CHROMOSOMES ON THE MOVE:  
THE EDUCATIONAL AND NEUROLOGICAL ADVANTAGES OF USING BODY MOVEMENT TO 
TEACH CELLULAR DIVISION

A thesis presented

by

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to
The Department of Biology

In partial fulfillment of the requirements for the degree of 
Master of Science

in the field of 
Biology

Northeastern University 
Boston, Massachusetts  
October, 2012
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ABSTRACT OF THESIS

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in the Graduate School of Science of Northeastern University
October, 2012
Abstract:

As education and neuroscience begin to merge, creating the new field of brain-based education, teachers are working to integrate scientific research into the classroom. While working to improve my own teaching, I developed a lesson plan to teach mitosis and meiosis through movement. My thesis reviews education theory and neuroscience to support using movement as a teaching tool in high-level, subject-based classrooms. I then outline my lesson plan and present my investigations of its effectiveness as demonstrated through short-term memory, long-term memory, and students’ personal responses to the class.

Two experiments were completed with biology lab sections at Northeastern University between 2009 and 2012; I taught my lesson to experimental groups while control groups learned through video-based lessons. The short-term study showed significant improvement in both the grades and enjoyment of the experimental groups. The long-term, retroactive study yielded no significant data, possibly due to weaknesses in the experimental design.
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**Introduction:**

Educators teach the concepts of biology to students several times throughout their school careers, but the lessons do not always stick. Even college students, who have been exposed to the material several times, are often confused by basic processes such as cellular division. As I worked to improve my own teaching in graduate school, I developed a movement-based lesson plan for mitosis and meiosis as a way to merge my research in education theory and neuroscience with my experience in the classroom. My students appeared to enjoy the class and learn well during the lesson time and time again, and I began to wonder if there was support for my teaching technique in the literature.

My thesis begins with overviews of education theory and basic neuroscience. For centuries, philosophers, scientists, and educators have formed working hypotheses and complex structural frameworks through which to view human learning. Recent developments in education have emphasized the biological role of the brain in education as well as the variety of human learning styles.

As biologists and medical researchers unfold the mysteries of brain function, they provide educators with increasingly precise information about how students learn. The emerging field of brain-based education strives to utilize this information in the classroom to create more effective and enjoyable teaching for both the instructor and the students. My research into education, neuroscience, and the places where they converge supports the effectiveness of my cellular division lesson, particularly my use of movement.
Many authors have praised the use of movement in the classroom, but none has completed a scientific investigation of its effectiveness in higher-level, subject-based teaching. For my thesis, I investigated the effectiveness of my movement-based lesson plan in college students as demonstrated through short-term and long-term memory and students’ personal responses to the class.
Chapter I: A Brief History of Learning Theory

Part I: Basis of Modern Learning and Intelligence Theory

The roots of our current, Western school systems can be traced back to several key events. In the nineteenth century, Horace Mann championed the idea of a centralized public school system in the United States, cementing the still-held ideal of educating every child. He highlighted the practical benefits of a common education and was instrumental in Massachusetts adopting a model based on the Prussians’, often called the “factory model.” Mann did not support the idea that education’s purpose was to create docile, obedient factory workers—as the founders of the original Prussian model did; he focused on the centralization and organization inherent in the system (Jensen 2005). The Prussian model for education was state-funded and mandatory for eight years—the wealthy often sent their children for another 4 years after graduation. The schools stressed reading, writing, and arithmetic, along with other skills the state considered to be important in the burgeoning industrial revolution: ethics, duty, discipline, orderliness, respect for authority, and obedience to it. These schools made workers.

As public schools began to emerge in the United States, a revolution, of sorts, occurred simultaneously in France with Jean Piaget and Alfred Binet. While Binet developed the IQ test to test intelligence scientifically and uniformly, Piaget emerged with a complete conception of how learning took place in the brain over the course of childhood.
Binet worked in Paris, France, as a member of the Free Society for the Psychological Study of the Child, developing his intelligence test with his protégé, Theodore Simon, and later Piaget. The original purpose of the test was to determine which children in the school needed help beyond normal instruction and should be placed in a special classroom. From the start, the IQ test targeted students who were not achieving as expected in a classroom setting. Binet’s test became a scientific way to group students with similar needs into one classroom (Gardner 1993). Binet himself was particularly interested in attention span and suggestibility as key factors in school success.

The Binet-Simon Intelligence Test, commonly referred to as the IQ test, emerged from a culture of factory-model schooling, evaluating skills such as verbal ability logical/mathematical thinking, which could make or break a student's academic career. It was the first usable scientific test for intelligence, and was used throughout the world reasonably often until World War I, when the United States Army boosted its popularity when it used the test to evaluate over one million military recruits (Gardner 1993). The IQ test continues to be a staple in intelligence assessment around the world.

As Binet and Simon developed a means of measuring intelligence, Piaget studied how learning took place in children’s minds. Piaget’s assertions about child development continue to be taught as required readings in education courses today. One of his most important theories which has become almost universally accepted is that play has educational properties and is necessary for healthy child development (Pellegrini and Bohn 2005 for review). Although Piaget practically created the field of child development, his
theories can be broken down into two main categories, child-thinking and intellectual activity.

As Piaget assisted Binet in his IQ testing, he spent years observing children in semi-clinical interviews. He noticed that young children consistently answered specific kinds of questions incorrectly in a similar manner, a manner than older children and adults did not share. For example, he observed that children between the ages of 2 and 7 years old only categorized objects in terms of one of their traits—grouping all red blocks together regardless of their shape or size. Children over the age of 7 were able to group objects according to several observable traits and able to organize objects into a sequence, by size, for instance (Atherton 2011). Piaget believed that these trends indicated that as a child’s brain matured, the act of becoming older—indeed of the outside world—gave the child greater cognitive abilities (Atherton 2011).

Piaget distilled his years of observation into four stages of development: the sensorimotor stage during which children understand their world in purely sensory and physical ways (ages 0-2); the preoperational stage, or magical thinking years, when logic cannot be applied properly, and the child is highly egocentric (ages 2-7); the concrete operational stage, when children lose their egocentrism, can use logic with guidance, and develop concrete thinking (ages 7-11 or 12), and the formal operation stage, when children fully develop abstract and logical thinking (ages 11 or 12 and up) (Atherton 2011). Piaget specified that these stages were age-dependent, universal, and sequential, where each stage must be mastered by the child before progressing to the next cognitive stage.
How do children progress to the next cognitive stage? They do so through intellectual activity, the adaptation to the world. Piaget argues that intellectual activity—the end result of which is learning—occurs through two processes based on experience, assimilation, and accommodation (Zull 2002). During assimilation, a learner has an experience that matches her view of the world. She assimilates the new information into her pre-existing knowledge of how the world works. During accommodation, a learner has an experience that does not match her world view, an experience usually marked by some sort of failure. In this case, she cannot assimilate the information and must instead reform her view of the world to accommodate this new information. Through these cognitive processes, children master their current level of intellectual development and then move to the next one.

