphere; societies (some hierarchical and some holarchical); atoms; organism tissues; buildings; holarchic layers of complexity in organisms (from DNA/RNA components to the whole).
Time (Calendars)	Time as a binary of movement and memory; observed by connecting several spaces; arrow of time; cycle of time; counting; progression.	Chinese calendars; sundials; Roman calendar; Aboriginal dream time; clocks as circles.
Arrows	Time as arrow; flow; progression; links; time's arrows are the equivalent of tubes in space; directionality; connections in space; arrows between binaries – up and down, in and out; sequences.	Acceleration; pilgrimages; journeys; nerve transmission; osmosis; velocity; rivers; wind;
Breaks	Transformations; change; leaps; shifts; sequences of stages; dilemmas and decisions.	Punctuated equilibrium (evolution); waterfalls; revolutions; crashing waves; from star to supernova; from concentrating to daydreaming; birth; metamorphosis; marriage; shifts upon entering a new layer (holarchy or hierarchy); branches; insights; breakthroughs.

(Table continued)

(Table 2 continued)

Metapatterns	Description	Examples
Cycles	Repetition in space or time; circulation; cycles and arrows becoming spirals or helices.	Kreb's cycle; Earth's rotation and orbit; animal wings; biological rhythms; breathing; laps in a race; engines; water cycle; seasons, tides, bird songs; wheel of karma.

Chaos and Complexity Theories

Chaos and complexity theories, with their emphases on additional processes that lead to the emergence of order, contribute to an encompassing and complex view of a variety of systems. Capra (1996), in tying these theoretical perspectives together, classifies the criteria of systems under three broad headings: (a) **patterns of organization**, which involve the relationships that provide any particular system's characteristics and include autopoiesis; (b) **structure**, which is a system's physical presence (i.e., actual components) and includes dissipative structures; and (c) **process**, which continually generates the structures that manifest the patterns of organization and includes cognition (broadly defined as the process of life by Bateson [1979] and Maturana and Varela [1998]).

Autopoiesis is concerned with the patterns of self-generating, self-amplifying, and self-maintaining systems, which operate through networks of production processes. At points of instability and at points far from equilibrium, new forms of order are generated, which, in turn, lead to higher levels of organization (Maturana and Varela [1998] refer to such organization as circular) and increased diversity (Capra, 1996; Maturana & Varela, 1998). Although autopoiesis is concerned with biological and physical systems, some researchers are drawing links to social systems (Luhmann, as cited in Capra, 1996). Later in this paper, we will see how ongoing arguments tend to display the characteristics of self-maintaining systems, such as circular patterns of organization, over limited periods of time. From a metapatterns perspective, such self-organizing (autopoietic) systems can be represented by interacting cycles, arrows, breaks, binaries, centers, layers, and so forth.

Dissipative structures self-maintain an organized structure through self-amplifying feedback loops at points which are far from equilibrium. These structures develop around attractors, which are "points" around which activity occurs, such as the center of the vortex of a tornado. As such structures self-amplify, new attractors (i.e., bifurcation points) may arise. At these points, new structures may develop with an increase in complexity (Capra, 1996; Prigogine & Stengers, 1984). Essentially, such structures maintain patterns of organization, yet are unpredictable in terms of specifying precise future events or conditions. Just as a tornado maintains its overall pattern of organization (i.e., characteristic shape), it continually changes its specific shape and may even split into two or more funnels (the result of bifurcation points). A metapatterns representation of such structures may involve centers as attractors, breaks as bifurcation points, along with cycles and arrows representing self-amplifying feedback loops. However, a somewhat troublesome comparison involves centers and attractors. Attractors connote a sense of intense activity around a specific point or event, whereas centers seem to imply a more static point. In the present paper, this particular issue may be more problematic in modeling dynamic social systems. On the other hand, when we talk about cognition, attractors may fall short in describing particular ideas, which are significant to the individual, but may not stimulate a lot of activity. For instance, if we look at the notion of schema, an exemplar or sets of defining characteristics may be highly significant to an individual's thinking and learning, but may not stimulate any particular activity. In such cases, the notion of center, rather than attractor, is a more useful descriptor or model.

The processes of chaotic systems are production processes. As mentioned previously, these processes are considered to be cognitive in the broad sense of communicating information. In terms of classroom discourse, cognition as individual and communicative processes produces structures which represent emergent patterns of organization. For instance, as students begin discussing a particular topic (i.e., attractor) patterns of organization in the discussion emerge and produce a structure characteristic of the particular discussion. The more students disagree (i.e., the farther they are from equilibrium), the more the processes push the discussion towards higher levels of organization and complexity. Such cognitive processes can be modeled with the metapatterns of centers (exemplar, defining characteristic, specific idea or concept, etc.), cycles (looping processes of inferences, etc.), layers (holarchic or hierarchic classifications), spheres (schemata), arrows (progression), tubes (relations), and so forth.

Table 2. Comparison of Major Principles of Chaos and Complexity Theories and Metapatterns.

Chaos & Complexity Theories	**Metapatterns** (Bateson's and Volk's)
General Characteristics	
Unpredictability	Develops out of Breaks in Time, Cycles, etc.
Emergence	Arrows affecting cycles, etc. and emerging through layers and arrows of time.
Whole is greater than the sum of its parts	Sphere – Layers, Binaries, Centers, etc.
Small event may have a large effect	Break affecting Arrows -Cycles
Patterns of Organization	
Cybernetic feedback loops	Cycles
Spiral and more complex circular patterns	Cycles and Arrows
Autopoiesis (self-generating, self-organizing, self-amplifying, self-maintaining systems)	Cycles, Centers, Arrows, Breaks, Binaries, Layers, etc.
Relations:	Symmetrical (Bateson) - Competitive Binary (Volk)
	Complementary (Bateson) - Disparate Binary (Volk
	Reciprocal (Bateson) - Cooperative Binary (Volk)
Processes of Production	
Cognition:	Sphere with Centers, Tubes, Binaries (e.g., schema, consciousness, context)
	Tubes between Spheres and Centers (e.g., relations, concepts)
	Centers-Spheres-Borders-Pores (e.g., categorizing)
	Centers-Binaries (Trinaries, etc.)-Tubes-Arrows (e.g., inferences)
Structures	
Dissipative Structures	Layers (as systems of interacting parts) with Cycles, Tubes, Spheres, Time, Borders and Pores, Arrows, Breaks, Binaries, etc.
Non-Linear	Cycles, Spheres, Sheets, Cycles-Arrows (spirals)
Far From Equilibrium	Centers-Binaries-Arrows-Breaks
Self-Generating, Self-Maintaining, Self-Amplifying, etc. (Autopoietic)	Cycles, Centers, Time, Arrows, etc.
Attractors	Centers (centrality)
Bifurcation Points	Binaries-Centers-Breaks
Increase in Complexity	Spheres (entities), Tubes (relations), Layers (hierarchies and holarchies) with Arrows, etc.

