One of the central concerns in educational research is the application of research results to practice. Just as psychologists are often accused of "physics envy" in their search for tidy causal mechanisms, educational researchers could be accused of "medical envy" in their search for modes of research that will be respected and wholeheartedly adopted by practitioners. Unlike research in medicine, however, educational research is often not viewed by practitioners or by the public as necessary for practice--common sense and experience are considered to be enough. Why do medical practitioners feel an urgency to keep up on the latest medical research, but teachers do not feel anything like that same urgency about educational research? What is it that is different about educational research and medical research? Following are four important differences:

• Western medical research is guided by dominant analytical paradigms and metaphors, such as germ theory and the metaphor of the body as a machine. Material causes are always ultimately sought for symptoms--even when the symptoms are thought to be psychosomatic, as with stress-related disorders, the assumption is that the brain initiates a material, chemical change in the body resulting in the symptoms. By contrast, in educational research there are a number of competing paradigms and metaphors.

• Because there is agreement on foundational entities such as germs and the metaphor of the body as a machine, research and development can focus on manipulation of these entities within the overall metaphor, resulting in powerful technologies adopted wholeheartedly by practitioners. By contrast, because of the cacophony of foundational entities and metaphors in educational research, much effort is spent in research arguing for particular paradigms rather than taking a paradigm for granted and working from there. When the latter is the case, the technologies developed (such as teaching approaches, curricula, etc.) are often neglected or rejected by practitioners because they do not share the same paradigm. In cases in which practitioners do use the technologies, their use often does not resemble the use envisioned by the developers.

• There is a comparatively clear separation between medical practitioners and the systems they interact with (the bodies of patients). It is relatively clear what perturbations a doctor has initiated in the system by focusing on material interactions such as injections, medications, surgery, etc. By contrast, teachers are an integral part of the systems they interact with (classrooms). Because of this, everything a teacher
does introduces a perturbation to the system, and the teacher's personal dynamics, such as personality, teaching style, orientation to students, and implicit views of what constitutes learning, substantially influence the evolution of the dynamics of the system.

- The goals in medicine are *comparatively* (although not absolutely) clear—the health of the patient. The goals in educational research are much less clear, ranging from conceptual understanding to process skills to curiosity to critical thinking to knowing the material and passing tests.

In line with these points, the public perception of medicine and medical research can be summarized as follows: researchers identify causes of disease or dysfunction, which are always tied to foundational entities such as germs or body chemicals or to a macroscopic part of the body-machine that is broken (e.g., a bone or ligament). Developers then engineer ways to materially intervene to overcome the disease or dysfunction. Practitioners then employ these technologies to restore patients to health. This perception has of course been challenged (Schon 1983, 1987), but it remains a strong public perception, and, I would argue, a perception which is much more accurately applied to medical research than to educational research.

What is to be done? Should research in more "mature" fields such as medicine provide a standard for emulation? The parallel to the above in educational research is the following (which I would argue is often implicitly assumed to be the direction in which educational research should go). Educational researchers identify the causes of educational dysfunction, which are tied to foundational analytical entities and metaphors. Educational developers then engineer ways to intervene to overcome the dysfunction, focusing on the foundational entities as viewed through the dominant metaphor. Practitioners then employ these technologies to properly educate students.

Many would argue that what is needed is the equivalent of germ theory in educational research—a dominant paradigm that establishes particular analytical entities (such as microorganisms in germ theory) as foundational. For example, after reviewing the similarities and differences between a Vygotskian and Piagetian perspective, Confrey (1995) asks "What kind of integrated theory of learning and development can lead toward mathematics education programs that allow for successful and equitable participation in mathematics by all students?" In a similar article Marin et al (2000) write: "This common ground shared by both social constructivism and Piagetian constructivism opens up new possibilities for joint action by both groups to improve syllabus design and teaching methodology" (p. 233). The focus in both of these is on the foundational elements and corresponding analytical structure that can provide the basis for the development of effective technologies of teaching.

The first step in this process is to come up with a consensus on foundational entities and guiding metaphors. Because of the implicit comparison to medical research, the battle is fierce to establish primacy for each camp's choice of foundational entities and guiding metaphors. Only when a particular analytical framework becomes dominant can educational research hope to emulate the success of medical research. Unfortunately, in
educational research we have a cacophony of foundational entities and guiding metaphors with little apparent hope of one analytical perspective emerging as consensual.

What I have come to believe is that the way out of this is not the establishment of a consensual analytical framework but rather the establishment of a different kind of orientation, what I call a "navigational" orientation, which can accept the results of research employing widely varying foundational entities. In this paper I would like to suggest such an orientation that embraces the central aspects of a number of analytical frameworks while at the same time being clearly counter to a "traditional" orientation. To do this I will first take a look at some of the analytical frameworks employed in research on teaching and learning. This will then lead to a perspective that encompasses the central ideas of all of the analytical frameworks. However, the intent of this is not to set up this new perspective as a new analytical framework. Rather the intent is to steer toward a navigational, rather than an analytical, orientation.

**Particular analytical frameworks**

The following table outlines briefly a few of the analytical orientations that have been brought to bear on education.

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<th>Analytical orientation</th>
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<th>Typical foundational entities</th>
<th>Guiding metaphor</th>
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Table 1: A comparison of analytical orientations in educational research

Is it model construction and refinement that characterizes learning, or is it learning to talk in particular ways? Or is it the settling of neural dynamics into particular attractors (i.e., connectionism)? Is it too simple to say "all of the above"? Depending on the level of dynamics to be focused on (from neural to conceptual to social dynamics) different
specific dynamic systems (neurons, conceptual models/ecologies, and symbolic systems) provide the most leverage in looking at those dynamics. Where the problem comes is in reifying one level of dynamics. Not only does this blind us to other levels of dynamics, it blinds us to interplays between other levels and the level we focus on.

Each of these orientations rests on a metaphor of some kind of dynamic, nonlinear system. While insights can be gained by pursuing the individual metaphors, difficulties can arise if the metaphors are reified and the particular level of the overall dynamic system the metaphor can best handle is treated as the whole. By contrast here I focus directly on the ideas of dynamic systems to see what insights can be drawn from this perspective. It is not a different perspective than those above. Rather it is a perspective which embraces all of them because it explores the nature of dynamic systems in general rather than being bound by a metaphor for a particular kind of dynamic system. This also has the advantage of freeing us from a predominant focus on one level of dynamics to the exclusion of others.

There are two central ideas which are shared by these above analytical frameworks. These are the ideas of intrinsic dynamism and nonlinearity (Weiner, 1961; von Bertalanffy, 1973; von Foerster, 1996; Powers, 1973; Thelen & Smith, 1994; van Geert, 1994).

**Intrinsic dynamism**

A system with intrinsic dynamism is one which, although perceptually stable, is in constant flux. The human body provides a good example. It is fairly common knowledge that most of a human body’s cells regenerate so that the actual cells making up my body are physically different from the ones which earlier made up my body. It takes only a few years for the body to completely regenerate in this fashion. Like a bucket with water flowing both in and out, my material substance undergoes a regular updating.

One term for this kind of “remaining the same but changing” is “dynamic equilibrium.” Systems in dynamic equilibrium are “thing-like” in that in many respects they remain the same, but they are not “thing-like” in that they are in constant flux. It is much easier to think of a person as an enduring individual than it is to think of the processes which are in dynamic flux, producing the perceptually stable person. In many cases it is appropriate to ignore the dynamics and treat the system in flux as having an enduring identity. For many purposes I am the same person I was twenty years ago. It would cause legal nightmares if people were considered to be completely different individuals every few years. But in other ways I am not the same person. Certainly in terms of the cells I am composed of I am almost completely different. And in terms of how I relate to the world I am different.

Whether we view systems in dynamic equilibria as objects with enduring identities or as systems in flux depends on the context. But if we are locked into viewing systems in flux as entities with enduring identities, then we miss out on important ways of seeing and valuing which can be crucial for certain contexts. In the context of education, we are
primarily concerned about change. Students are not in school so that they will remain the same. They are in school so that they will emerge changed in some way. If we view the person as essentially the same, then we need to view these changes as additions to this essence (e.g., water poured into essentially the same bucket, pieces added to essentially the same frame, or the same person moved to a different place). But if in this context we adopt a view of students as systems in flux embedded in other systems in flux, then we have the beginnings of a new way of viewing students and teaching and learning, the beginnings of a new common sense. Do we view people as fixed and thing-like, or do we view them as growing and evolving, embedded in dynamic systems (classrooms, schools, communities, families, ecosystems, etc.) which contribute to them and to which they contribute? To adopt this latter view is to view students and classrooms as dynamic systems, opening up possibilities for profoundly new ways of seeing and valuing.