Researchers and clinicians use Piaget’s stages in everything from animal studies to robotics because they present such clearly delineated steps for progressing from one stage to the next. His stages perfectly mirror his contemporaries’ view of the brain as a highly complex and structured biological machine. Like an unobservable machine in an impenetrable black box, a brain processes defined input, i.e. stimulus, and creates observable output, i.e. behavior. Respected psychologists in the 1940’s through 1960’s, such as John Watson and B. F. Skinner, advocated for brain research that would define the relationships between the input and the output. They eventually posited that if a defined stimulus causes a specific and predictable reaction, then each stimulus moves through a predetermined pathway that can only lead to the predicted outcome. For instance, if praise makes children feel good, then praise will always make children feel good. Because of this, an adult can use praise to
elicit a positive reaction whenever they wish. Teaching techniques that appeared to apply this theory to the classroom, such as bribery, reward, and punishment were already common and apparently successful for many students.

These mid-twentieth century researchers focused so intensely on their novel mechanical views of the brain, that they simplified human interaction and response, leaving significant gaps in their theories. For instance, how could they explain the fact that some people have different reactions to the same stimulus without losing the universality of their theories? How would they account for the same person responding differently to the same input when it appears in different contexts? Many scientists at the time did not recognize the importance of experience, context, and how our brains make connections.

Not all psychologists and educators agreed with a mechanistic view of the brain. Maria Montessori is a prominent example. Born in 1870, she was the first woman in Italy to receive a medical degree before creating a comprehensive philosophy of experiential learning.

“Scientific observation has established that education is not what the teacher gives; education is a natural process spontaneously carried out by the human individual, and is acquired not by listening to words but by experiences upon the environment. The task of the teacher becomes that of preparing a series of motives of cultural activity, spread over a specially prepared environment, and then refraining from obstructive interference. Human teachers can only help the great work that is being done, as servants help the master” (Montessori 1946).
Montessori advocated for the idea that children as owners of individual potential that developed over the course of their education, not as blank slates to be programmed. As students learned to be obedient, docile, and quiet, Montessori commented that they also felt humiliated (Jensen 2005). She viewed students as whole people who needed to be challenged and supported physically, mentally, emotionally, and spiritually so they could reach their greatest potential.

A review of the history of education philosophy, would not be complete without the mention of John Dewey. Dewey wrote on the importance of experience in education and the importance of education in a democratic society. He worked with schools during the progressive movement in the early twentieth century and created a comprehensive philosophy to guide both the progressive and traditional schools. While his work is also required reading in education programs, and his philosophy of experience supports Piaget’s, he conceived of learning in a particularly modern way. Because of his ability to understand children, students, and teachers, he integrated into his philosophies ideas about human brain function before they had been proven, ideas that have only recently been supported by modern discoveries in neurology and behavioral neuroscience (such as the formation of memory).

Piaget’s schemas, and his mechanistic view of the brain, make excellent starting places for learning theory, but as discoveries prove the mind to be increasingly complex, this ordered, mechanistic view becomes less relevant. In the 1960's, William Kessen argued against the
view that the mind could only be understood by observing the inputs and outputs. His interest in how young children perceived the world, discussed in his book *The Child* (1965), began the movement to develop research beyond the mechanistic model used to guide research in the past. He suggested that instead of studying results of an input/output system—the limited available data of a black-box brain—psychologist could actually study the processes that occurred within the so-called black-box. He integrated the importance of personal experience and perception of the world with the role of biology in psychology into his theories on infant cognitive development. With Kessen, learning became an observable, complex, cycling process—not an unknowable series or steps that mysteriously linked one input to one output—if an investigator applied the correct experimental formats. His understanding of the brain laid the groundwork for a variety of new studies. “Three [major] lines of inquiry grew out of this movement: (1) the role of biology in shaping the growth of human thought and behavior (for a review, see Gilbert Gottlieb, 1976, and Gerald Edelman, 1989), (2) the role of learning and experience in perceptual development (for a review see Donald O. Hebb, 1949), and (3) the importance of cognitive development during infancy (for a review see Jerome Bruner, 1976)” (Slavkin 2004). By understanding the process by which the human brain learns, psychologists, parents and teachers could now support that process and, in turn, support greater learning. (Slavkin 2004).

During the 1960’s and 1970’s, the role of individuality in learning continued to cement itself in areas other than psychology, especially mainstream education theory and developmental biology. Lev Vygotsky, a twentieth-century Russian philosopher and
founder of the cultural-historical psychology movement, was the first to argue against Piaget’s ideas. Vygotsky reasoned that the prior knowledge of each person is different due to his perceptions of the world, especially his personal culture and experiences, even before school. Because all people have different prior knowledge, they will not develop in exactly the same way. Moreover, they will move through different stages at different times in life, possibly in different orders (Kolb and Kolb 2005). Vygotsky’s emphasis on prior knowledge fell out of mainstream thought until a resurgence of individual-centric philosophies in the 1970's. Since this time, his ideas continue to influence most education theories today.

In the last thirty years, education theory has seen another shift. As early as the 1980's, researchers such as David Kolb and Howard Gardner began picking analyzing and rethinking the learning process even further, building on Kessen's emphasis on learning as a process and Vygotsky’s focus on the individual. In 1983, while working with the Harvard Graduate School of Education, Gardner published *Frames of Mind*, the first in a series of books about his theory of Multiple Intelligences. Gardner places his theory in opposition to Binet’s image of intelligence, stating that Binet only tests the easily quantifiable linguistic and logical-mathematical forms of intelligence, leaving the other seven forms untested and, therefore, undervalued (Gardner 1993). For Gardner, the devaluation of other forms of intelligence—such as the kinesthetic, visual-spatial, and interpersonal skills that may have been particularly useful when education came in the form of apprenticeships—devalued a large number of modern students. The range of human intelligences had not changed, but the education system had. By undervaluing all but two forms of intelligence, he became
concerned that intelligent students, without verbal or logical-mathematic skills, felt stupid or unimportant, when in fact they had significant intelligence. The school systems and evaluations contain the weaknesses of being unable to find a way to quantify and assess these students properly. He argues that all individuals are born with certain levels of each form of intelligence, sometimes balanced, sometimes not. If students are weak in the areas most stressed by schools, they will tend to do poorly, not because they are incapable of learning, but because they are less capable of learning in the way material is being presented.

Gardner’s work has been the greatest popularizer of multiple-intelligence thinking as a new and useful way to look at all students, and particularly those with what are usually termed learning disabilities. But his is not the only philosophy out there. His philosophy usefully categorizes and labels observable and common tendencies. Labels help schools and even individuals better maneuver their world, but it can also be limiting. The most important aspect of Gardner’s work is the now commonplace understanding that there are different types of learners that flourish with different types of instruction. The later parts of my thesis will focus on theories that guide practical applications, and more universal ideas about, how human brains learn and function.