Chaos, Complexity, and Metapatterns in Cognition and Discourse

Although cognition can proceed along linear and nonlinear pathways depending on the specific context, this particular paper will focus on thinking as a nonlinear or chaotic system. In general, much thinking occurs as back-and-forth and circular processes (Bateson, 1979; 1991). Such nonlinear thinking processes occur in response to (a) the action or talk of others (from the immediate or more distant past in a social, audio-visual, or textual context); (b) interaction with one's environment; or (c) self-generated thoughts. In all situations, variation plays a key role as both a source of cognition and a product of cognition (Bloom, 1998, April). In responding to action, talk, or events, variation plays an important role in the cognitive response. During everyday activities, we also generate seemingly random thoughts not associated with any particular goal. Such thoughts appear to fill in the gaps and are often referred to as our "mind wandering." In addition, variation is characteristic of the external stimuli themselves. When we react to variable stimuli (both internal and external), we draw on a wealth of potential cognitive resources. Such resources have been described as "contexts of meaning," which include (a) formal knowledge; (b) emotions-values-aesthetics; (c) interpretive frameworks (e.g., beliefs, models, phenomenological primitives [diSessa, 1993], etc.); (d) metaphors; (e) imagery; (f) personal experiences; (g) stories; (h) fantasy; and so forth (Bloom, 1990; 1992a; 1992b).

In addition to the basic characteristics of variation as a source and product of cognition (i.e., multiple perspectives or understandings) and of nonlinearity, Finke and Bettle (1996) have described a number of additional characteristics of chaotic cognition. These characteristics tend to be nonlinear and reactive and to focus on occurrences of the moment. As such, chaotic cognition lends itself to participation in impassioned and intense student-to-student discourse.

Although previous research has been informative in terms of helping develop specific understandings of classroom discourse (Bakhtin, 1986; Cazden, 1988; Gallas, 1995; Gee, 1994, April; Lemke, 1990), the nature of discourse from a holistic perspective is still somewhat elusive. In this paper, concepts from chaos and complexity theories, as well as metapatterns theory will be used to formulate a broader view of the dynamics of student discourse. In particular, the notion of feedback loops from cybernetics (Bateson, 1979; Capra, 1996; Weiner, 1948) contributes a framework for how discourse process interconnects across differing points of view and provides for emergent patterns of organization. In the case of student discourse and argument, the process tends to be self-initiating, self-reinforcing, and self-amplifying, where the continuation of the process tends to amplify the effect of the initial disagreement. Such amplifying effects arise out of what Bateson referred to as symmetrical relationships (from a metapatterns perspective this can be called a competitive binary[Volk, 2001, personal communication]), where the party on one side of a relationship competes with the party on the other side. This pattern of relationship (and self-amplifying process) can lead to an inescapable divergence. On the other hand, the prototypical classroom tends to operate as a linear and highly structured process, where the teacher strives to control the action and limit student-to-student discourse. In addition, the teacher and students tend to lock into complementary relationships (metapatterns: disparate binary) (Bateson, 1979), where the teacher is in control and the students are subservient. Although such relationships also tend to diverge, the divergence may be less explicitly observable or may lead to dysfunctional behaviors. Ideally, the healthiest relationships are those that are reciprocal (metapatterns: cooperative binary [Volk, 2001, personal communication]), where both parties engage on equal ground and in a negotiative process of give and take.

Chaotic and Complex Systems in Student-to-Student Discourse

The following discussion revolves around a specific case of a student argument about density (Bloom, in press). This particular study occurred in a small, multi-graded classroom of 10 students in grades 5 to 7. All of the conversations were audio and video taped, then transcribed. The argument itself began after an activity that involved predicting which of a variety of objects would float or sink. The one object which was predicted incorrectly by all students was a block of ebony. Shortly afterwards, one student suggested that the ebony "possibly could float if we put it in a larger body of water." The argument continued over five class sessions, and was primarily controlled and re-initiated on different days by the students.

In looking at the overall structure of argument from the perspective of chaos, complexity, and metapatterns theories, we see a coherent process that maintains its overall structure and increases in complexity as it proceeds. In Figure 1, the central focus of a specific classroom argument involves the initial event of a block of ebony sinking. This event acts as the attractor (metapatterns: center) around which the entire argument revolves. However, additional lines of the argument branch off as the argument proceeds. As the argument continues, one student's claims were countered by another's, which in terms of metapatterns, depicts a binary, or, more specifically, a competitive binary. These counter arguments are, in turn, met with responses, which often introduce new information to support the original claim. Such a dynamic is shown as cybernetic feedback loops. Such looping processes lead to an increase in complexity of the argument by initiating a branching off of additional conceptual lines of thought in response to counter arguments. These branches occur at bifurcation points (metapatterns: breaks), which are new (secondary) attractors or centers.

Looking at the argument in its entirety, the overall pattern is autopoietic or self-initiating, self-maintaining, and self-amplifying. Such a pattern includes the cyclical patterns (e.g., feedback loops) of discourse that feed information from one loop to the next in a spiral pattern. From a metapatterns perspective, such spiraling is described as cycles affected by perpendicular arrows of time. In fact, several spirals related to each bifurcation point thread their way through the temporal sequence of events, where one loop feeds into another loop further along the sequence, such as where "compression" is introduced and picked up again in a later feedback loop. In addition, the symmetrical pattern (Bateson, 1979; i.e., where both sides are vying for control or, in this case, vying for the correct explanation) of relationship among the participants provides a fundamental characteristic for stimulating a conflict (i.e., argument) from which divergent lines of thought emerge and grow in complexity.