**Nonlinearity**

The human body is a very complex system which has many mechanisms for keeping things stable. If it gets hot, my body sweats so that the evaporation will cool it off. If I exercise so that the cells in my body need to metabolize more quickly, my heart pumps faster so that my blood can circulate throughout my body and care for these faster metabolic processes. Such maintenance of equilibrium under widely varying conditions is termed “homeostasis” in the body, but this general tendency is a property of many dynamic systems. Because of the interdependence of elements in the system, they interact in ways which seek to move the system toward “attractor” states.

Consider a simple ecosystem of rabbits and grass. If the rabbits get enough grass to eat they will have the energy to live and to reproduce. However, if the rabbits don’t have enough to eat, they will start to die of starvation. The following scenario illustrates a kind of dynamic equilibrium that is similar to homeostasis in the body. If the population of rabbits gets too high, they will eat too much grass. This will decrease the population of grass to the point where the rabbits won’t have enough to eat. Many rabbits will die of starvation. Enough rabbits may die that the grass can grow almost without check, greatly increasing the population of grass. In this environment of plenty, the remaining rabbits will flourish, increasing the rabbit population, returning us to another surplus of rabbits who will eat too much grass....
In the graph above, from a Starlogo (1997) simulation, the population of rabbits is plotted in red and the population of grass in green. The population of rabbits starts off at over 900, and the population of grass starts off at about 300 units. The rabbits stabilize at about 150, and the grass stabilizes at about 250 units, both after several substantial oscillations. So we can see that the population of rabbits is dependent on the population of grass and vice versa. This interdependence will keep the populations oscillating around relatively stable values. Because of the setup of the system (the system boundaries and the interacting elements and their characteristics), the system seems attracted to this state of affairs. In fact, in dynamic systems terminology this is called an “attractor.” There is no central control making the system “settle” into this state of affairs, yet the system seems uncannily guided to its dynamic equilibrium state. We could start out with quite different initial conditions and the system would still settle into the same attractor, as illustrated by the following graph of the same ecosystem, this time starting with 100 rabbits. Because the initial values are closer to the attractor values, the oscillations are not as wild.
This is of course an oversimplified picture of a real ecosystem, which would include seasonal changes, predators, disease, etc. But it does illustrate the essential difference between a linear dynamic equilibrium in which the flow rates are not dependent on each other (the bucket), and a nonlinear dynamic equilibrium in which the changes in population levels are interdependent (the rabbits and grass). The essential element of nonlinearity is interdependence rather than independence of elements.

However, while this simulation is helpful in introducing the idea of interdependence leading to a dynamic equilibrium, in most dynamic systems the comparatively stable states evolve over time (unlike the oversimplified rabbit and grass ecosystem which would tend to remain at the dynamic equilibrium positions indefinitely). Let’s explore these notions of independence, interdependence, and evolution of stabilities further with another Starlogo (1997) simulation. To quote from the information provided with this simulation:

“This project is inspired by the aggregation behavior of slime-mold cells. It shows how creatures can aggregate into clusters using a very decentralized strategy, without any "leader" involved. In this example, each creature drops a chemical pheromone (shown in green). The creatures also "sniff" ahead, trying to follow the gradient of the chemical.
Meanwhile, the patches diffuse and evaporate the chemical. Following these simple, decentralized rules, the creatures aggregate into clusters.”

This first simulation illustrates independence. At the beginning of the simulation, there are 100 cells (each shown by a red dot).

Figure 3
As they move about, each creature drops a chemical pheromone (shown in green) which evaporates eventually. The creatures also "sniff" ahead, moving where they sense a greater concentration of pheromone. Here there are not many cells and so they move about fairly independently--there never develops a high enough concentration of pheromone to attract a substantial group of cells. There is dynamism but not much in the way of interdependence.

Figure 4
But when the number of cells increase, they become more interdependent, and the system moves toward attractor states or stabilities as patches of dense pheromone develop. Below 700 slime mold cells start out in a particular configuration:

![Figure 5](image-url)
After some time they have clumped together into groups where there is a high concentration of pheromone:

Figure 6
With a different initial condition (i.e., a different placement of individual cells, although the same number of cells):
They still clump together, but the clumps are in different places.

Figure 8
After some further time, these clumps have conglomerated even more:

Figure 9
And even more after more time:

Figure 10

So we see that the stabilities are constantly evolving with time. In a similar way if you look into a cocktail party or other party in which people are free to move about it looks like a collection of groups of people talking. If you look later, it still looks this way, although if you look closely the groups have changed--some no longer exist, others have grown larger, etc. Also, if you have another party, the actual groups that form and the places they form after the same amount of time will vary from the first party, although one can predict with near certainty what the general look of the party will be. This Starlogo simulation and the cocktail party can be taken as a metaphor for many complex systems. In general, after a certain amount of time, nonlinear dynamic systems “settle” into stabilities or attractors, similar to the look of the cocktail party. But these attractors or stabilities are not set in stone--they exist because of the dynamic interdependencies of
the individual agents in the system. Because of this, the stabilities continually evolve. Also, environmental factors can influence this settling. If tables or bars are present at the cocktail party, it is a sure bet that groups of people will tend to gather around these (although not all tables will have groups, and for any given table it is impossible to predict in advance whether it will have a group or not, how many will be in the group, who will be in the group, etc.). If the tables are rearranged, this will have an effect on the arrangement of the groups. In a similar way, different environments or contexts will have effects on the evolution of dynamic systems.

Each of the red dots is constantly in motion. Once in an area of white it is less likely to leave since it is trying to move to “where the action is,” pheromonally speaking. However, because of their activity cells do leave clumps, causing the clumps to evolve. Similarly, in a cocktail party, each participant is active. While not physically very active, each participant is actively following the conversation they are a part of, more or less, relating the conversation to their own experiences and trying to think of a good story or example or point which will carry the conversation further. When the topic is no longer of interest to someone, she thinks of how to extricate herself from the group or change the topic.

The cocktail party also illustrates “embeddedness.” Each individual in the party is dynamically evolving, each group is dynamically evolving, and the party as a whole is dynamically evolving. The people are dynamic systems embedded in dynamic groups that are embedded in the overall dynamic party, which further is embedded in the larger dynamic community, etc. If we had access to an infinitely large computer and extremely precise information about each of the agents involved in the party, we could keep track of all of these interactions in an unimaginably complex “state space.” This state space would have information about all of the agents and their dynamics which could impact on the state of the party, from the neural dynamics of each of the participants to weather variables to political variables. The course of the party could then be seen as the development in time of this state space. Variables at very different levels could have strong influences on the course of the party. Agents embedded in the party could have an effect. One person may come up with an idea for a party game, dramatically altering the course of the party. Alternatively, systems in which the party is embedded could have an effect. A sudden storm or news story may turn many of the conversations to related topics, and if the party is outdoors the effect of a storm will be even more dramatic on the course of the party.

But while outside influences have effects on dynamic systems, in many cases these effects are somewhat unpredictable and somewhat counterintuitive. For example, if you introduce a number of rabbits to the rabbit and grass ecosystem (causing a bump in the red graph line), after further oscillations the population of rabbits will stabilize at roughly the earlier level of 150. It’s almost as if you’ve added rabbits and then they disappeared. We can reason out why this would be the case, but the usual expectation is that if I add something to a system, I expect there to be more of it. If I turn on the tap I expect the water level to rise in the bucket - I’ve added more and so there should be more, and with a linear system that is what happens. But nonlinear dynamic systems do unexpected things.
By contrast, consider another situation often used as a metaphor for learning--building. First you lay the foundation, then you build higher and higher. Someone might argue that in this case there is interdependence since the higher floors of the building are dependent on the lower floors being there, and all are dependent on the foundation being there. But this is an example of dependence, not of interdependence. The foundation does not depend on the fifth floor--when the fifth floor is added the foundation does not change. This is a linear process. There is dependence also of later aspects of the process on earlier aspects, but there is not interdependence.

This metaphor is of particular interest because it is the basis for a widely quoted maxim: “students construct or build their own knowledge.” From a static and linear perspective this “constructivist” statement does not make much sense. Do buildings build themselves? Do widgets construct themselves? With these metaphors the statement does not make much sense, but the way that it is stated tends to tap into such metaphors. So if knowledge is viewed as individual bricks or pieces (facts or subskills) put together to form an overall edifice, and building or constructing is viewed as the linear process of putting these bricks or pieces together, then students constructing their own knowledge does not make much sense.

I would like to suggest an alternative understanding of these ideas which is consistent with the view of teaching and learning I am developing here.

- As a student I can be thought of as a dynamic system embedded in other dynamic systems. Under this view knowledge involves the “settling” of the overall dynamic system into attractors, that is, “places” where the dynamics of the system would “like to be.” This overall dynamic system can be seen as involving dynamics of all of the foundational entities mentioned in Table 1.

- Learning involves changes in students’ dynamics. These changes are an outcome of dynamic system processes involving the interaction of relevant, interdependent systems--again dynamics of all of the foundational entities mentioned in Table 1.