**Part II: Kinesthetic, Physical, and Experiential Learning Styles**

In this new world of multiple styles of learning, several authors have coined terms to coincide with their learning schemes. Movement in the classroom particularly aids certain
types of learners across the board: Howard Gardner’s special learners and body-kinesthetic learners, David Kolb’s active testers, David Hunt’s Westerners, and finally all of Dewey’s students benefitted from movement and experience. The following will briefly outline the theories of each expert and explain the benefits of the modality of movement in the author’s terms using the mitosis/meiosis and Punnett evolution lessons that appear in the appendix.

For Howard Gardner, physical learning takes place in two arenas, that of spatial intelligence and that of body-kinesthetic intelligence. Movement as a modality taps into both forms of intelligence simultaneously. He defines spatial intelligence as “the ability to form a mental model of a spatial world and to be able to maneuver and operate using that model. Sailors, engineers, surgeons, sculptors, and painters, to name just a few examples, all have highly developed spatial intelligence” (Gardner 1993). Body-kinesthetic intelligence is “the ability to solve problems or to fashion products using ones whole body, or parts of the body. Dancers, athletes, surgeons, and craftspeople all exhibit highly developed bodily-kinesthetic intelligence” (Gardner 1993). When considering a lesson plan that asks students to use their whole bodies as they move around the room as if it were, itself, a model of a cell or a continent, the relationship between spatial and body-kinesthetic learning in this class becomes clear. Gardner emphasizes specialized learning—both delivery and subject matter—that targets specific intelligences. Essentially, by putting the same material through a different mode of input, students with strengths understanding that mode of input will have greater success processing, remembering, and problem-solving with the new information.
David Kolb’s work on experiential learning theory (ELT), which built solidly on Dewey’s philosophy, led him to develop his learning style inventory (LSI) in the 1980’s. Kolb described ELT as a theory that “draws on the work of prominent 20th century scholars who gave experience a central role in their theories of human learning and development—notably John Dewey, Kurt Lewin, Jean Piaget, William James, Carl Jung, Paulo Freire, Carl Rogers and others—to develop a holistic model of the experiential learning process and a multilinear model of adult development” (Kolb and Kolb 2005). The theory depends on six propositions, which he explores, explains, and defends in his book, *Experiential Learning: Experience as the Source of Learning and Development* (Kolb 1984):

1) Learning is best conceived as a process, not in terms of outcomes.
2) All learning is *re*learning.
3) Learning requires the resolution of conflicts between dialectically opposed modes of adaptation to the world.
4) Learning is a holistic process of adaptation to the world.
5) Learning results from synergetic transactions between the person and the environment.
6) Learning is the process of creating knowledge. (Kolb and Kolb 2005)

ELT calls learning “the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience” (Kolb 1984). Kolb delineates grasping experience as happening either through Concrete Experience (CE) or Abstract Conceptualization (AC). Transforming can also be done in two ways that mirror styles of grasping, Reflective Observation (RO) and Active Experimentation (AE). All four stages of grasping and processing experience are included
in what Kolb deems the experiential learning cycle, or spiral. First, a learner has a concrete experience, which is then processed through reflective observation. These observations give rise to abstract concepts or hypotheses of the way the world works, which can then be actively tested. Once a student actively experiments with their abstract hypothesis in the physical world, they create another concrete experience, and the cycle repeats, continuously honing or expanding the information learned.

The four stages of grasping and processing in the learning cycle also relate to four areas of the cerebral cortex (figure 1). Zull describes this process in his 2002 book, *The Art of Changing the Brain*: “Concrete experiences come through the sensory cortex, reflective observation involves the integrative cortex at the back, creating new abstract concepts occurs in the frontal integrative cortex, and active testing involves the motor brain. In other words, the learning cycle arises from the structure of the brain.”
Figure 1: Experiential Learning Cycle (Zull 2002). Note the mirroring relationship between learning-cycle stages and the movement of information through the brain.

Kolb posits that “learning style describes individual differences in learning based on the learner’s preference for employing different phases of the learning cycle” (Kolb and Kolb 2005). All learners must go through the entire learning cycle to learn, but because people tend to have one particular strength in the cycle, they tend to focus on those areas while learning. If a student focuses too much on his strengths, while not bolstering his weaker processes, he will have weaker learning skills. Kolb defines his four main learning styles, each a combination of grasping and processing strengths: diverging-style learners focus on concrete experience and reflective observation, assimilating-style learners focus on abstract concepts and reflective observation, converging-style learners focus on abstract concepts and active experimentation, and accommodating-style learners focus on concrete experience and active experimentation.

In terms of Kolb’s learning styles, those with a focus on concrete experience tend to work well with movement in the classroom because it gives them a physical experience that has distinct parts: beginnings, ends, and interaction with peers. Accommodating learners are particularly well-suited for whole-body or whole-classroom modeling of concepts, as they tend to focus on active experimentation, allowing them to get an easy foothold into anything actually done in the physical world. One of the most important aspects of Kolb’s work is his emphasis on skilled learners needing to strengthen the entire learning cycle,
something that he views as happening over a lifetime.\(^1\) For this reason, Kolb cautions against the use of learning styles as stereotypes, where a person, their learning, and their behaviors are pigeonholed by the perception of her learning style.

David Hunt expanded on Kolb’s four stages of the learning cycle. Hunt posits that it can also be the single weakest stage that most actively defines a person’s learning style, as this is the part of the learning cycle with which they struggle most. These are categorized as Northern, Eastern, Southern, and Western styles of learning, based on the learning-spaces grid in figure 2. He (Hunt 1987), along with D. S. Abbey and J. C. Weiser (1985), developed a set of nine learning styles that combine Kolb’s original four styles with his four weakness-based styles and a central, well-rounded learner (Fig. 2).

\(^1\)“The Experiential Learning Theory developmental model (Kolb 1984) defines three stages: (1) acquisition, from birth to adolescence, where basic abilities and cognitive structures develop; (2) specialization, from formal schooling through the early work and personal experiences of adulthood, where social, educational, and organizational socialization forces shape the development of a particular, specialized, learning style; and (3) Integration in midcareer and later life, where non-dominant modes of learning are expressed in work and personal life. Development through these stages is characterized by increasing complexity and relativism in adapting to the world and by increased integration of the dialectic conflicts between AC and CE and AE and RO. Development is conceived as multilinear, based on an individual’s particular learning style and life path—development of CE increases affective complexity, of RO increases perceptual complexity, of AC increases symbolic complexity, and of AE increases behavioral complexity” (Kolb and Kolb 2005).
Figure 2: The Nine-Region Learning Style Grid (Kolb and Kolb 2005). Note the similarity to the overlay of learning stages on the brain from figure 1.