The production process, which connects the pattern with the structure, is fundamentally the students' cognition. Their inferring, generating supportive and contradictory examples, dismissing others' claims, explaining, providing counter arguments, and so forth are the specific processes. These processes in turn manifest as the cyclical and spiraling cybernetic feedback loops or cycles and arrows.

In terms of the structure, two aspects or levels of structure are evident. The first level involves the actual components of the argument: the conceptual content. The structure and organization of the ideas generated change as the argument proceeds. In other words, the structure and organization is emergent. This notion of emergence is important in understanding the nature of chaotic systems. The specific conceptual outcome of such an argument cannot be predicted, because of the inherent variation in the ideas generated and in the production processes at work in the system. However, such variation provides for the possibility of the emergent development of increasingly complex conceptual understandings.

Figure 1. Student-to-student argument about density represented as a chaotic system with equivalent concepts from metapatterns.

At a more holistic level, the structure of the argument as a whole is quite similar to a dissipative structure. Such structures can be described as a complex association of various metapatterns, including tubes (relations), centers (attractors), cycles and arrows, binaries, breaks, and so forth. As discussed previously, dissipative structures operate far from equilibrium (competitive binaries) and are nonlinear. The oppositional nature of any argument is an indication of being far from equilibrium. By contrast, the existence of such binary states far from equilibrium in traditional classrooms are generally subverted and not allowed to manifest. In fact, the tendency is to suppress such states by overt control by the teacher. When course content is presented in ways that expect students to take in the material and respond on tests, the likelihood of stimulating an argument involving students is diminished.

At the same time, the argument, in this paper, does not follow a linear path. In fact, the model depicted in Figure 1 looks much like a tornado (a classic example of a dissipative structure). The production processes that generate the basic patterns serve to continually reinforce and perpetuate the overall structure of the argument. In other words, student cognition as expressed in the dialogue manifests as circular feedback loops and as spiral patterns that carry ideas and concepts forward. The result is a nonlinear, self-maintaining argument that generates increasingly complex conceptualizations.

Chaos, Complexity, and Metapatterns in Student Cognition

The focus of this section involves student representations of their ideas of floating through context maps (Bloom, 1995). Context maps are brainstorming activities, in which students are instructed to write down all of their ideas around the central idea ("floating" in this particular case), then to draw lines linking related ideas and to label these relational links. The way these maps are organized, such as with clusters, is entirely up to the students. What is of particular interest in maps with clusters are the links that extend between clusters. Such links or relations extend across varying degrees of what can be referred to as conceptual distance. In figures 2 and 3, Gina represents her ideas in clusters and has both intra- and inter-cluster links. However, her categorization of items within clusters is more cohesive in her post-unit floating context map. In addition, her post-unit map clusters tend to be more fully developed with details.

From the perspective of chaos, complexity, and metapatterns, the primary center or attractor is the focus topic (e.g., floating). Additional centers or attractors emerge from the children's thinking as they work on constructing the maps. In Gina's map (figures 2 and 3), she has less distinctive centers in her pre-unit map. For example, one cluster begins with "rafts (boats)" with links to "angels," "heaven," clouds," and "sky." However, in her post-unit map, the centers and related items are more cohesive (i.e., the items tend to be more conceptually consistent within the cluster categories). In a sense, we can see how the attractive power of centers can develop and help generate more conceptually consistent understandings. At the same time, the centers also help to develop richer understandings as more detailed and extensive items are included. The attractive and enriching powers of centers are more evident in the next figure. The top portion of figure 4 depicts both of the above concept maps in terms of metapatterns. The large sphere represents the context or initial center or attractor of floating. Contained within this sphere are smaller contextual spheres or centers representing the clusters or conceptual contexts.

The smallest spheres are the most specific conceptual centers. The tubes represent relations between the conceptual centers, with the larger tubes depicting the inter-cluster or contextual spheres relations or links. In the pre-unit sphere, “flying” has the most inter-cluster tubular connections, but has only one conceptual center (“bird”) contained within the cluster. However, in the post-unit sphere, the “horseback riding” contextual sphere or cluster has four conceptual centers and four inter-cluster relational tubes. Of particular significance in the horseback riding cluster is the level of conceptual specificity of the specific centers or intra-cluster items. These items include “cantering,” “ trotting,” “jumping,” and “dressage.” In contrast to any of the items contained in either context map, these terms show a more detailed understanding of the particular conceptual context. Based on the work of Eleanor Rosch, et al. (1976), a cognitive categorization perspective places such items at the subordinate level, which is indicative of greater expertise or knowledge. Other items included in these and other students’ context maps fall into basic (e.g., boats, rockets, planes) and superordinate (e.g., birds, planets, stars) level categories.

In order to explore further the notion of centricity or the attractive power of specific conceptual centers (i.e., the specific items included in context maps), two diagrammatic representations of centricity are included in figure 4, as well as in figures 5 and 6. In the middle of figure 4 (and the diagrams in figure 5), the circles represent the number of relational links connected to specific items or nodes (note: the initial link between items and the central topic of floating is not included). The line thickness represents the number of items, with the same number of relational link connections. Although the greatest number of links is the same (i.e., six) in both maps, there is a movement towards more items having a greater number of links in the post-unit context map (i.e., additional lines approaches the center and the thicker lines moving towards the center).