- As a result of these interactions and dynamics, the overall system and subsystems will “settle” into new stabilities which are somewhat unpredictable but represent new knowledge in that context.

perspective view cognition as the dynamic interplay of highly interconnected (and thus nonlinear) networks of neurons that adaptively reorganize their connections (Rumelhart & McClelland, 1986; Rumelhart, 1989; Smolensky, 1986, 1988; Bereiter, 1991; Ellis, 1998; Schaverien & Cosgrove, 1999, 2000). So we can see that all of these perspectives share a dynamic orientation to learning. They differ, however, in what systems they tend to focus on. In the current perspective, I argue that all of these systems are embedded within each other. Dynamics at various levels can affect dynamics at other levels. This perspective aligns with a number of recent perspectives on the nature of cognition as embodied, metaphorical, fluid, and contextual (Lakoff, 1987, 1993; Johnson, 1987; Varela, Thompson, & Rosch, 1991).

**Navigational perspective**

Although I've tried to show that the dynamic systems perspective captures something central in all the analytical perspectives discussed above, my purpose in introducing the dynamic systems perspective is not to set it up as a new over-arching analytical perspective. Rather my purpose is in part to use the dynamic systems perspective to show the futility of a purely analytical perspective in educational research. In what follows I develop the argument that what we need is a navigational perspective, a perspective that uses the results of research to guide the practitioner from within the dynamics rather than using the results of research to produce technologies that are applied to the dynamics of systems from the outside.

From the perspective of practice, the central goal of analysis is to provide the basis for the development of new technologies to control systems. In education these technologies take the form of instructional approaches and techniques, curricula, software, etc. An implicit assumption in this approach is that the practitioner operates on the system. A dynamic systems perspective denies us this assumption--the teacher is an integral part of the system in question, the instructional situation. Teachers do not operate on students in the way that doctors operate on patients, from the outside. Rather they are an integral part of a dynamic system--an instructional situation such as a classroom or tutoring session. Rather than applying technologies to entities which are outside of themselves, teachers need to view their actions as contributing to the dynamic evolution of the instructional situation, a dynamic system embedded in larger systems (schools, communities, etc.) and which embeds subsystems (social cliques, individual students, conceptual dynamics, etc.).

From the navigational dynamic systems perspective, the goal of research becomes the refocusing of intuitions of those navigating through the dynamic systems in question (cf. Brown, 1993, 1995, for an argument that one goal of instruction is the refocusing of students' intuitions). Another way of saying this is that the goal is to develop new conceptual spectacles that help navigators see the dynamics of their situations in order to navigate more successfully.

There are a number of perspectives which could be adopted as new “conceptual spectacles” through which to view learning and teaching. We could view students as
theory adopters. Learning would then be viewed as adopting a new theory, often in replacement of an older, less able theory (Posner et al., 1982; McCloskey, 1983; Vosniadou & Brewer, 1992; Chi, 1992; Chinn & Brewer, 1993). Alternatively, students might be viewed as lacking systematicity in their knowledge, as making decisions in their thinking based on loosely connected intuitive fragments rather than systematic theories. The goal then would not be theory change but rather theory formation from existing, rather disconnected fragments (diSessa, 1988, 1993; Yates, 1988). Others take a more ecological perspective on conceptual development and change. Students’ conceptual knowledge adapts or equilibrates to new contexts (Piaget, 1970; von Glasersfeld, 1995; also the notion of a conceptual ecology in Posner et al., 1982). Still others consider a focus on conceptual issues to be a red herring. What is needed is rather a focus on students’ ways of speaking, writing, gesturing, and otherwise communicating symbolically (Lemke, 1990; Edwards, 1993).

All of these perspectives contain important insights, but each focuses on only “one part of the elephant.” Viewing students as rational theory adopters tends to ignore less consciously accessible processes (such as diSessa’s p-prims) which undergo gradual adaptation or equilibration. By contrast, claiming all conceptual change to be less than conscious ignores rational processes of theory comparison and adoption (Brown, 1995; Hammer, in press). A focus on purely social aspects, while greatly helpful in expanding our vista to include social dynamics, often ignores very important issues with regard to conceptual aspects of content. Further, all of the above perspectives tend to focus on “cold” or overly cerebral aspects of student interaction and/or thinking (Pintrich, Marx, & Boyle, 1993).

While the above perspectives are often seen as antithetical to each other, I argue that each of them has something to add to the conceptual spectacles of a practitioner. What is needed is a general orientation that can help to integrate the insights obtained from research employing these various perspectives, a new common sense that will be hospitable to the insights concerning dynamics at various levels.

**General common sense**

Drawing on a cybernetic perspective on interactions in systems (Weiner, 1961; Powers, 1973; von Foerster, 1996), I argue that in our interactions with our environment there are three important aspects: our ways of acting, ways of seeing, and ways of valuing. A typical cybernetic example is helpful in illustrating these. Consider a thermostat/furnace as an agent. This senses the ambient temperature around the thermostat—the thermostat "sees" the temperature. If this temperature is lower than a reference temperature, the thermostat values this negatively, causing the action of turning on the furnace. This then acts on the environment, increasing the ambient temperature until it is high enough for the thermostat to value it positively, thus turning off the furnace. If it is cold out, this will then bring down the temperature, starting the cycle all over again. While this can be helpful in gaining an initial understanding of ways of seeing, valuing, and acting, it falls short rather quickly when applied to human agents in whom ways of seeing, valuing, and acting are much deeper, more flexible, and more multidimensional. But with this in mind, the thermostat example is helpful in gaining an initial picture of these three ideas.
Like the thermostat/furnace, as humans we constantly interact with our environment in ways which seek to maintain the equilibria we value. Prescribed actions which conflict with such equilibrium maintenance are unlikely to be carried out as envisioned by the prescribers.

“Common sense” is a term which is roughly equivalent with “implicit ways of seeing, valuing, and acting which help us to navigate our daily lives.” As the term implies, common sense is commonly shared--members of a culture who observe another member acting in ways which violate their common sense will take notice of this. I would like to question whether the common sense we have as teachers and learners about teaching and learning is serving us well in all the contexts in which we teach and learn. If not, what might a new common sense of teaching and learning look like?

A widespread commonsense view of teaching and learning can be summarized as follows: Students don’t know certain things. They need to be taught so they will learn these things. This commonsense view has four components: 1) Students know and/or can do little, 2) they need to be taught, 3) this teaching is in order to learn things, and 4) this learning is in order to know and/or be able to do more. I do not claim that this is an incorrect view, but simply that it is a limited view.

Virtually any learning can be phrased to fit this pattern so that it will sound perfectly reasonable. “She didn’t know how to read and she needed to be taught so she could learn to read.” “He didn’t know much about chemistry and he needed to be in a course to learn about it.” “She doesn’t know algebra so she needs to take a course to learn about it.” This all sounds very reasonable--it fits with our common sense. But just as American traffic sense can be useless, and even dangerous, in countries that drive on the left side of the road, the commonsense view of teaching and learning can be useless, even counterproductive, in contexts where it does not fit. A dynamic systems perspective argues against this common sense as general. I would like to examine the assumptions underlying this commonsense orientation to teaching and learning and then suggest an alternative. I am not arguing that the commonsense view is wrong, but simply that the assumptions underlying this commonsense view are limited in their application, much like the implicit assumption that traffic will always come first from the left when crossing the street is limited in its application.

The first assumption in the commonsense view is that students know and/or can do little. This assumption has come under serious attack in many fields where research clearly shows that students have many ideas related to the content to be learned long before any formal instruction (see Pfundt & Duit, 1998, for a bibliography including about 4500 references). Dynamic conceptual and interactional processes have evolved stabilities, sometimes called misconceptions or alternative conceptions, that serve as attractors, drawing conceptual dynamics away from more desirable conceptual attractors.

The second assumption is that students need to be taught (that is, told, drilled, and pushed), and that such teaching is sufficient. Young children ask many more questions than any parent, no matter how patient, is capable of dealing with. Our minds are constantly active from a very young age. Of course the activity may not be in the desired
direction and so children quickly learn to suppress their curiosity and creativity in order not to get into trouble in structured settings. But the curiosity and creativity are still there and exhibit themselves in many ways, some sanctioned, some not. In the commonsense view the student is viewed as essentially inert, needing to be pushed, pulled, or somehow motivated to move through the learning process. However, in many cases the student is better thought of as intrinsically curious, active, and exploring, in short, intrinsically dynamic rather than inert (Piaget, 1970; Duckworth, 1987).