Again, the obvious tie between moving in the classroom and learning style is active experimentation. From the perspective of preparing for a movement activity, any learning style except those based on reflective observation in which active experimentation is a distinct weakness (eastern side of figure 2) would benefit from a certain amount of movement in the classroom, so long as it simultaneously allows for concrete experience in the physical world and time for abstract conceptualization. From the perspective of experiencing and understanding the activity, any learning style based on concrete experience and not abstract conceptualization would benefit. The learners with strengths in the areas of feeling and acting, such as north-western learners, would clearly benefit the most if movement as a modality, making it an important addition to lesson-planning.
One important aspect of the learning-spaces grid to consider is the need for all learners to be able to move between styles of learning depending on the material and manner of presentation (Kolb and Kolb 2005). The act of moving from one style of learning to another takes practice, but a learner who can do this reaps the benefits of an integrated understanding of her subject matter. This is one reason why Kolb created his development model for experiential learning theory: development essentially equals strengthening weaknesses, thereby allowing the person to move more freely between all learning spaces on the grid. Using movement as a modality in the current education system can actually improve this ability to move between learning spaces by giving students the opportunity to practice in a classroom setting. It presents a guideline for how to move between learning spaces in order to strengthen the mental skills necessary to do this effectively when guidance is not available.

Finally, Dewey speaks of all learners as experiential learners. His philosophy of experience sets out clear reasoning why experience is the core of learning and how it should be used in the classroom. Dewey views the teacher as a leader of group experiences. He cites the “loss of integration with environment” that comes with new experiences as a key factor in learning.

“The rhythm of loss of integration with environment and recovery of union not only persists in man, but becomes conscious with him; its conditions are material out of which he forms purposes. Emotion is the conscious sign of a break, actual or impending. The discord is the occasion that induces
reflection. Desire for restoration of the union converts mere emotion into interest in objects as conditions of realization of harmony. With the realization, material of reflection is incorporated into objects as their meaning" (Dewey 1934).

In short, without experiences that force students to question their understanding of the world, they will not create new meaning, new ideas, new understanding of their world.

Dewey’s emphasis on experience as the key to learning, along with Kolb’s learning stages and their relationship to both the processes of the brain and learning spaces, indicate a use for movement in the classroom beyond reaching students with specific learning styles. Using movement forces a shift in perception, in learning space, in a guided and organized way that can increase the transitional skills of any student, even those that already do well in the current school system.
Chapter 2: The Brain Moves

The brain moves information from place to place, absorbing, integrating, abstracting, and processing thought into action. The brain also moves the body, and the body affects the brain. This chapter will discuss the evolution and roles of key parts of the brain, memory formation, how the brain creates movement, and the ways action can influence the brain's processing of information.

Part I: Parts of the Brain

Our brains evolved to respond to environmental cues that influences our survival. Out of necessity, our brains monitor the physical world around us. We all experience a deep connection to the physical world in our lives, whether it be learning to walk or remembering a baseball game to help in a physics class. James Zull (2002) articulates this connection as he experienced it during research for his book *The Art of Changing the Brain*.

It seemed that I could only understand things when they were described in physical terms. My digging up facts about the brain began to help me see why. This seems to be an innate characteristic of the brain itself. All that the brain knows comes from the physical world, the things in its environment, the physical body that holds the brain itself.
Figure 1: The so-called reptilian brain contains both the brain stem (cerebellum, medulla, pons, and hindbrain) and the midbrain. The midbrain is composed of nuclei, previously termed ganglia, that control factors necessary to maintain homeostasis (e.g. thalamus, hypothalamus, pituitary gland, and suprachiasmatic nucleus). The paleomammalian brain, previously known as the limbic system, controls memory and emotion with the amygdala, hippocampus, and mammillary bodies. The most recently evolved area of the brain, the neomammalian brain or cortex, allows humans to think abstractly, plan ahead, and otherwise refine brain function into what many people term higher functions.

We possess what noted twentieth century physician and neuroscientist Paul MacLean (1967) describes as a triune brain (fig 1). As the brain evolved, it maintained traits of the existing structures that were beneficial while adding new structures when the need arose. The vertebrate brain first evolved in fish, and—while the basic parts have stayed the same—the relative proportions of brain areas changed to suit the needs of each new vertebrate class. Endothermic classes have relatively large cerebellums and optic lobes, while mammals have the largest cerebrum and a cerebellum of the vertebrate classes.
The area that has historically been called the reptilian brain (with reduced cerebellum) lies at the base of the brain and regulates most of our involuntary responses and functions. More recently, scientists have come to view the reptilian brain as being subdivided into two regions. First, the brain stem contains the cerebellum, medulla, pons, and the hindbrain. These areas mainly regulate movement and balance, both voluntary and involuntary. Second, the midbrain contains nuclei (previously termed ganglia), such as the thalamus, hypothalamus, pituitary gland, and suprachiasmatic nucleus. These areas regulate hormones, circadian cycles, temperature, blood pressure, and the central nervous system.

The next layer of the brain to develop was the paleomammalian brain, termed for its emergence in endothermic vertebrates. Currently termed the limbic system, it surrounds the reptilian brain and contains the amygdala, mammillary bodies, and hippocampus. These key areas of the brain are the foundation of memory and the emergence of emotion—particularly fear—in the animal kingdom. While many animals possess a paleomammalian brain, it remains the most basal part of human memory and emotion. The evolution of human emotion and memory are inexorably tied to social interaction and increasingly complex interactions with the external world, and therefore highly integrated into the human learning process (Kolb and Whishaw 2011, Ratey 2001).

The neomammalian brain, or cortex, developed most recently. It contains four lobes—frontal, occipital, parietal, and temporal—which are responsible for thinking abstractly, storing memory, planning detailed actions, refining lower functions with conscious thought.
and varied emotional responses, and creating associations between information stored in different parts of the brain (Carter 2009).

The adult human brain contains approximately ten billion neurons organized into many different suborgans, regions, nuclei, and lobes that tend to carry out specific functions. The more we learn about the brain, the more we find that many parts of the brain’s anatomy carry out more than one function. While there are specific parts of the brain that carry out dominant and specialized functions, these areas are plastic and often have several secondary functions and—in the case of trauma or injury—can change function if necessary. The human brain begins as undifferentiated neurons and maintains some of this plasticity throughout a person’s life. A highly adaptable organ, the brain strengthens areas that are used frequently and allows rarely-used connections to atrophy. This is particularly extreme in infants who may never fully recover the skills pruned by inaction. As an example of this process, think of a child playing with blocks to build a tower. Her brain processed information about block weight, balance, strength grip, movement of her hand and arm through space, how gravity pulls on objects. If she watches someone build with blocks on television, she may begin to understand gravity and how blocks can be stacked, but fewer parts of her brain are activated. With less activation, those parts of an infant’s brain appear less necessary and are therefore pruned so the brain can develop what it processes as more essential functions—possibly eye movement and optical processing (Jensen 2005).
One of the benefits of the human brain’s high plasticity is the ability to reassign tasks when one part of the organ is injured, as with stroke victims who learn to speak by training another area of their brain to carry out the functions usually done by Brocca’s area. In these cases, the brain registers the importance of speech through attention and repetition, thereby cuing the brain to prioritize speaking and hijack a low-priority functional area to create a new pathway for speaking (Carter 2009). This plasticity—which also allows for changing connections between areas of the brain, not just changing tasks—is essential for the learning process, as connections constantly bridge areas of the brain that may, at first glance, appear unrelated, such as the cortex and the cerebellum.

Despite this plasticity, human brains do have suborgans that can be defined by their dominant functions. The areas essential for learning—those that relate to emotion, memory, attention, and movement—are discussed here.