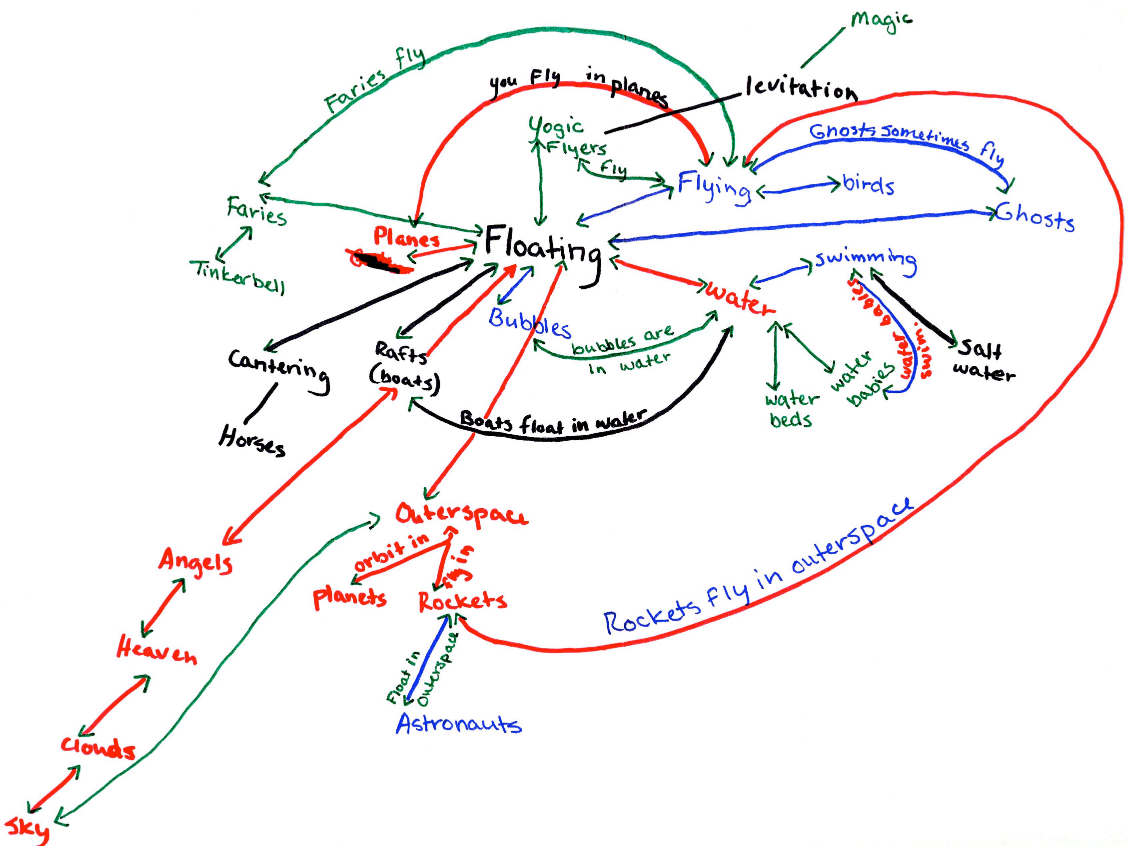

Figure 2. Gina's pre-unit floating context map.

Figure 3. Gina's post-unit floating context map.

The bottom set of diagrams in figure 4 (and in figure 6) takes a slightly different perspective of nodal centricity. The middle of each diagram depicts the highest number of links per node. Then, in order to capture a sense of centricity, the lower links per node appear on both sides of the middle (i.e., highest links per node). The vertical dimension represents the number of links per node (i.e., centricity); and the horizontal dimension represents the number of nodes with the same number of links per node. The post-unit diagram shows a distinct move towards centricity and breadth.

Table 3. Pre- and post-unit floating context map data: number of links per node (or item). (NOTE: The first letter of student names corresponds to the numerical equivalent for grade level [i.e., E = grade 5, F = grade 6, G = grade 7].)

Name		**Number of Nodes**	**Numbers in Table Refer to Number of Occurrences**									
			Number of links per node									
			0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Eric	**Pre-**	4	1	2	1							
	Post-	17	1	10	2	1	1	1				1
Frank	**Pre-**	8		3	4	1						
	Post-	15	7	6	2							
Fred	**Pre-**	8		6	2							
	Post-	10		8	2							
Gail	**Pre-**	19	3	9	7							
	Post-	26	1			8	5	11	1			
George	**Pre-**	15	1	7	3		3		1			
	Post-	23	2	7	14							
Gina	**Pre-**	26		12	10	2		1	1			
	Post-	34		7	9	11	2	3	2			
Gloria	**Pre-**	21	13	2	4	1	1					
	Post-	24		9	11	3	1					
Grace	**Pre-**	17		11	5	1						
	Post-	35		30			5					
Graham	**Pre-**	10		6	4							
	Post-	14	1	7	4		2					
Greg	**Pre-**	9	1	4	4							
	Post-	31		12	15	4						

Pre-Unit **Post-Unit**

Figure 4. TOP: Metapattern representations of Gina's pre- and post-unit floating context maps. [NOTE: Embedded spheres and tubes of relations.] **MIDDLE**: Diagrams representing nodal centricity (i.e., how many links at each node) on the pre- and post-unit maps. [NOTE: Line thickness corresponds to the number of nodes.] **BOTTOM**: Another representation of centricity on the pre- and post-unit context maps. Here the vertical dimension represents the number of links per node (range = 1 to 6) and the horizontal dimension the number of nodes (range = 1 to 12). With the exception of the central vertical bar, the right and left sides are mirrored in order to capture the sense of centrality and breadth.

Figure 5. Centricity diagrams of students' pre- and post-unit floating context maps. [NOTE: Each circle corresponds to the number of links per node (12 links per node is at the center point and 0 links per node is at the periphery of each diagram). Line thickness indicates number of nodes (instances).]

Figure 6. Comparison of pre-unit and post-unit bar graph representations of centricity in floating context maps. [NOTE: Vertical dimension represents number of links per node; horizontal dimension represents number of instances; range of links per node is 0 to 6 across all subjects; range of instances is 1 to 33.]