This brings me to the third assumption, that students need to learn things. More explicitly, students need to learn the basics and then proceed in a sequence to more advanced areas, usually as pushed or pulled along by the teacher. Learning is conceptualized as a journey with a well defined beginning, middle, and end. So students are “left behind” and need to “catch up.” The teacher might go “off on a tangent” and need to “get back on track” and students are said to be “off task.” Content is “covered” just as a car covers miles, and teachers talk about “getting through” such and such a chapter (see Lakoff & Johnson, 1980, for many examples of the way we talk and think about things as constrained by such metaphors). An alternative view to that of learning as a linear journey is that of learning as nonlinear, as like exploring a forest, a field, or some other two dimensional (or multidimensional) space. The teacher and students wander around this space until the students “know it like the backs of their hands.” In other words, from any point in the space they know where it is located with respect to other important points in the space and how to get from each important point to any other point.

The fourth assumption is that students learn in order to know and/or be able to do more. For all practical purposes this could be reduced to “students learn in order to be able to do more.” This view collapses the complex dynamics involved in successfully merging with a conceptually rich target space. Behavioral objectives made this explicit—knowledge, understanding, ability to synthesize and evaluate, were all to be operationally defined as what the student was able to do. In many cases, particularly in the USA, this is reduced to how well students can choose correct distractors on multiple choice exams—if you have learned it, then you should get right answers or perform correctly or quickly or accurately. Conversely, if you get right answers or perform well, then you have learned it. We have taken a view which works well in describing the learning of rote behavioral skills and stretched it to cover all learning (Doran et al., 1994). Just as our focus in other areas is almost exclusively on ways of acting, our commonsense view of learning and instruction seems defined by the learning of behavioral skills. But this view may work far less well in other areas.

For example, can one claim that if a student can balance accurately many different kinds of chemical equations that the student has “learned about chemical equations”? Through drill and practice students can learn to balance even complicated equations so that the number of atoms of any substance on the left side of the equation is equal to the number of atoms of the substance on the right side of the equation. But I would argue that this is not the point of learning about chemical equations. Students can be trained to notice patterns on both sides and through various tricks end up with balanced equations with the same number of each kind of letter on both sides. However, unless a student goes on to
study advanced chemistry (not something most chemistry students do), the skill of balancing chemical equations is of little value. By contrast, conceptual understanding of ideas in the kinetic molecular picture of matter can be very valuable for students, even if they take no further chemistry courses.

What I argue is that teachers need a flexible repertoire of approaches (ways of acting), but more importantly teachers need ways of seeing and valuing which effectively guide them in deciding when to use various approaches, not an ideological commitment to a particular new approach nor an ideological rejection of anything new. What is very common sense in driving--sometimes you need to speed up, sometimes slow down, sometimes steer right, sometimes steer left, etc., depending on the situation--does not seem to be common sense in teaching. Teachers should always teach the basics, or they should always have open classrooms, or they should always use cooperative learning, etc. But saying teachers should decide what to do based on the situation is problematic also since these decisions are based on common sense, on ways of seeing and valuing which may be limited in their range of appropriate application, just as American traffic sense is in many ways useless, and even dangerous, in England.

If the commonsense view of teaching and learning is limited in its application, what might be a new view which would have wider application? To address this, let us reexamine the commonsense view of teaching and learning. The statement of this view was: Students don’t know certain things. They need to be taught so they will learn these things. This commonsense view could be rephrased as: Students are not where they need to be. They need to be led so they will get to where they need to be. Under this phrasing, teaching is seen as leading, learning as following, and this leading and following are along a path leading to an end point. This phrasing evokes the image of learning as a journey. Another rephrasing might be: Students are not filled with enough of what they need. They need to be filled so they will have enough. Learning here is viewed as being filled with knowledge and skills and evokes the image of the teacher pouring knowledge and skills into the students’ heads. Yet another rephrasing might be: Students are not as functional as they should be. They need to have things added to them so they will be more functional. Learning here is viewed as having knowledge and skills added on and evokes the image of an assembly line, with students moving through the grades or curriculum and having the appropriate knowledge or skills added at each grade level or stage of the curriculum.

Each of these ways of stating the commonsense view of teaching and learning views the process as one which proceeds from a beginning to an end by a sequence of little steps. Although there may be some slowing or speeding up in certain “tough spots,” the overall rate is relatively constant. And without outside intervention (the guide, the bucket filler, the assembly line worker, or the teacher), the travelers, buckets, widgets, or students would stay in essentially the same state or position. Let me illustrate this somewhat abstractly with a diagram:
The position of the rectangle represents the current state of the system; the position of the traveler, the water level in the bucket, the state of the widget, or the knowledge state of the student. The arrow represents the influence motivating a change in the state of the system; the guide, the bucket filler, the assembly line workers, or the teacher. The line represents the trajectory, where the system is being moved to or through or along; the path, the increasing water level, the conveyor belt, or the curriculum.

In all of these processes, there are two similar characteristics. First, the entities are all seen as passive or inert. The traveler is guided, the bucket is filled, the widget is assembled, and the student is taught. Second, the motivating influence moves the state of the system in a sequence of small steps, at a comparatively constant rate, through to the end of the trajectory. The traveler is guided step by step, the bucket is filled bit by bit, the widget is assembled piece by piece, and the student is taught lesson by lesson. These two aspects, essential passivity and additivity or linearity, are characteristic of much common sense. So we can see that a dynamic systems perspective, which views the instructional situation dynamically, can help practitioners view instructional situations in a way which is very different from traditional common sense and which correlates well with a number of recent perspectives on teaching and learning.

**Target spaces as dynamic and nonlinear**

So far we've been looking at the dynamic aspects of learners and instructional situations. But target spaces can also be considered as dynamic systems. Current events provides a very good example of this dynamism. Newspapers and network news programs have new headlines every day, and CNN’s Headline News (tm) has headlines every half hour, often with a different breaking story from one half hour to the next. Students cannot simply take a course in current events in school and be done with it. Current events are constantly in flux. They are also in many cases interdependent. When President Bill Clinton initiated the bombing of Iraq on the eve of the vote on impeachment over the Monica Lewinsky affair, the interdependencies of the two apparently unrelated stories became the topic of much discussion amongst pundits, spin doctors, and the general public. This is but one striking example--an understanding of economic news frequently impacts on an understanding of foreign affairs and vice versa, and sports news often seems more appropriate on the business pages with strikes, lockouts, and salary negotiations. Politicians often (with some justification) accuse the media of creating rather than just reporting the news. The simple linear model of news happening in a number of independent areas which is objectively reported by the media and read, seen, or heard by the public is overly simplistic. Current events provides a good example of a dynamic, nonlinear target space, a target space consisting of constantly evolving and interdependent stories.

If current events provides a good example of a dynamic target space, then certainly science provides a good example of a comparatively stable, even static target space. Or does it? Science newsletters and magazines such as Discover (tm) and Science News
(tm) bring to public awareness the most striking news of the day, week, or month, gleaned from the pages of literally thousands of scientific journals, the equivalent of “current events for scientists.” But certainly the basic ideas in science remain the same, providing the stable backdrop for the experimentation and theorizing reported in the journals and the more popular science publications. There is some truth to this, but what is relatively stable (although not completely static) for scientists at the frontier may bear little resemblance to what is treated as gospel in school science. Students who take a number of courses in a particular branch of science often complain that their teachers and professors keep telling them “what you learned last year is wrong, here’s a new way to think about it that is the right way.” For example, students might move from learning about matter as continuous to matter composed of atoms like extremely small spheres to matter composed of atoms like miniature solar systems to matter composed of atoms with clouds of electrons to matter composed of atoms describable only mathematically. In some cases, in every new course students have to unlearn their old way of thinking and learn a new way.

To say that science is dynamic and constantly in flux is not to deny that there are substantial stabilities. There are substantial stabilities in current events. The leadership of many countries remains stable over a period of years, and certain organizing metaphors (e.g., the “cold war”) remain in force for long periods of time. Even more stable are the basics of human nature which govern much of the news--the lust for power, prestige, and pleasure; territorialism and tribalism; and magnanimity and altruism. In the same way there are stabilities and levels of stability in science, but this stability is a dynamic stability or equilibrium. Of course one could argue that a particular equation or principle in physics has been written down for many years, so it’s objectively there, static and unchanging. However, such symbols are simply “evocative tokens.” In other words, they mean different things to different people--they evoke different meanings and reactions. Where these symbols gain their relevance and power is in the sense people make of them and the use they put this sense to. It is this that is constantly evolving, the meaning that individual scientists and communities of scientists attach to a particular principle or equation. Again this is not to say that there is not substantial stability in this sense-making among like-minded scientists. It is this stability which enables the exchange of ideas with a high level of shared meaning. But these stabilities are dynamic, the product of dynamics at many levels, from the neural dynamics of individual scientists to the dynamics of scientific interchange (conferences, peer review of articles, etc.) to the historical dynamics of the evolution of scientific ideas.

While I would argue that all situations and target spaces are dynamic, it is my view that it is possible to have a fully dynamic perspective on both students and target spaces yet for practical purposes treat one or both of these as less than fully dynamic and nonlinear. In the same way, all modern physicists acknowledge the primacy of quantum mechanical thinking over “classical” thinking. However, in a wide range of phenomena that do not deal with either the very fast or the very small, classical models (such as Newton’s laws of motion and gravitation) are still very useful.