The amygdala processes emotion, both ours and the emotions of those around us. One of the most important roles the amygdala plays is that involved in fear. Sensory information collected in the brain passes through the amygdala before any other area, and, when the outside world appears threatening, the amygdala takes control without consulting our frontal cortex (the root of conscious thought). In short, when people feel threatened, they lose some of their ability to think through situations. Overcoming this reaction takes practice, and is a key feature in military training, when a split second of indecision could mean people’s lives (Vagg 2008). Once a student’s amygdala becomes engaged through feelings of anxiety, panic, or a perceived threat, teachers will find it increasingly difficult to
guide them through cognitive tasks without addressing the amygdala’s emotional response first. When carrying out the cell-division lesson plan described in chapter three, teachers must remain aware of the amygdala’s power to slow or stop thought through anxiety, fear, or defensiveness if a student senses a threat. For example, a student may feel nervous if a teacher enters her personal space without asking permission. A popular student may feel threatened if a teacher publicly corrects him in front of peers. A female student may feel personally offended if a teacher tries to help her manage the movement in her high heels. As soon as a the students’ bodies enter into a classroom plan, the potential for personal discomfort or implied threat—to personal space, ego, social standing, or self-perception—rises. These feelings can activate the amygdala without a student’s conscious effort, making the resulting distraction, anxiety, or slow processing speed a difficult place form which to recover.

The hippocampus—named for its seahorse shape—acts as a memory filing system and place of initial judgments on what information is important enough to store and what can be discarded. It groups and sorts sensory input by experience, linking sensory input according to their relationships with each other in time and space, and then sends these packets of memory to be stored in the appropriate area of the cortex. It is intimately connected with the amygdala, both receiving information from it an sending information to it. This is no coincidence. As scientists learn more about how memory forms, the role of emotion in memory formation appears increasingly important. For example, Larry Cahill and his colleagues showed that people with damaged amygdalas cannot remember highly emotional events as well as people with fully functioning amygdalas (Cahill et. al. 1995).
Because emotion plays a powerful role in memory retention, it also plays a powerful role in learning. Jenson (2005) discusses how our emotions affect how accurately we remember experiences as well as play key roles in what we remember and whether or not we remember at all. All the educators I know have observed this phenomenon for years in the classroom as excited, engaged, happy students tend to remember more information than bored, frustrated, angry students.

When people think about brain function, they usually imagine the uppermost layer of the brain, called the cortex. The frontal cortex houses conscious thoughts and executive functions. This is where information moves to become conscious after it has been processed by the lower parts of the brain. It also regulates such essential functions as attention, self-discipline, focus, and abstraction (Kolb and Whishaw 2011). Without these abilities, students become quickly overwhelmed in a classroom, as observed in students with Attention Deficit/Hyperactivity Disorder or any kind of Executive Function Disorder who have no techniques for coping with their deficiencies (Sousa 2007). Because this is the area of conscious thought, students can work on frontal cortex skills with the right instruction and be completely aware of their progress and needs. When students receive exposure to different techniques—such as color-coding their notes, taking short movement breaks during class, or creating a list for how to start writing a paper—they can actively support their weaker skills, which makes identifying these difficulties and providing students with support extremely important.
The motor and premotor cortex direct movement and prioritize our intentions relating to the movements we make. Anything that the body does, in which it interacts with the outside world, connects to the motor cortex, from scratching an itch to doing cartwheels to completing a precise measuring process in a lab. The motor cortex also receives information from the body. Sensory neurons, located within muscle tissue, send information about the muscle’s action back to the motor cortex to be processed for use in future actions (Carter 2009). For educators, it is important to note that the motor cortex carries out this same function in all situations in which the brain must sequence information, including those found in academia. “Higher” cognitive functions, such as placing events on a timeline, using a number line, understanding cause and effect, and organizing essays all build upon—in fact, require—the parts of the brain developed for movement.

The same connection can be seen between “higher” cognitive processes and the more basal functions of the cerebellum. The cerebellum evolved in the same way as the forebrain, in Paul MacLean’s reptilian, limbic system, and cortex layers (fig 1). The increasing functional layers of the cerebellum indicate strong connections between the functions of the cerebellum and the higher thought processes of the cortex (Ratey 2001). The cerebellum, one tenth of the brain’s volume, houses over half of all the neurons in an adult human and is essential to human movement (Kolb and Whishaw 2011, Ivry and Fiez 2000). For decades, neurologists have considered the role of the cerebellum to be singular, that of minutely timing and ordering the muscle contracts necessary to make movement possible and safe. In the last twenty years, studies—such as those conducted by W. T. Thach, H. P.
Goodkin, and J. G. Keating—have begun revealing another role of the cerebellum, that of integrating sensory feedback from a motion into a new and more accurate plan. The cerebellum appears essential to maintaining accurate movement by changing the movement plans—something previously thought to occur only in the motor cortex. Thach, Goodkin, and Keating ran an experiment in which people with functioning cerebellums (control) and those with cerebellar damage (experimental) threw three series of darts at a target. During the second series, subjects wore prism-containing glasses that shifted vision to make everything appear to the left of its actual location. The first and last series were completed without any changes to perception. The first series of darts was generally accurate for both groups, but the group trends changed for the second series. Control subjects quickly began to adjust their aim to account for the left-shift of the glasses; experimental subjects did not show a trend toward correction. In the third series, the control subjects showed an initial bias to the right before quickly correcting their aim to be close to their initial abilities. The experimental group showed no such right-leaning overcompensation; their third-round aim looked just like their first-round aim from the beginning (Thach, Goodkin, and Keating 1992). Thach, Goodkin, and Keating (1992) concluded that the cerebellum completed minute adjustments in movement by comparing its theoretically perfect plan with the actual, physical outcome as carried out by the body. When it receives sensory information about the action, it begins to recalculate its plan in order to improve its accuracy the next time. There is a striking resemblance between the cerebellum’s unconscious cycle of planning, executing, feedback, and re-planning and David Kolb’s cycle of experiential learning.
Part II: Survival, Memory, and the Classroom

What is so important that it should be remembered? What is superfluous to our survival? Needless to say, the experiences that were essential to our hunter-gatherer predecessors usually do not come up in our modern lives, but the response mechanisms in our brains are still the same (Ratey 2001).

Without evolutionary perspective on why we learn the way we do—what affects learning, how memory can be destroyed, which responses can inhibit learning and memory—teachers may not be able to overcome barriers they run into within their students. These barriers may be perfectly natural, and even effective tools for survival, but detrimental when triggered in the classroom.

People respond defensively when they feel a loss of control, for instance. A situation that causes us to feel a loss of control alerts the brain that our survival may be at risk, so we initiate control-regaining strategies. While living in modern society, we rarely face life-threatening situations, but our brains still respond defensively to loss of control in an experience such as being taught in a classroom (Zull 2002). Students who feel out of control will often act out as a way of regaining control, or even shut down to avoid that thing that they feel they cannot control. This can be particularly disruptive if students have additional issues that negatively affect their classroom performance (such as anxiety.
disorders, mood disorders, or ADHD), but it can also happen to otherwise capable students who suddenly feel overwhelmed or lost.