The use of chaos, complexity, and metapatterns as a model of cognition provides a perspective that emphasizes the significance (centricity) of particular ideas based on the relations (tubular links) evident in the student context maps. Over time (arrows of time), the breadth and centricity in the context maps tended to increase (as evident in the pre- and post-unit maps). In all but case, the breadth (spread of linked relations) increased. From the data in table 3 and figures 5 and 6, we see that in six out of the 10 students, centricity clearly increased. However, in one of the four cases (i.e., George) where there was a decrease in centricity, there was an increase in the number of nodes with a greater number of links. In this case, George's pre-unit map had four nodes with four or six links per node. In the post-unit map, he had 14 nodes with 2 links (an increase from 3 nodes with 2 links). In this case, the breadth increased with a more even distribution of links among the items. The most dramatic increase in centricity and breadth occurred from the pre- to the post-unit context maps of Eric. With only 4 nodes or items and one nodes with two links in his pre-unit map, Eric included 17 items in his post-unit map. These nodes included one with nine links, one each with three, four, and five links. In both maps, "water" occupied the most central position. (See the Appendix for a complete list of floating context map items for each student.)

Although context maps are not intended to show specific conceptual understandings or development, they do show the centrality and breadth of meaningful conceptual contexts. In addition, context maps help to show the relationships students see between various aspects of their maps. Such relationships can include those between similar items and those between diverse items. In those maps with clusters (e.g., the context maps in figures 2 and 3), the relational links within a cluster are fairly straight forward, whereas those between clusters are at a higher conceptual level. Such meaningful conceptual contexts describe the notion of centricity, where particular nodes or ideas are linked to other nodes. Breadth involves the number of nodes or ideas depicted in the context maps. In table 4, student context maps on "machines" show a range from breadth only, where numerous ideas are included, but with no linking relations, to context maps with high centricity. As we have seen in the context maps from the floating unit, there is a strong suggestion that such meaningful conceptual contexts increased in breadth and centrality during the instructional unit.

Table 4. A sample of post-unit context map data from a study of instruction on machines.

Topic	Grade	# of Nodes	Numbers in Table Refer to Number of Occurrences						
			Number of links per node						
			0	1	2	3	4	5	6
Machines	4	7	7						
	4	20	20						
	4	25	25						
	4	29	29						
	4	34	34						
	4	35	35						
	4	13	9	4					
	4	12	6	6					
	4	17	10	7					
	4	14	2	9					
	4	19	1	12					
	4	5	2	2	1				
	4	14	3	10	1				
	4	16	3	12	1				
	4	40	31	7	2				
	4	10	2	6	2				
	4	16	8	6	2				
	4	14		12	2				
	4	17		14	2				
	4	30	25	2	3				
	4	24	9	12	3				
	4	22	5	14	3				
	4	20	8	8	4				
	4	22		18	4				
	4	18	1	12	5				
	4	23		18	5				
	4	17	1	10	6				
	4	19		12	7				
	4	25	1	16	8				
	4	9	3	4	2				
	4	14		12	2				
	4	13	4	7	2				
	4	14	1	10	2	1			
	4	18		15	2	1			
	4	12	2	5	4	1			
	4	19	4	9	5	1			
	4	9	1	1	6	1			
	4	22	1	10	10	1			
	4	25	16	5	1	3			
	4	24	11	5	6	1		1	
	4	6		1	2	2		1	
	4	21	3	10	7				1
	4	29	8	10	8		2		1

In addition to breaks (bifurcation points), tubes (of relations), breadth, and centricity, which have been discussed previously, other aspects of metapatterns and chaos and complexity theories evident in student thinking include cycles (or feedback loops), layers, arrows, and binaries. Table 5 provides a summary of these aspects with examples of each. Although some of these aspects have been described in terms of student argument, they also apply to children's thinking as expressed in context maps. For instance, cycles or feedback loops are quite apparent in arguments, when students make assertions and counter-assertions. However, such cycles and loops are evident in context maps, when students construct relational links between two or more nodes. Gina's post-unit floating context map contains a number of such looping links, such as when she links "horseback riding" to "cantering" then to "trotting" and "jumping" and back to "horseback riding." Such looping relations demonstrate a high level of integrated understandings of the specific material.

Table 5. Examples of metapatterns and aspects of chaos and complexity in the argument and context maps.

Metapatterns and Chaos-Complexity	Examples
Spheres	Topic: Floating or Machines Sub-topics or clusters: water, horseback riding
Center/Attractor	Argument focus: ebony sinking Topic: Floating Item: horses
Tubes	Theme in argument: pressure. Relations: fish [node] "are consumed by" birds [node]
Cycles/Feedback Loop	Argument: assertions and counter-assertions Looping relations: horseback riding to cantering to trotting and jumping to horseback riding
Layers	Of complexity in argument as new conceptual or thematic material became the focus of discussion. Of nodal centricity in context maps (from no centricity with no links per node to high centricity with four or more links per node).
Arrows	Change and development over time in the development of themes in the argument
Binaries	Two sides of the argument. "Float" and "sink." "Washer" and "dryer."
Breaks/Bifurcation Points	Divergence and emergence of new themes during the argument.

Layers are evident as increases in conceptual complexity. During the argument about density, new conceptual material was introduced, around which new discussions took place. Each of these new discussions occurred within a new level or layer of complexity. In the context maps, the notion of nodal centricity (i.e., increased numbers of links per node) involves layers of increasing complexity, as suggested by the diagrams in figure 5.

Arrows of time are apparent in the five-day argument of density. Such arrows affected the cycles of argument to the point where they became thematic spirals throughout the entire argument. In the context maps, several students used arrows to indicate relational links. In such cases the tubes of relations took on directionality with the addition of arrows. In these two cases, arrows act as movement through time and as directionality of relationships.

Binaries occur in arguments with two oppositional sides or perspectives. As in the argument about density, the binary was situated between Greg's assertion that ebony could float because of pressure affecting water and Gina's contention that water could not be compressed. We also see binaries occurring in context maps, such as float-sink, washer-dryer, wheels-axle, "get stuff hot-keep thing cool," and so forth. In another task (see figure 7), which asked students to explain what life on Earth was like to aliens, one grade five boy used extensive use of binaries, including life is full of ups and downs, a good place to live – a bad place to live, and so forth.

Figure 7. A grade 5 boy's explanation of life on Earth task showing extensive use of binaries.