In a similar way, even the traditional view of learning and teaching can be seen as a subcategory of the dynamic view. For example, consider the following graph that shows
the skill development of a hypothetical student learning to type. At a macroscopic or birds-eye level the student’s skill development seems to steadily increase. In the graph below the student’s skill (some combination of typing speed and accuracy) is measured at five different times (represented by the data points shown on the graph). A “line of best fit” can be drawn through these points to show the postulated linear skill development.

Figure 12

However, on closer inspection (looking closely at the line inside the circle), the “line” looks anything but linear. There are many “fits and starts” as the learning proceeds in the development of new attractors in a dynamic system of finger muscles, bones, tendons, ligaments, nerves, neural processes in the brain, and contextual factors such as the type of keyboard. Thelen and Smith (1994) look closely at the development of walking in infants and come to a similar conclusion--that outwardly it seems like a relatively linear development, from seemingly random kicking motions to standing with help to walking with support to walking independently. But microscopically the development is rather messy.
“The grand sweep of development seems neatly rule-driven. In detail, however, development is messy. As we turn up the magnification of our microscope, we see that our visions of linearity, uniformity, inevitable sequencing, and even irreversibility break down. What looks like a cohesive, orchestrated process from afar takes on the flavor of a more exploratory, opportunistic, syncretic, and function-driven process in its instantiation.” (p. xvi)

Figure 13

However, since the nonlinearities of student learning are rather microscopic, for practical purposes the student can be thought of as progressing in a reasonably linear fashion from unskilled to skilled behavior. At the level of lessons these fits and starts generally work themselves out, and the regimen of drill and practice is enough to insure fairly linear skill development over a long enough period of time.

In a similar way the target space can be thought of as dynamic. The meaning of typing rests on an understanding of language, more specifically an understanding of written language. Just as scientific principles mean different things to different people, so typing means something different for a monkey or a baby than it does for an adult human. Knowing that the finished product will be a communication is important in persevering
and finishing the typing accurately. However, as this understanding is shared by virtually all students who take typing, the dynamic processes which are necessary for the development of typing skill are for all practical purposes inevitable and therefore invisible--they can be taken for granted with impunity. Everyone who takes typing knows that typing is for communicating with written language. The stable attractors necessary for the development of typing skill have already developed. The bucket is there, it just needs to be filled. The target space of typing can be considered for practical purposes as linear and fixed.

Since the dynamic nature of the student and the target space can be ignored in the case of learning to type, traditional common sense provides a good way to look at teaching and learning typing. When a simple model works, why spend the effort to understand the system with a more complicated model? Newton’s laws were used to put men on the moon, not the more complicated equations of quantum mechanics.

So while all learning can be seen to be the merging of the dynamics of students and target spaces, for practical purposes simpler models can be useful in certain situations. But again, the task is one of developing ways of seeing and valuing which will allow us as teachers to decide when a simpler model is appropriate and when it is not. In science there are situations in which the target space and the students are fruitfully viewed as linear and static, for example learning nomenclature in chemistry. Naming various compounds in chemistry involves the application of systematic rules depending on the composition of the molecules in the compound. Similar to learning to type, if the student can go back and forth from chemical formula to chemical name, then she has learned chemical nomenclature. And most students are unlikely to be intrinsically motivated to learn chemical nomenclature. Telling and drill and practice may work effectively. By contrast, understanding the processes involved in the formation of molecules is a different story. This involves a web of interdependent ideas with concepts and interrelationships of concepts that are fraught with potential conceptual difficulties. Treating students and the target space in this case as linear and static will likely lead to widespread memorization of the names of processes with little attendant understanding of these processes.

We are left with the complex task of deciding for each specific case which orientation to adopt and then how to navigate the dynamics within that orientation. If we choose to always adopt a traditional orientation, treating students and target spaces as linear and static, then our job as teachers becomes much easier. However, our students suffer as they end up with knowledge and skills that are frequently meaningless to them and soon forgotten. And we as teachers suffer since dragging students along paths they would not otherwise choose, with the result of imparting knowledge and skills they do not value (often with good reason), can be tiresome indeed. While not rejecting a traditional orientation, we need to see it in its place as an orientation of limited applicability. In many instances we need to view students and target spaces as dynamic and nonlinear, as dynamically evolving systems with interdependent entities. But this way of viewing students and target spaces is unfamiliar. We not only need to re-tune our common sense to pay attention to these dynamics, we need to develop “noses” for specific dynamics in specific contexts which are not immediately visible to the “naked eye” brought up on
traditional common sense. In the following section I illustrate this idea of hidden dynamics with several examples from my own research.

Seeing hidden dynamics

Depth

In my own work and the work of many others, observable actions converge into stabilities and instabilities which hint at inner, often deep stabilities and instabilities. Attempts by other researchers at characterizing students' conceptions indicate a trend toward thinking about "deep" conceptions versus more surface or conscious conceptions. Deeper conceptions are often characterized as more universally held, more far-reaching in their effects on students' assimilation of instruction, and more resistant to instructional remediation. These deeper conceptions have been variously termed "entrenched beliefs" (Vosniadou and Brewer, 1992), "core ideas" (Heller and Finley, 1992), "epistemological obstacles" (Johsua and Dupin, 1987), "critical barriers" (Hawkins, 1978), "epistemological beliefs" (Reiner, Chi, & Resnick, 1988), "ontological categories" (Chi, 1992), "gestalts of causation" (Andersson, 1986), and "phenomenological primitives" (diSessa, 1988, 1993). As used by these authors, these various terms are certainly not equivalent, but all indicate a recognition of some student conceptions as more ingrained and more subliminally employed than others.

These deep stabilities need to be attended to in instruction, not just observable actions. The following tutoring interview (from Brown & Clement, 1989) exemplifies this depth in the conceptual arena. When asked about a book resting on a table, the student, whom I will call Mark, responded confidently without a pause that the table would not be exerting an upward force on the book.

I: Is the table pushing up on the book or exerting an upward force on the book?

S: No, it's just a barrier between the floor and the um the position the book is at right now.

With similar confidence he answered that a spring would push back against his hand.

S: I can't explain why a spring will push back. It's just something I've always accepted...I really can't explain at this point why the spring acts as it does.

These responses illustrate two characteristics of conceptual depth: a high degree of confidence and an inability to articulate reasons--in other words a "gut level" intuition that simply describes the way things are.

After discussing a number of bridging analogies including a book on a spring, a book on a flexible board between two sawhorses and his own analogy of pressing down on the flexible board with his hand, he seemed to come to a new way of seeing the table as microscopically flexible and thus able to push back, much as a spring would push back. When asked to relate the book on the table with the situation of a book on a bendy board, he replied:
S: Uh, the board is flexible and, yeah I guess that's, that's essentially it, the board is flexible and, it, ah, it probably isn't different, um, I'm starting to realize how technically it probably isn't different, it just appears different. Ah, you know, because it's a thin board, it's flexible, and you can see easier that it's, um, the board is pushing up on the books. Especially after talking about the springs previously and, uh, the table is really, ah, rigid, it doesn't appear flexible even though it is in the, ah, you know, in a really, really small microscopic, ah, sense.

Because of this discussion, Mark seems to have intuitively readjusted or refocused. In Figure 14a the book is the initiating agent pushing down (represented by the circle with a downward arrow), but the table is inert, it is just in the way, "a barrier between the floor and the position the book is at right now" (represented by the empty circle). By contrast, in Figure 14b the spring is a reactive agent which pushes back when pressed (see Brown 1993 for a more in depth discussion of deep conceptual intuitions and the diagramming system employed here).

![Figure 14](image1)

After the analogical discussion Mark seemed able to think of the table as a reactive agent, as springy on a microscopic scale. In terms of the model being developed here, Mark developed a new way of seeing the table and the interaction of the book and the table (see Figure 15).

![Figure 15](image2)
This has been an example of conceptual depth. I would like now to consider an example of what could be called "depth of connection"--here a students' deep and extended interest in exploring light and magnifying glasses.

This segment is about a fourth grade boy named Palab studying the properties of hand lenses and of light in a summer science camp. Palab worked alone on his experiments with light. The other students had left the table, and he remained seated in his original position. No verbal transcript exists for this section since Palab was alone at the table and was not speaking. Up to this point, he had worked intermittently on his self-directed exploration of light. This segment, when Palab was working by himself exclusively on his investigation of light, lasted about two minutes.