The brain does not like to lose control or be surprised in survival-threatenning situations, but the conscious part of the brain, the frontal cortex, takes time to process information. For this reason, the brain developed a safeguard pathway to the frontal cortex that passes information through the amygdala. As the seat of fear and the fight-or-flight response, the amygdala has a first look at sensory input to determine if it threatens the body even before that information becomes conscious. This split-second decision can cause us to duck before we realize something is coming toward us, or cause us to feel frozen with fear as information stalls at the amygdala before reaching the frontal and motor cortexes. In the classroom, this means that students can feel threatened without being conscious of the feeling or what caused it. Something as simple as being reprimanded during class can activate the student’s amygdala, leaving them unable to concentrate or regain their focus until their frontal lobes can regain control. Even if a student does not consciously feel threatened—they know that they were talking in class and that the teacher should have told them to be quiet—their amygdala may still activate an anxiety or defensive response that overrides attention.

Sensory input triggering an amygdala response, evolutionarily, implies danger, no matter what the original input might have been. Humans often act on those “gut” feelings—our term for unconscious amygdala response. Emotions evolved for many purposes, one of which appears to be as a way to emphasize experience (Ratey 2001, Kolb and Whishaw
When we feel something, we remember it more intensely. When something hurts us, we don’t want to experience that thing anymore. When something makes us feel good, we want more of it. A human being cannot respond equally to all input, but if he eats something that gives him a stomach ache, that qualifies as important. If he finds a better way to kill prey, or encounters danger while attacking the wrong prey, these are lessons that the hippocampus deems important enough to store. These experiences elicit a strong emotional response, which in turn, triggers learning. The stronger this response, positive or negative, the faster the lesson learned. Every child learns quickly that a stove will burn her and that sugar tastes good. Pain, in particular, cues our conscious brain to imminent bodily danger. To observe the advantages to feelings like pain, one need only study patients with congenital insensitivity to pain (CIP) or analgesia. These people are often unaware of infections or injuries that could have negative long-lasting effects on their health. Emotions can have strong effects on the memories we make, how they are remembered, and if they are organized in such a way that makes them retrievable quickly in times of need. They help our brains filter what is important and what can be ignored.

In school, emotion affects student learning by creating internal responses to the experience of being in the classroom. As Dewey, Levine, Jensen, Novak, and others have pointed out, students always have experiences, even if those experiences are not what the teacher planned. For instance, a student might not learn cellular respiration in a given class, but he may learn whether or not the teacher thinks the subject is interesting or boring. He has a classroom experience, and learning—processing input and turning it into memory—is a
part of it. The question now arises, which sensory input will remain in the brain as memory, and which input will be discarded as unimportant or unprocessed information?

With our brains filtering so much input—both external input and internal responses—what makes an experience rich? Why do we remember some things in detail and not others? In the simplest terms, it is the quality, amount, and emotional responses of the input we are receiving. From this it follows that the greater teachers can make a targeted, effective—not overwhelming—sensory input from the physical world, the greater the memory that can be formed within the student.

Teachers can magnify inputs by increasing the intensity of a single sense, making material louder, brighter, or bigger. Many of these techniques are recommended by brain-based learning advocates, such as Jensen, and elementary school educators whose students are just learning to focus their own attention and hone their movement skills (for review see Robertson 2004). Input can also be magnified by increasing the variability of input. A teacher speaks to a student so he can auditorily process her lesson. She draws on the board so he can hear and see. She speaks, draws, and hands a student a sample so he can hear and see and feel and do. The more complex an experience, the more sensory input is contained in that one experience (Zull 2002, Dewey 1938, Jensen 2005). With more input, the student has more sensory options to choose from when grasping the material. He has more ways the material may spark his interest, disgust, or any feeling that will indicate to the brain that this is an experience worth remembering.
A traditional classroom often reduces chances for students to move their bodies, thereby significantly reducing a large range of potential input. To move a body, a brain must integrate complex series of external and internal information. All of these inputs become associated with the activity being performed at the time. When students stand up and walk around after a long lecture, they might feel relief, a release of physical and mental tension. If they are asked to stand up after a long lecture in order to act out a behavior, or model a process, some of those internal-input feelings of stretching and the release of muscle tension will be associated with the activity they are asked to perform.

Using movement therefore benefits the teacher in two ways. First, it expands the types of input a student receives. Second, the teacher can co-opt the natural body responses to movement to use in her lesson plan. She takes a physical need—to move around periodically—and integrates it into the learning experience. In this way, students are less distracted while learning (Bovee 2011), feel that their natural impulses to move are not restricted or labeled as wrong, gain the benefits of movement, and, with a little help from the teacher, can understand the role of the whole body in cognition.

If memory formation is the groundwork for all learning, there are two key factors to note for our purposes: 1) learning and memory formation require time, and 2) there are data limitations for each stage for the process. These can often inhibit learning in traditional classrooms where time is not provided for memory storage and data processing.
The first step of memory formation, of learning, usually begins in the frontal lobes. The frontal lobes are known to regulate executive function tasks, such as directing attention, maintaining and breaking focus at the proper times, organizing thoughts and plans of action, and reminding the brain to continue with an important activity even if other desires arise. In addition to influencing how we take in information, the frontal lobes contain most of our short-term visual memory, after the brain receives it from our ocular nerves. Short-term memory is limited to an average of four sets of information (Linden et al. (2003) used a complex shape to represent one set of information) before the brain begins to miss new input or needs to drop previously held information (Linden et al., 2003). Without time to store information properly, students' brains will reach a point when their working memories must drop information before taking in more. Whether the first lessons of a class are dropped, or the later lessons are never grasped, the students cannot retain all of the learning. Using movement provides processing time because moving takes time and provides a non-material focus for students during down time, such as standing, looking around, walking to a new position.

The second step in moving information from short-term to long-term memory involves protein synthesis. “The physical process of building connections for explicit learning begins within 15 minutes of exposure to new information, and the synaptic connections continue to strengthen during the next hour,” (Jensen 2005). Neurons recycle and reform proteins during this time (For more on protein formation and recycling in brain function, see Dodart, Mathis, and Ungerer, 2000; Mansuy and Shenolikar, 2006; Lesne, et al. 2006). Schroth (1992) first described this phenomenon and the need for learning to integrate
breaks or rest sessions during which these physiological processes can be accomplished. Goda and Davis (2003) showed that it can take up to six hours for these synapses to form completely. This can be quite a challenge when, as described by Milner (1999), a memory can be lost if it is disturbed during the process of setting itself into the neurons. Many experts, including Hobson, Milner, Sanes, and Lichtman, agree with neuroscientist Terry Sejnowsky when he suggested his own solution to the need for breaks in learning, “Learn, discuss, then take a walk,” (quoted in Jensen 2005). The shorter breaks inherent in lab experiments and my movement lesson do not negate the brain’s need for longer breaks between exposure to novel information. Students’ brains constantly begin the cycle of cementing new information as it is being presented, which can be facilitated by small, frequent breaks from the material. When students’ brains reach their limit of short-term information, they require time to complete building the neural connections of long-term memory, usually at least an hour, and sometimes a whole night’s sleep (Schroth 1992).