Learning for Complex Understandings

As we have seen in the examination of student discourse and student generated artifacts, student thinking takes on the characteristics of chaotic and complex systems. Such characteristics involve the notion of emergence, where new ideas and concepts arise out of the specific context of the classroom (i.e., discourse and other activities). The emergence of such ideas is unpredictable, because of the inherent non-linearity (i.e., chaotic nature) of the entire process. Although we may be able to predict that certain types of events or ideas may arise, we cannot predict the specific content or outcome. By providing attractors or centers, such as ebony as a discrepant event or a task topic (e.g., context map on floating), we can predict that students may engage in a meaningful process of learning, but with no clear picture of the specific nature of the ensuing process or outcome.

Such a view of student thinking and discourse involves several key notions about students and classrooms. In order for students to engage in meaningful classroom discourse, such as in the argument described previously, teacher control needs to be minimized as students take more control over the content and flow of the classroom talk. In essence, this shift in control allows students to take ownership over the process and content and to develop much more complex understandings. As a result, there is a dramatic increase in the potential for (a) the development of complex understandings and (b) the development of meaningfulness of understandings, and (c) the integration of the content and process involved in such discourse. However, the status quo of schooling tends not to support such a shift in control, the lack of predictability, the non-linearity of approach, or the seemingly chaotic processes that can occur.

Justification for an approach to schooling based on chaos, complexity, and metapatterns may lie in ways of planning that encourage student engagement, ownership, and complex thinking. One possible model is based on Mary Catherine Bateson's (1979) notion of patterns which connect (note: "patterns which connect" is a concept developed by her father, Gregory Bateson, as an extension of "metapatterns"). She describes this notion as helical patterns of learning throughout a lifetime. As we engage in thinking about a particular idea or theme, it becomes situated as a pattern of learning that winds its way through our life. The theme may lie dormant than arise again. At some points, two or more related thematic (and helical) patterns connect and spark new insights and relationships. Figure 8 depicts such a model, where specific emphases become the individual spirals through the term of a particular schooling experience. Such a model may share a common conceptual focus, such as, a unit on evolution. Then the individual strands or themes are initiated. As students proceed to work through these themes, we have provided potentialities for making connections.

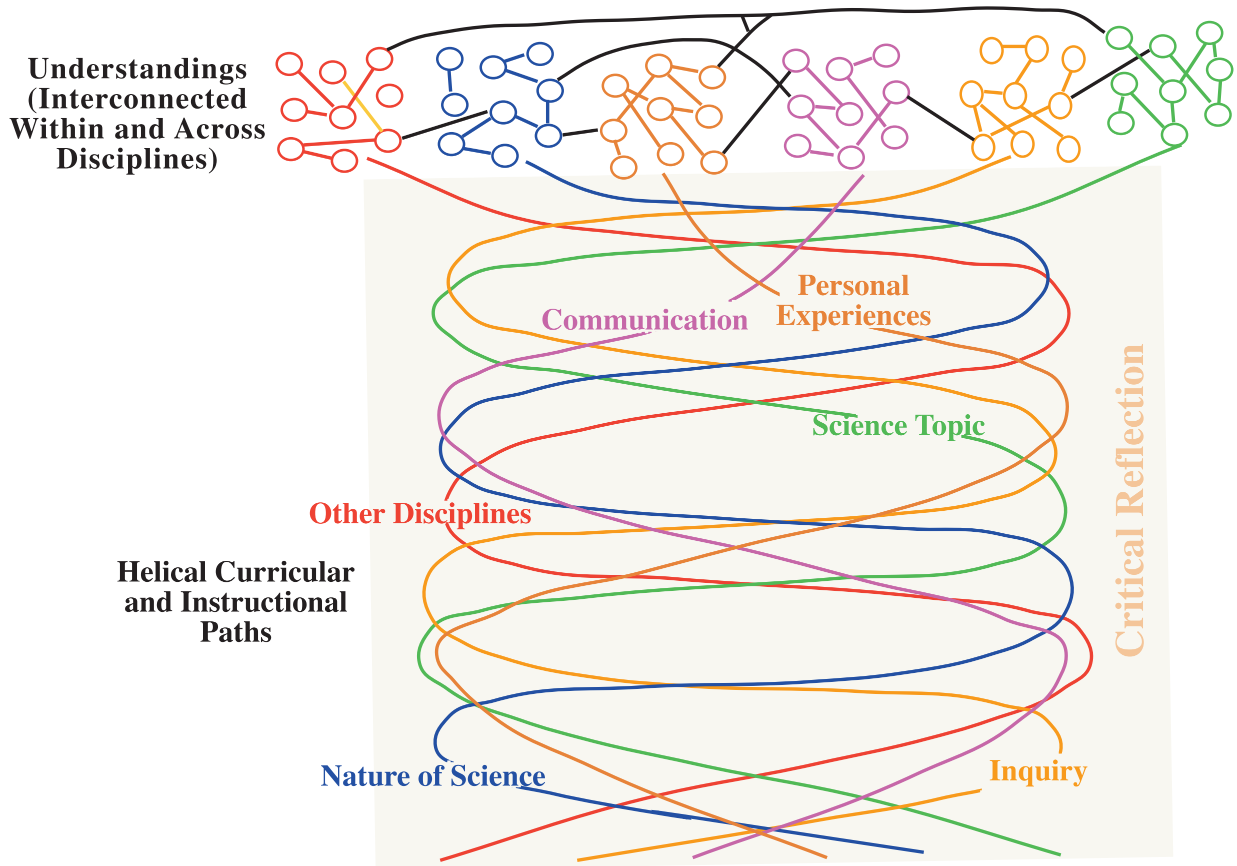

Figure 8. A patterns that connect curricular model that is supportive of a metapattern at chaos and complexity approach.

A similar model has been used in elementary pre-service courses, with thematic strands of inquiry, children's learning, nature of science, actual work with children on investigations, modes of communication, and integrating across the curriculum. All of these themes are embedded in a context of reflective learning and teaching, so that students have an opportunity to ponder and discuss the connections they see. Although no systematic data has been collected on this process, students frequently discuss how their work with children on investigations connect to some experience they have had or to one of the strands we have been exploring in class and in readings. The making of such connections provides opportunities to construct more complex and meaningful understandings. Such opportunities may help connect formal knowledge in several areas (e.g., children's learning, nature of science, etc.), past personal experiences, recent experiences in different contexts, and so forth. In viewing patterns that connect, the basic notion is provide conceptual stimuli as a basis for initiating student engagement. As in the density argument, themes, such as "compression," wound their way through both sides of the argument while increasing the complexity of the emergent conceptualizations.