When the girl seated across from him named Ashley left the table, Palab was holding two hand lenses. He experimented with those two for a minute or so, holding them in various positions and looking through them. Then he reached across the table and grabbed the two hand lenses that Ashley had laid down on her side before departing. With four hand lenses in his possession, he arranged them on the table in front of him, apparently deciding how to conduct his experiments. Then he picked up three lenses and looked through the three of them. This might have been a test of his ideas (mentioned earlier) that more hand lenses gives the image, or light, a greater magnification, or he may have been simply trying to see what happens without any prior hypothesis, but it does seem that he was closely observing the lenses and trying to find out more about them. Then he picked up the fourth hand lens. It was hard to keep the four lenses in the right arrangement and he struggled with that for a few seconds. Then he peeked through the combined four lenses. This might have been another test of his ideas about magnifying light and making light bigger. After looking through the four lenses, he put them down.

He had been trying to get other students to participate in his exploration of light and magnifying lenses, but they did not find the topic interesting enough to join him. Due to his strong, personal interest in the topic (which came out repeatedly in an individual interview), he went right on exploring. When he was left alone at the table, instead of searching the room for his group members, he continued to explore with the hand lenses. He seemed deeply connected with this phenomenon in an exploratory mode of engagement (Rath & Brown, 1996).

In addition to the above mentioned depths of conceptions and of connection with phenomena, other areas of depth have been explored in doctoral dissertations which I have had the privilege of working with. Richard Frazier (1996) explored "ways of being" and "ways of working," deep stabilities in the nature of elementary children's activities with phenomena which he characterized through evocative river metaphors, illustrating these ways of being and working as flows of action which are deep and unitary, splintered into tributaries, etc. Hui-ju Huang (1998) and Isabel Nicdao-Quita (1997) both explored deep level stabilities which characterize consistent ways of sense-making (as opposed to deep stabilities in the sense that was made), and Chin explored deep versus shallow approaches in science activities (Chin & Brown, 2000, in press). As these studies indicate, focusing only on observable behaviors misses stabilities and instabilities at deep levels. Although we are only beginning
to understand these depths, they cannot be ignored in coming to a deeper understanding of student interactions, and they are often initially invisible to both researchers and teachers.

**Stabilities and instabilities in a class discussion**

Leander and Brown (1999) and Brown and Leander (1998) explore a classroom discussion in a high school physics class. In this discussion, there was a great deal of instability in the focal situation under consideration, but at the same time several of the students demonstrated substantial conceptual stability in their ways of looking at these various situations. The teacher started the discussion with the following question:

An object oscillates horizontally. At maximum extension which of the following will be maximum?

A. velocity  
B. momentum  
C. acceleration  
D. kinetic energy

The correct answer is C, acceleration is maximum. Velocity would be zero since the object is turning around and is momentarily motionless. Momentum and kinetic energy would similarly be zero since they are multiples of velocity. This leaves acceleration as the only choice, which is a very counter-intuitive answer.

During the course of the interaction, a number of different situations were presented as either problems to be solved or evidence for positions held by the speakers. These situations were primarily constructed through gestures and talk, although one used an actual object in the classroom (a pencil). Once introduced, these situations were responsive to past discourse, recombining in various ways and forming hybrids. The first situation introduced by the teacher was that of a horizontal harmonic oscillator moving across the room. The system was briefly and vaguely described by the teacher as moving "all the way to the door-door wide and window, wide." Not only was the system described generally, through the teacher's gestures an ambiguity was introduced that became important later in the discussion, namely, on three occasions where he gestured the vibrating mass, he began to inscribe a slight upward-arc, a pendulum-like motion with his hand or finger in space.

The second major situation was introduced when the teacher, whom we call Mr. Hamin (all names are pseudonyms), threw a pencil upward in order to demonstrate its constant acceleration as it rises and then falls. The actual classroom debate began with Joan's challenge to the teacher: "I still don't buy it-cause I think the acceleration would be, like right before it got down." Rather than responding to the pencil illustration, however, Joan gestured a pendulum in space in front of her, thus stabilizing the pendulum as an object under consideration. Michael, seated near Joan at the back of the room, interrupted the teacher and offered his own rebuttal to Joan, which was largely a more animated version of the teacher's original oscillating mass problem. However, Michael importantly introduced a spring into the teacher's description, which was "whipping [the mass] back." Brenda, picking up on Michael's' comment, briefly attempted to stabilize the system: "Are we talking about a
spring, or a pendulum, or what?" Significantly, Brenda did not wait for the teacher's
response to her question, but to maintain the momentum of her argument proceeded to argue
with the pendulum at center, discussing the "force of the string."

Later instabilities in the problem situation include Michael's vertical reorientation of the
oscillating spring, and Charlene's concretizing of a pendulum through a sketch. When this
attempt failed, Mr. Hamin drew on everyday occurrences and constructed a brief narrative
about a mother who is controlling her baby with a "rubber band" that is tied between them:
"The farther away the baby is, the more force the mother will force the baby to come back to
her?" Later, after Brenda remarked "That analogy kind of missed me," Mary, another
student, also drew upon everyday situations to convince Brenda by discussing a speedometer:
"Let's say you want to get at thirty miles per hour, if, when you first push the gas pedal, the
needle like jumps up."

In contrast to this instability of the focal situation under consideration, it seems that several
individuals in the class had a great deal of conceptual stability. The teacher and Michael
appeared to focus on the spring or gravity as initiating agents (Brown, 1993, 1995) and
viewed the object as simply affected by the spring or gravity. The focus thus was on the
agency or causal power of the spring or gravity. By contrast, Brenda seemed to focus on the
object as an initiated agent--the agency (signaled by motion) is the most when the force has
accumulated in it. Thus Brenda seemed to be focusing on the "power" or "motion" or agency
of the object rather than on the spring's or gravity's ability to cause a change. She
consistently maintained that the maximum acceleration would be at the point right before
highest velocity, when all the forces "are done pulling it." This stability is illustrated in the
following responses to the pendulum and to the vertical spring, respectively (underlining
indicates vocal emphasis).

BRENDA: But g is pulling it down, and then the force of the string is making it come
back this way, so wouldn't like, the, I just think the acceleration is like, just like logically,
in my mind, it would be right where its done, all the forces are done pulling it, so
everything combined at that one point.

BRENDA: But see what I'm saying is if it's going down and the spring is pushing it
down, why wouldn't it be greater after the spring's pushed it some?

I illustrate Brenda's stable focus in Figure 16. In this diagram, the spring or gravity is an
initiating agent, that is, what makes things happen. This is represented by the circle with the
arrow in it. The pendulum bob or mass at the end of the spring is an initiated agent, that is, it
has agency or causal power or "umph" transferred to it by the initiating agent, the spring or
gravity (represented by the circle with the sideways T). The vertical arrow indicates that
Brenda's focus seemed to be on the agency of the mass or pendulum bob. Further, this
agency is correlated with motion. From this perspective it does not make sense that the
"umph" would be the most when it's not moving.
So far we have seen focal and conceptual stabilities and instabilities within the simple harmonic motion discussion. Leander and Brown (1999) introduce six different stabilities and instabilities which dynamically interact in the whole context. In addition to focal and conceptual stabilities and instabilities which we saw above, Leander and Brown introduce discursive/symbolic, institutional, social, and affective stabilities and instabilities. Discursive/symbolic modes or forms of communication varied widely between the teacher and students. Students tended to animate stories about particular situations while the teacher tended to focus on abstractions, bringing in individual situations as examples of these abstractions. Institutional stabilities and instabilities are those imposed by institutional structures and policies such as grades, syllabi, standardized tests, etc. Social stabilities and instabilities are exhibited in interpersonal alignments and misalignments, and affective stabilities and instabilities are exhibited in various expressions of emotion such as frustration, laughter, withdrawal, etc.

The following interaction illustrates discursive and conceptual misalignments between the students (particularly Brenda) and the teacher.

TEACHER: Let me point out here a very dangerous trend, that's happening. The dangerous trend that's happening is that you have a formula that we systematically derived, and we believed in our derivation from the beginning. Now we have a formula that tells us that the maximum acceleration happens when this is maximum. The mass is constant and the spring constant is constant. The only thing that's changing is x. So the maximum acceleration happens when x is maximum, which means when x is equal to A. That's when the velocity is zero. The systematic derivation is telling us that the acceleration maximum happens at a point when our intuitive thinking right now is saying no, and what we are doing now, which is a dangerous thing, we are preferring our own intuitive thinking (pointing to head)-over the systematic thinking, in science (pointing back to board)). That's very dangerous.

BRENDA: Well no, I'm trying to make it so I understand both=

TEACHER: What I expect you to do is this must be right ((pointing to board)), and I cannot understand it. You keep vibrating around it ((making circular motions with hand)), vibrating around it, until you solve it. You don't just discard it=

BRENDA: I didn't discard it, that's why I'm asking!
Throughout the interaction Brenda was stable in her orientation toward trying to understand the situations intuitively. Conversely, the teacher was stable in his orientation toward trying to help the students "buy" the answers provided by systematic analysis. This orientation toward correct answers was further co-constructed by other students in various ways as they tried to help Brenda accept the correctness of the idea of maximum acceleration and move on. This orientation was further supported by the institutional structure in which the discussion was embedded--the discussion broke out in the middle of a test review.