The hippocampus does much of its organization and distribution of memory to various parts of the brain during sleep (Stickgold 2005), but does not have high capacity to hold information that has not been consolidated—turned from electrical and chemical input into memory (Kelso 1997). This leads to obvious problems when students are asked to learn extensive amounts of information in one day. At a certain point in the day, they will not be able, physically, to hold new information in their brains without time to consolidate and form memories.
It is in the hippocampus—the essential organ of memory and consolidation—that emotion and judgment are integrated into memory formation. In the brain, the question of what is important is rarely determined by the teacher. She may say what is important to learn, but the individual doing the learning must agree, must care about the subject, care about the test, or simply have a strong reaction to the data presented. The purpose of the “What is important?” function of the hippocampus is an evolutionary one and can not be overpowered by an outside force without the student’s agreement. A student can judge something to be important in two ways: unconsciously or consciously. Many times students judge material to be important unconsciously when it interests them or relates to a topic that does, i.e., their future career. Other times students must consciously activate their executive functions of attention and focus to indicate the importance of lessons, i.e. reminding themselves that this material will help them reach their goal of good MCAT scores.

Once consolidated by the hippocampus, input can either become a short-term/working memory, or a long-term memory. These two types of memory differ greatly in their formation, location, and function in the brain. For example, depending on the information received, the brain will store the resulting memory in a different location in the cortex. Memories of sequences and how objects, steps, or concepts can be put into an order are localized in the motor cortex (Zull 2002, Wickelgren 1999). Short-term memory is used by the brain while it is actively solving problems, not as an information source. Informative, long-term memory learning tends to be the focus for educators and will be the focus here.
Long-term memory can become either implicit or explicit. The first type of long-term memory, implicit memory, tends to influence our feelings and responses unconsciously, while explicit memory is remembered consciously and can therefore be deliberately recalled. One of the best examples of this difference is conveyed by LeDoux (1998) in his book *The Emotional Brain*. He recounts a story told to him by French physician Edouard Claparede. Claparede had an amnesia patient who did not remember him, so at the beginning of each appointment Claparede introduced himself and shook the patient’s hand. One day, Claparede hid a pin in his hand and pricked his patient during their handshake. The following appointment, the patient entered the room and introduced himself, but was hesitant to shake hands. The patient did not know why he did not want to shake the stranger’s hand, but Claparede accurately discerned that it was because the man’s implicit memory mechanisms had not been damaged when he acquired amnesia.

Implicit memory is a powerful source of emotions, as with Claparede’s patient, and a source of skills we use every day, such as walking and moving our mouths to form words. It can affect what people are willing to change—most people can easily override or supplement their explicit memories because they are conscious and can be manipulated consciously, but stick stubbornly to their implicit ones (Zull 202). Implicit memories contain both sensory input from an event and the unconscious emotions surrounding that experience. “Long-term memory mechanisms that lead to encoding, transcription, and synaptic growth are *modulatory dependent*, meaning that they need the presence of emotions,” (Jensen 2005). These emotions, necessary to create the memory, can color our perspective in ways in which we are not aware.
The connection between emotion and implicit memory—along with the human aversion to implicit-memory change—can be a complex obstacle for teachers. If a student has an itch in class, needs to use the bathroom, or can't get a cramp out of his leg, his experience will be tainted by those emotions of frustration, and this may begin to interfere with his learning. His teacher has no control over these unconscious aspects of his experience, yet they might become the most lasting memories of the class, teacher, or subject. One way teachers have been managing these effects for decades is by using classroom design to create unconscious cues for their students to be relaxed, open, and engaged. Movement-based lessons provide another technique for managing students' unconscious responses that so often arise in modern high-school and college classrooms. Movement provides a muscular release from sitting that usually comes as a welcome break for students, and suddenly, increasingly positive implicit memories can be formed.

The second form of long-term memories are explicit memories. Teachers usually spend most of their time considering how to develop their students' explicit memory, not implicit memories. How will students remember the facts I am telling them? Will they be able to access these ideas when they need to solve a problem? Teachers tend to think well about explicit memories, but sometimes forget that almost all explicit memories are also episodic memories that contain conscious perceptions and unconscious feelings.

“Episodic memories are stories. They are the memories we reweave as we recreate an event or an episode in our life,” (Zull 2002). They are highly integrative, and therefore can
be swayed by many factors, our feelings about the episode, the information received from others after it was finished, and our understanding of what happened before and after the event itself. These are the memories from which we build ideas about ourselves and our lives. These are the memories that store complex concepts, such as those in science and art. These are the ideas that people tend to remember most, and in which people tend to be the most confident. These are the memories teachers test with process-based and essay questions.

It turns out that explicit, long-term memories all form in the same place, the hippocampus (fig. 3). The hippocampus has long been known to be involved with memories associated with location and place, essential to any organism that moves and particularly to those ancestors of ours that traveled wide swaths of land for food and shelter. Eleanor Maguire and her team (2000) demonstrated this in their now-famous study of London taxi drivers and their enlarged hippocampi. The hippocampus “is now thought to be the route taken by all the information in the surrounding integrative cortex for the back cortex [a key receiver of sensory, especially visual, data]. The current idea is that sensory input, which has been integrated into images, patterns, faces, sounds, and location all finds its way there” (Zull 2002). The hippocampus—during the process of consolidation—groups these facts by episodes, adding pieces of information to the memory of one event if they are at all associated with that event. At this point, the pieces of the episodic memory all relate to each other, and the memory is formed.
Figure 3: Central location of the amygdala and hippocampus.

Episodic memories, once formed in the hippocampus, are returned to the cortex for storage. The grouped information can then be recalled or reassembled later. Jensen points out that when we do recall information, it is not always the exact same memory we stored. Our memories must be reassembled when we remember them, because we must “unpack” them from where they are stored in the cortex. This can lead to distortions and confusion (Jensen 2005, Ratey 2001). The more sensory data associated with an experience, the more there is to integrate and therefore, the more dynamic a memory can become. Bryan Kolb and Ian Whishaw (2011) point out that simple learning, such as learning that a stove is hot or learning a single word, usually happens quickly and accurately. In these lessons, sensory data appears extremely powerful in comparison to the lesson learned. If a child burns himself, he feels a lot of pain, but only has to remember not to touch the stove. This type of consolidation also happens when children are deeply connected to the touch, smell, and look one toy. If she learns that toy’s name, she can manipulate situations so that she can always have her toy by remembering only one word. If teachers can increase the sensory input associated with more complex lessons (along the lines of learning toy names,
and not corporal punishment), they may be able to begin to shift the balance. Giving a student more to work with helps her understanding and her brain can then store that memory in a concise neural short-hand, in the same way that the brain stores well-learned muscle memory. More information may also lead to greater checks and balances within a memory, leading to better recall and less distortion when memories are revisited (Jensen 2005).