By identifying conceptual themes, whether within or across disciplines, teachers can plan activities that stimulate student engagement. If student engagement can be achieved, we may not be able to predict specific outcomes, but we can predict general areas of conceptual learning and that such learning will be more complex than that achieved by linear and narrowly focused approaches.

Pursuing an approach to teaching and schooling that is based on a model of learning, which is non-linear and unpredictable and in which knowledge structures emerge, requires transformations in the assumptions underlying present views of education. One such assumption is that instruction can occur followed by an assessment of that learning (i.e., learning can occur in a linear, pre-formed structure over a limited period of time). From a chaotic systems perspective, we see that learning is a continual process and that significant learning may not occur until further connections are made – a process which is unpredictable and which may take weeks, months, or years. In addition, complex learning involves the development of thorough, interconnected understandings. As opposed to "learning" enough for testing, followed by a dramatic decrease in recall of such "learning," complex understandings are embedded in meaningful contexts and continue to develop (often sporadically) over a lifetime. Assessing such learning needs to take place periodically over longer periods of time and needs to look at more complex knowledge structures.

A related assumption involves the notion of teaching as a highly structured and sequential process. At the same time, the expectation is that students will engage in meaningful learning. However, meaningful learning requires that students see the relevance of the instruction and that they have ownership over the conceptual content. In order for students to see the relevance and meaningfulness and to own the material, as well as the process of learning, the classroom context needs to accommodate and promote structures and sequences that emerge from the complex interactions among students and between students and the teacher. The students and teachers must be co-participants and co-owners in the processes involved in allowing meaningful and relevant structures to arise and take shape based on the specific needs of all involved. Such a view of emergent structure and sequence is especially significant if we wish to engage children in inquiry. In such a situation, inquiry that is relevant and meaningful arises from children's questions and insights. The path is unpredictable, but can lead to more significant and complex learning. Such learning not only includes the conceptual focus of the inquiry, but also includes learning about the process of inquiry and the nature of science itself.

Although my final remarks are beyond the scope of this particular paper, I believe they warrant mention. As we saw in figure 7, where a boy used binaries extensively to describe life on Earth, metapatterns, as well as chaos and complexity, can serve as a focus of instruction. Providing children with opportunities to begin developing broad and complex understandings of concepts (metapatterns) that span multiple disciplines as well as everyday personal experiences can be far more important than learning fragmented and isolated concepts, which all too often hold no perceived relevance to the child.

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Appendix

[*Children's spellings maintained.]

Name	Task	Nodal Items with Number of Links [#]			
Eric	Pre-	• water **[2]**	• boat **[1]**	• flying **[0]**	• liqued **[1]**
	Post-	• water **[9]** • air **[5]** • little tiny one celled thing **[4]** • Earth **[3]**	• space **[2]** • wood **[2]** • ice **[1]** • Jello **[1]** • steam **[1]**	• helicopter **[1]** • subway **[1]** • no air **[1]** • boat **[1]**	• gas **[1]** • oil **[1]** • sub **[1]** • density **[0]**
Frank	Pre-	• magic **[3]** • natural law **[2]**	• air vapor **[2]** • air **[2]**	• yoga flyers **[2]** • goast **[1]**	• 2 dollar bill **[1]** • make believe **[1]**
	Post-	• ballon **[2]** • heleum **[2]** • helecopters **[1]** • space **[1]** • hover **[1]** • hot air **[1]**	• yogic flyers **[1]** • Superman **[1]** • magic **[0]** • bottom rids **[0]** • ping pong balls **[0]**	• ameba (one celled creaturs) **[0]** • elevated trains **[0]**	• parade floats **[0]** • drinks floating on top of each other (my at home project) **[0]**
Fred	Pre-	• hippies with harps **[2]** • things **[2]**	• feathers **[1]** • sports **[1]**	• sky **[1]** • clouds **[1]**	• abstractness **[1]** • basketball **[1]**
	Post-	• water **[2]** • sky **[2]** • clouds **[1]**	• helicopters **[1]** • basketball players **[1]**	• staying in front of net **[1]** • bubbles **[1]**	• boats **[1]** • soap **[1]** • grenadin **[1]**
Gail	Pre-	• boats **[2]** • umbrella **[2]** • ballons **[2]**	• leaves **[2]** • in the water **[2]** • up high **[1]**	• down low **[1]** • people **[1]** • paper **[1]**	• ghosts **[1]** • hair **[0]** • fish **[0]**