This next segment illustrates a social rift created when a student assumed an authoritative stance and his subsequent efforts to mend this rift.

BRENDA: But see what I'm saying is if it's going down and the spring is pushing it down, why wouldn't it be greater after the spring's pushed it some?

At this point, Michael corrected Brenda--the quantity she was talking about should be called "velocity" not "acceleration." This correction and apparent entrance into authoritative discourse was met with laughter from the rest of the class. In order to save face, Michael had to recast himself as a clueless student.

MICHAEL: That-that would be the-((softer voice)) velocity ((smiles, glances at camera, and makes some inaudible comment)).

STUDENT: Velocity (             ) ((laughter from several in class--noticing and looking back at camera and filming))

MICHAEL: Well I think-I'm not claiming to be an expert, but, or to-necessarily even have a clue ((laughs for a few seconds, others in class laugh)) but the way I understand it is, the acceleration is the change in velocity, so you've got, your velocity that's going upward pretty fast, and then the spring, um, the acceleration that's pulling it from going upward pretty fast to going downward pretty fast, all at the same time

After "stepping over the line" into socially distancing authoritative discourse, Michael artfully realigned himself with the rest of the students while at the same time continuing to instruct Brenda in the less distancing fashion of animating a story about the vertical spring.

The important idea here is that the individuals are embedded in the larger system of stabilities and instabilities and the larger system embeds the individual stabilities and instabilities. As such it is not necessary (although sometimes analytically fruitful) to talk about what is going on within the student and what is going on outside of the student. Rather there is a whole dynamic system which, in the course of its dynamics, evokes various stabilities and instabilities, and the system's evolution is affected by these stabilities and instabilities, some of which may be intrapersonal and some of which may be interpersonal.
For example, Brenda's conceptual stability, a deep intrapersonal stability, had a strong effect on the overall interaction. The institutional stability of getting through the interaction efficiently, etc., also had a strong effect on the interaction and on Brenda's and other students' orientations toward the situations considered. Thus there is an interchange between these dynamisms at all different levels, they are all embedded within each other and co-evolve dynamically.

**Stabilities and instabilities in hands-on inquiry**

In the context of hands-on activities in a summer science camp, Brown, Beck, and Frasier (1997) describe several stabilities and instabilities which emerged through analysis of a number of interactions. These stabilities and instabilities include contexts and modes of engagement, group structure, nature of teacher's interactions, structure of the activity, and invitations of the phenomena. Contexts and modes of engagement are observed ways students have of connecting with phenomena. These include exploration (to find out about the object and study its basic properties, Palab's orientation above in exploring the hand lenses), engineering (a focus on making something happen), pet care (a personal connection focused on nurturing), procedural (an imitation and step-following orientation), performance (soliciting attention using the phenomenon as a prop), and fantasy (an imaginative play activity which builds on some aspect of the phenomena). Group structure describes stabilities and instabilities in the structure a small group actually assumes, who is in the group, how turn taking is decided, what roles students have, etc. The nature of teachers' interactions with students includes initial directions and on-going interactions with students. The structure of the activity is the imposed or emergent structuring of interaction with phenomena, and invitations of the phenomena indicate what the phenomena "invite" the students to do (i.e., what the students intrinsically want to do with materials when they encounter them). In the following I explore two examples of student interaction in light of these interacting stabilities and instabilities. In the first interaction three third grade girls explored floating and sinking in the context of placing objects into a mixture of several liquids which were separated into layers of differing density.

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**Mrs. F.:** You might want to try the tomato. Remember to try the tomato first.
**Theresa:** Level 1.
**Chrissy:** Just a second. What was the washer? Level 6?
**Sally:** 2, 1, 5, 1 [reading from the worksheet].
**Chrissy:** 6.
**Sally:** There's only 5.
**Mrs. F.:** Remember to try the tomato in the water first.
**Theresa:** Oh, that's a little tomato.
**Chrissy:** Just a second. Who gets to do it?
**Theresa:** Who's turn is it?
**Chrissy:** Your turn.
**Sally:** Your turn.
**Theresa:** OK.
**Chrissy:** Wait wait wait. I haven't got all this stuff down.
**Theresa:** I'll take this (mumble).
This interaction represents a largely procedural context of engagement in which the girls were oriented toward the teacher’s procedural introduction of the activity (first place your objects in the water, predict what level it will fall to in the layered column, place the object in the column, record your observations) and continuing procedural interactions along with an emphasis on working like scientists in a neat and orderly fashion. The group structure included both imposed and emergent aspects. The teacher had the girls sit together, but in the course of the interaction they discussed turn taking and roles at some length. Finally the girls seemed invited by the phenomena to stick their hands in and stir the column of liquids. However, they were prohibited from doing so since it would make a mess. Again we see embedded dynamics at various levels working together, sometimes in harmony, sometimes in disharmony.

The following interaction has a very different flavor. In this interaction two fifth grade girls responded to the teacher’s open-ended introduction to make the “water work for you” by constructing a fantasy context of a strawberry milkshake machine (see Brown, Beck, Frazier, and Rath 1996 for an extended discussion of this). After two iterations of construction of a strawberry milkshake machine (ending with the production of a milkshake), one of the girls proposed a new goal.

Mary: OK, now we got to think of a faster way to do this because people are going to want their drinks in a hurry. [Pause] Alright here's the strawberries [coffee can] and here's the ice cream [basin], and this is what we put it in [large plastic cup], let's think how to do this fast.

After a couple of minutes of involved activity, they came up with their third milkshake.

Mary: All we do is pour a little bit more strawberry in it [Sue gets a small plastic cup from the back table and asks Mary to "put it in here"], and a little bit of ice cream, and then [Sue puts the cup she had gotten down right next to the large plastic cup, apparently to give Mary another chance to put the shake in there], done. Shake it up [tries covering the large plastic cup with the small plastic cup Sue had gotten and seems to think it's too small, so she empties out another large plastic cup holding pencils and rulers and uses it inverted as a top for shaking], and give it to the window [hands the shake toward the imaginary window to the left of the screen].

In the third iteration, Mary seemed to notice that the shake container was not full enough and added a little more water from the coffee can and from the basin. She apparently tried to rectify this problem by specifying how much ice cream and strawberry should go in.
Mary: OK. OK. Try this again. OK, get your tube (mumble). Mine takes about three cups of ice cream and your's takes about four cups of strawberry.

Cindy: Have you guys done it the other way, from here [basin] to there [coffee can] or there [cup] to here [basin]?

Mary: OK. Done. [both ignore Cindy]

Sue: Whoa, I only had two cups in there.

Mary: Don't want to step out the window [moves from end of table back into camera view].

Sue: Put it in here, put it in this cup. That's enough. And then give it to them [hands cup briefly in direction of an imaginary window]. Hey, let's have one of the teachers come over here and we'll make them for them.

Mary: OK, get Mrs. Traxler. [pause - Mary cleaning up, Sue leaves to get teacher]

The fourth segment ends a little over one minute after its start. The girls' reaction to Cindy is interesting. Cindy proposed another problem and both girls ignored her (interestingly, it is the same problem that the teacher, Mrs. Traxler, challenged the girls with in a later segment). One possible explanation is that they were so engrossed in the interaction here that they did not want to be interrupted.

This is a fairly clear example of a fantasy context of engagement which provided an overall stability within which other modes of engagement (particularly engineering and performance) made frequent appearances. The group structure was largely emergent, with Mary tending to take the lead while Sue followed in activities oriented toward the improvement of their strawberry milkshake machine. Later on in the interaction the teacher kindly but firmly reoriented their activity away from the fantasy and toward a procedure of siphoning. Again we see a layering of stabilities and instabilities interacting dynamically.

Analysis is still very important in a navigational perspective. The difference is that from a navigational perspective the analysis can help to provide a new window on hidden dynamics that would not otherwise be visible. However, rather than using these insights into hidden dynamics in analytical fashion as pieces to be put together into a technology of teaching, these pieces become touch points for the refocusing of intuitions of both researchers and practitioners. In other words, these analytical insights become the focal point for dynamic, analog development within the researcher or practitioner, or within the community of researchers or the community of practitioners. The outcome here is growth and refinement of intuition rather than the assembly of machine-like technology.

**Developing ways of valuing: Merging dynamics**

From this perspective learning involves the merging of the student’s dynamics with what the student is to learn. An appropriate metaphor here is one of growth, and teaching then
is helping the student to grow. But helping the student to grow in what way? In
biological growth, the answer is “to grow toward healthy adulthood,” in which “healthy”
means a harmony of all the different subsystems of the body. For example, the dynamics
of the respiratory system merge seamlessly with the dynamics of the circulatory system
so that the oxygen I inhale into my lungs is distributed by the circulatory system to all the
cells in my body. So a different statement of the goal is “to grow toward harmony of the
dynamics of the various subsystems.” This definition can be taken more generally than
simply for biological maturity.