		• magic **[2]** • in the air **[2]**	• snow **[1]** • angel **[1]**	• paper clips **[1]** • science **[1]**	• stirafome **[0]**
	Post-	• hair **[6]** • tinfoil **[5]** • things **[5]** • styraphoam **[5]** • bouys **[5]** • oil **[5]**	• ducks **[5]** • horses **[5]** • fish **[5]** • birds **[5]** • elephants **[5]** • animals **[5]** • rubber **[4]**	• keel **[4]** • boat **[4]** • bouancy **[4]** • sails **[4]** • in the air **[3]** • leaves **[3]** • magic &ghost **[3]**	• ghosts **[3]** • poltergist **[3]** • ladys **[3]** • stars **[3]** • clouds **[3]** • life jackets **[0]**
George	Pre-	• wood floats (unless it's petrified) **[6]** • ducks float **[4]** • water crafts (boats) **[4]** • animals **[4]** • air increases buoyancy as well as hellium **[2]**	• different organic items **[2]** • some stuff floats but seits water (like duck feathers) **[2]** • when a boat hits a rock and smashes it doesn't float **[1]**	• although water or liquid is not a solid it can still prevent flotation (not always **[1]** • chemichals that increase bouancy **[1]** • bouancy **[1]** • lots of things float **[1]**	• you can prevent floatation by filling the object with a solid **[1]** • floating houses **[1]** • it's a good thing when swimming **[0]**
	Post-	• it's fun to float **[2]** • when you sink you don't float **[2]** • ebony doesn't float **[2]** • lite objects float in air **[2]** • ducks float even when they're dead **[2]** • some wood floats **[2]**	• when a cartoon goes over a cliff he floats until he/she looks down **[2]** • floating's fun yeah **[2]** • capsella floats **[2]** • witches float **[2]** • I like to float **[2]** • some people think they're floating but they aren't **[2]**	• some chemicals can decrease buoyancy **[2]** • if I were to fall in the water I would float **[2]** • when you sink you don't float **[1]** • music floats man! **[1]** • chemicals can increase buoyancy (helium) **[1]** • buoyancy **[1]**	• if you jump off a building you don't float **[1]** • things float in water, air and other places **[1]** • rocks don't float **[1]** • if a object doesn't float and it hits you on the head it hurts **[0]** • watch out for floating objects **[0]**
Gina	Pre-	• flying **[6]** • water **[5]** • rockets **[3]** • swimming **[3]** • clouds **[2]** • yogic flyers **[2]** • rafts (boats) **[2]**	• levitation **[2]** • outerspace **[2]** • heaven **[2]** • water babies **[2]** • angels **[2]** • faries **[2]** • sky **[2]**	• ghosts **[1]** • planes **[1]** • salt water **[1]** • magic **[1]** • cantering **[1]** • water beds **[1]**	• astronauts **[1]** • Tinkerbell **[1]** • birds **[1]** • planets **[1]** • horses **[1]** • bubbles **[1]**
	Post-	• jumping **[6]** • sky **[6]** • fish **[5]** • water **[5]** • fish **[5]** • horseback riding**[4]** • space **[4]** • people **[3]** • stars **[3]**	• cantering **[3]** • sniffing **[3]** • drugs **[3]** • nose **[3]** • smells **[3]** • manure **[3]** • rockets **[3]** • animals **[3]** • flying **[3]** • dressage **[2]**	• astronauts **[2]** • planes **[2]** • ghosts **[2]** • moon **[2]** • birds **[2]** • hippies **[2]** • boats **[2]** • water fowl float in water **[2]**	• hauntings **[1]** • soap **[1]** • foam **[1]** • make you feel as if you are floating **[1]** • sun **[1]** • air **[1]** • kites **[1]**

Gloria	Pre-	• in water **[4]** • in machine, boat, airplane **[3]** • paper **[2]** • wood **[2]** • leaves **[2]**	• in air **[2]** • upside down **[1]** • sideways **[1]** • high **[0]** • angle **[0]** • on wind flying **[0]**	• stirafoam **[0]** • inside **[0]** • Mary Poppins umbrella **[0]** • outside **[0]** • low **[0]** • magic **[0]**	• ballons with heliom **[0]** • fish **[0]** • without machine **[0]** • hair static eletrisity **[0]**
	Post-	• water **[4]** • bouyancy **[3]** • leaves **[3]** • hair **[3]** • plastic **[2]** • tinfoil **[2]**	• ducks **[2]** • leaves **[2]** • stirafoam **[2]** • wood **[2]** • paper clips **[2]** • glass **[2]**	• helium ballons **[2]** • wind **[2]** • snow **[2]** • boats **[1]** • oil **[1]** • low **[1]**	• paper **[1]** • tape **[1]** • in water **[1]** • fish **[1]** • air **[1]** • high **[1]**
Grace	Pre-	• magic floating **[3]** • experiment floating objects **[2]** • clouds **[2]** • in clouds **[2]**	• objects on water **[2]** • objects in air **[2]** • same as flying **[1]** • same as ghosts **[1]**	• science **[1]** • ghosts **[1]** • flying **[1]** • objects floating in air **[1]** • sky **[1]**	• on water **[1]** • experiments **[1]** • people **[1]** • same as objects floating on air **[1]**
	Post-	• sails **[4]** • weights **[4]** • boats **[4]** • bouyancy **[4]** • keel **[4]** • strong **[2]** • forceful **[2]** • powerful **[2]** • wind **[2]**	• force **[2]** • strong **[2]** • airplanes **[2]** • balloons **[2]** • helicopters **[2]** • dolphins **[2]** • gymnastics **[2]** • high jump **[2]** • life jackets **[2]**	• people on boats **[2]** • keep up **[2]** • leaves **[2]** • flying **[2]** • air **[2]** • powdery **[2]** • fluffy **[2]** • clouds **[2]**	• jumping **[2]** • swimming **[2]** • horses **[2]** • snow **[2]** • blowing wind **[2]** • heat **[2]** • hair **[2]** • leaves **[2]** • pollution **[2]**
Graham	Pre-	• fishing **[2]** • sports **[2]** • boats **[2]**	• swimming **[2]** • wings **[1]** • cork **[1]**	• sinking **[1]** • air **[1]**	• spong **[1]** • fish **[1]**
	Post-	• water **[4]** • water **[4]** • submarins **[2]** • cola **[2]**	• ice **[2]** • salt **[2]** • balist tanks **[1]** • fish **[1]**	• oil **[1]** • pressure **[1]** • wind **[1]**	• waves **[1]** • boats **[1]** • music on air **[0]**
Greg	Pre-	• swimming **[2]** • radio **[2]** • air **[2]**	• fraiser **[2]** • boats **[1]**	• wings **[1]** • sports **[1]**	• clouds **[1]** • ice cream **[0]**
	Post-	• rain **[3]** • Nova Scotian weather **[3]** • wind **[3]** • water **[3]** • bouyency **[2]** • Das Boat **[2]** • pillows **[2]** • feathers **[2]** • money **[2]**	• Canada savings bonds **[2]** • Jean Cretens brain **[2]** • Neal Armstrong **[2]** • waves **[2]** • ice cream **[2]** • ice cold drinks **[2]**	• Michael Jordan **[2]** • Devon White **[2]** • alcohol **[2]** • jello **[2]** • snow **[1]** • boats **[1]** • clouds **[1]** • water beds **[1]** • politics **[1]**	• air bags **[1]** • Roberta Bondar **[1]** • Kurt Browning **[1]** • cream cheese **[1]** • drugs **[1]** • food **[1]** • soap **[1]**