From an educational perspective, growth can be seen as the merging of students’
dynamics with the contexts in which they will be or could be embedded. When students
have “learned” from this perspective, they will feel at home in the new context or “target
space.” Students will be able to navigate in the target space, meeting challenges and
solving problems in a flexible, creative, and effective manner. We must develop ways of
seeing, valuing, and acting which will help us as teachers to help our students grow in
this way. Ways of acting are legion, from cooperative learning to hands on inquiry to
group discussion. Carefully worked out curricula are available which suggest many
specific ways of acting for many specific topics. I have worked on some, and more are
needed. But what is seriously lacking are new ways of seeing and valuing, a new general
common sense, based on a perspective of students as dynamic systems in flux embedded
in other dynamic systems in flux and attempting to merge their dynamics with relevant
target spaces, and more specific ways of seeing, valuing, and acting to help orient the
dynamics of specific situations.

Under this dynamic view both students and the target space are viewed as fully dynamic,
nonlinear systems--dynamic systems that are constantly evolving but which have
developed attractors that lend them some stability. The target space is seen as a
collection of interdependent ideas in which the ideas and the interdependencies are
evolving and open to debate. This is certainly a good characterization of science on the
frontier, however it is not clear whether it is or should be a good characterization of
science as learned in school. Should the emphasis in school instruction be on the
intrinsically dynamic, evolving, and debatable character of science or on the substantial
stability of many areas of science? These emphases are not mutually exclusive since
nonlinear dynamic systems are both intrinsically dynamic and evolve attractors that give
the system stability. However, if the stabilities are the predominant focus, then for all
intents and purposes the target space is seen as nonlinear but fixed.

This tension is illustrated by the somewhat divergent positions of the two authors of a
paper widely recognized as seminal in bringing constructivist ideas to prominence in
science education--Driver and Easley (1978). Rosalind Driver and her colleagues have
argued that science instruction needs to introduce students to the relatively stable ways of
making sense of natural phenomena that have evolved out of scientists’ activities, that is,
the standard concepts and theories of school science (Driver et al, 1985, 1994; Millar &
Driver, 1987). By contrast, Jack Easley (Driver’s graduate school mentor) preferred to
focus more on the dynamic and evolving nature of science and the ideas in science. His
emphasis was on involving children in the processes of theory construction and debate
about evidence and explanations (Easley, 1990).
Of course Rosalind Driver was concerned about involving students in the dynamic processes of theory construction and refinement, and Jack Easley was concerned about students gaining access to powerful and stable ideas which have evolved out of scientists’ activities over many years. So interestingly Driver and Easley are in virtually complete agreement about the nature of science and the nature of students and learning. What they are not in agreement about is whether to focus predominantly on the stabilities or the dynamic nature of science. Also interestingly Driver has focused her work predominantly at the secondary level while Easley has focused his work predominantly at the elementary or primary level. This may have something to do with the different emphases.

In any case, a dynamic perspective does not eliminate debate about the goals of education, but it can raise the debate to a higher level by enabling a discussion of dynamic situations, dynamic target spaces, and the merging of students' dynamics with the dynamics of the target spaces.

**Implications for the conduct and dissemination of educational research**

In the introductory discussion I outlined four differences between educational and medical research. I return here to these points and discuss each in turn, drawing on the ideas outlined in this paper to address these concerns.

- Western medical research is guided by dominant analytical paradigms and metaphors, whereas in educational research there are a number of competing paradigms and metaphors.

There are two common responses to this observation. The first response is that a dominant paradigm needs to emerge from the fray so that educational research will have the same grounding as medical research. In line with this, researchers either promote their paradigm over others or simply assume the dominance of their paradigm and take it for granted. The second response is one of eclecticism, a kind of post-modern shrug and acceptance of widely differing paradigms as indicative of the variety of human perspectives. However, the former ties us too narrowly to a single perspective while the latter leaves us blowing in the wind of varying opinions. What I am arguing is that we need an overall perspective that resonates with the essence of a variety of perspectives and gives practitioners a way of making sense of the cacophony that is educational research, without feeling that they have to either reify the foundational entities and metaphors of a perspective or reject it outright. This is what I have attempted to provide here with a dynamic, navigational perspective.

- Research and development in medicine can focus on developing powerful technologies adopted wholeheartedly by practitioners. By contrast, because of the cacophony of foundational entities and metaphors in educational research, the technologies developed are often neglected or rejected or misapplied by practitioners because they don't share the same paradigm.
As I have argued, one of the central goals of educational research should be to educate practitioners on a common paradigm, a dynamic perspective. However, this common paradigm cannot be an analytical paradigm, for the following reason.

- There is a comparatively clear separation between medical practitioners and the systems they interact with (the bodies of patients). By contrast, teachers are an integral part of the systems they interact with (classrooms).

Effective technologies are still needed in education, and a part of educational research should be devoted to the development of these technologies. However, since everything a teacher does introduces a perturbation to the system, these technologies cannot be uniformly applied. Teachers need to learn how to navigate the dynamics of their situations. They need help in developing effective ways of seeing and valuing (e.g., Tobin, 1993; Tobin & Ulerick, 1989), not just effective ways of acting.

- The goals in medicine are comparatively (although not absolutely) clear--the health of the patient. The goals in educational research are much less clear.

The overall goal in this perspective is the merging of dynamics of the students and the relevant target spaces. Of course there can still be debates, for example about whether to focus on the dynamic nature of the target space or to focus on the substantial stabilities that have evolved, but the perspective elevates these discussions to a higher level.

In conclusion then, I argue that as educational researchers we cannot look to areas such as medicine to supply us with an implicit template for educational research. Much (although not all) of educational research must, in principle, look different than research from a purely analytical perspective, no matter what the foundational entities and overall metaphors are of the analytical perspective. An analytical perspective might be characterized as follows: data goes into a process of analysis, which uses foundational entities and guiding metaphors to explicate causal relationships. These causal relationships then support a process of development resulting in new technologies. Practitioners then use these new technologies, applying them, in the case of education, to students. The result of this application of instructional technology is student learning. This is illustrated here in Figure 17.

![Diagram](image)

**Figure 17**

I am not arguing that research of this kind in education is fruitless. Rather I am arguing that such a template for research, whether the research is quantitative or qualitative, or whatever analytical framework is employed, in principal cannot lead to the kinds of
educational advances we would all want since "application" of technology by those who are embedded in the dynamics themselves is not possible. Such analytical research leading to the development of new technologies needs to be embedded in a larger navigational perspective. In this perspective, as a show in Figure 18 below, there are a number of entities which are in dynamic relationship with each other. I've chosen seven to show in the diagram below (there are certainly others, but the point is made well enough with these seven). Experiences, which may in some cases be called data, are interpretively wrestled with by researchers. Out of this wrestling arise new constructs, insights on dynamics and stabilities which were previously hidden. Considering these hidden dynamics can help to refocus the common sense of researchers and teachers. In looking through this new common sense, teachers can more effectively help students to merge dynamics with the experiences, constructs, and common sense that form the target space in their instructional setting.

Figure 18

In looking at this diagram, which I've drawn with dotted lines, imagine these dotted lines as moving, somewhat like ants marching, illustrating the dynamic and evolving nature of this entire enterprise. Also notice the symmetry of this perspective. In a sense researchers, teachers, and students' are all "in the same boat." All need to merge with experiences, constructs, and a refocusing of their intuition or common sense, which will help them to merge their dynamics with the dynamics of their particular target space. For the
researcher, this target space might be seen as insights into the dynamics of instructional
interactions. For teachers, the target space might be seen as the actuality of their practice
in instructional situations. For the student the target space might be seen as the totality of
their instructional experiences, the conceptual aspects of the content, the motivational and
affective aspects of fruitfully engaging this content, as well as the social aspects of
participating in this engagement with others.

The phrase "merging dynamics" thus can refer to the merging of dynamics of each of the
three groups--researchers, teachers, and students, with their respective target spaces. But
"merging dynamics" can also refer to the merging of the overall dynamics as shown in
Figure 18. In an ideal situation, researchers, teachers, and students are engaged in a
dynamic community of learners that continues to grow and evolve, as all parties
contribute to its continued development. Where teachers, researchers, and students have
been involved in such dynamic consideration of new ways of seeing, valuing, and acting
(e.g., Brown & Sinclair, 1993; Schifter, 1993; and Fosnot, 1996), many teachers have
made profound changes in their instructional approaches, and the insights gained
contribute greatly to the overall evolution of a community of practice dedicated to more
effectively navigating the dynamics of their respective situations. The community grows,
dynamics merge more naturally and effectively, research and practice become supporting
elements of the overall dynamics (as do various research perspectives and various
instructional strategies), not separate, often antithetical entities. And this is as it should
be.

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