More information is not always new information, but revisions of previous learning. Human beings maintain huge neural networks by the time they enter kindergarten, and even greater ones by the time they take their first biology classes. Existing knowledge found in these networks, or mental models, influences everything a student learns (Altman 2002, Steussy 2002). Often, learning can be difficult because it conflicts with pre-existing knowledge that is wrong, what Jensen (2005) calls “bogus mental models.” If this is the case, a teacher must determine the problem and find a way to re-teach the material that was previously misunderstood. This can be one of the most difficult challenges a teacher, and student, can face.

Students’ existing knowledge can also be a benefit to teachers, representing extensive neural networks that can be activated and tied into a new experience. For instance, people learn how to walk and speak, shake hands, and hold objects early in their lives. Neural networks store this information; it is previous learning. All associations—conscious, subconscious, and emotional—are also previous learning. Many of these are cultural and are therefore more universal and easier to draw upon in a lesson where many of the
children share this knowledge. Teachers often do this without prior planning by using examples or metaphors from mass culture to explain biological concepts—such as describing a cell’s organelles in terms of an American city or describing the organization of cells into tissues in terms of offensive and defensive players on a football team. By tapping into these existing neural networks, teachers achieve greater understanding, memory, and creative thinking in their students.

In short, these pre-existing mental models can act as powerful support systems for new information, if the instructor can find a way to integrate these models into the new learning in her classroom. As Jensen (2005) states, “It is reasonably easy to learn something that matches or extends an existing mental model.” Put another way, an instructor can strengthen a student’s learning of new material by integrating it into networks of previous knowledge. This, of course, assumes that previous learning is accurate, although, even if it is not accurate, it will still act as the scaffolding for new information. Years of building new learning on a foundation of inaccurate knowledge can lead to deep misunderstandings down the line. By using previous knowledge networks in a motion-based lesson plan—even the simplest knowledge like standing, walking, holding objects, standing in lines—the teacher strengthens new associations made in her classroom by tapping into some of the strongest learning that has already taken place without overtly supporting potentially inaccurate groundwork. While this occurs with many types of learning—reading the board taps into learning how to read, listening to a lecture taps into learning how to speak and understand language—movement is often associated with pleasure and non-academic activities. By associating experiences that can happen outside the classroom with
classroom learning, a teacher can sometimes instill greater learning in her students as, when they leave the classroom, they can be, conversely, reminded of a lesson. If students are asked to stand in two lines to represent sister chromatids paired off in the metaphase plate, they might think of this again when standing in two parallel lines at a movie theater. The new learning may be associated with relatively permanent, previous knowledge—such as how to wait in line, hold hands, or dance in a group.

In terms of memory, the pathways associated with what is commonly termed a fight-or-flight response can also affect memory through the release of hormones such as adrenaline and cortisol. James McGaugh and Benno Roozendaal (2002) proved the positive effects of adrenal stress hormones, namely the short-term stress hormones (epinephrine and glucocorticoids) injected into the blood stream, on rat memory. In 2005, Sonia Lupien and her team published a paper reviewing the role of glucocorticoids on both the hippocampus and frontal lobes of young teenagers through elderly subjects. They found reduction in hippocampal size and high sensitivity to both short and long-term exposure to high glucocorticoid levels as well as a negative relationship between stress, endogenously high glucocorticoids. “Altogether, the results of these studies show that both bottom–up (effects of glucocorticoids on cognitive function), and top–down (effects of cognitive processing on glucocorticoid secretion) effects exist in the human population,”(Lupien et. al. 2005). Other research shows that high levels of cortisol, a longer-lasting stress hormone, can deteriorate and even kill cells in the hippocampus. This cortisol reaction can permanently affect memory and may be one of the causes of post-traumatic stress disorder (For review, see
Sometimes, though, the amygdala will miss raw sensory data that might indicate danger. This is where the hippocampus comes in.

The hippocampus structures our diverse sensory input into episodes, grouping similar memories together. These memories are then either released back to the cortex for storage, or they move through the fornix (Fig. 2) and find their way back to the deep brain, circling around to the amygdala. Here, because of the route taken out of the hippocampus, the episode can be reevaluated for danger or pleasure. It can also be reevaluated for importance. Again, the increase in sensory stimulus caused by movement increases the number of sensory memories associated with an episode. This may lead the hippocampus to consider a specific event as important, therefore sending it through the fornix, and being judged by the amygdala.

Daniel Schacter and his colleagues (1996) found physical evidence of the importance of original sensory information in accurate memory formation, what he terms “true memories.” They studied the difference between true and false memories in the brain using positron emission tomography (PET) scans. When a person recalled a false memory, their hippocampus became activated. This makes sense, as most false memories are associated with true episodes that lay the factual, sensory, and emotional groundwork for creativity (Navarro and Karlins 2008). When a person recalled a true memory, her hippocampus activated and the part of the cortex that originally received the key sensory input was also activated. Memories appear to be innately tied to the physical stimulus received during the real event. It follows, then, to hypothesize that an episode can create a
stronger memory by inputting more stimuli into the brain, and therefore causing observable activity in more areas of the sensory cortex during recall. This has been tested over the last thirty years with students learning Spanish and mathematics. These studies introduced seemingly random sensory cues into the classroom to improve memory, cues such as odor (Schab 1991, Bahrick 1984, and Bahrick and Hall 1991) and variations in spatial orientation (Rosenzweig et al 2003). These studies showed that sensory cues, even those not related to the material, can trigger memories. The stronger the cue given at the time of teaching, such as the highly stimulating smell of chocolate or peppermint (Schab 1991), the easier it is for the person to remember the lesson after time has passed and they are again given the sensory stimulus. Even the spatial cues, such as a room or body position in which you learned, can positively affect retrieval when repeated (Rosenzweig et al 2003). Sensory cues are key to making lasting memories.

**Part III: Action and Brain**

Only animals that need to move possess brains (Ratey 2001). Even tunicates—an early marine chordate—lose their brains once the mobile young become sessile adults. The evolution of the brain is innately tied to movement, and, subsequently, so is learning. “The doing part of learning is the natural last step in the biological sequence that characterizes nervous systems: Sense => Integrate => Act” (Zull 2002).

Once the right skills are learned, though, they are stored back in the cortex (the putamen and parietal cortex for complex motor skills) in a kind of shorthand that can be easily and
quickly triggered by other parts of the brain. The dorsal visual pathway activates the putamen, an area of the basal ganglia that stores what can be called a movement-memory index, which, in turn, sends a signal to the parietal cortex, indicating which set of motor sequences to initiate.

The differentiation between conscious action and unconscious action also applies to cognitive processes. Evolutionarily, humans have depended on more than just sequences of motor skills to survive. The cognitive ability to connect predator spoor with danger, or the smell of decomposition with spoiled food, has been essential to our survival. For this reason, the processes used for these seemingly simple cognitive lessons are the basis of processes students apply in the classroom. When students are learning a concept, their minds process the information slowly because it must move through more areas of the brain than if they are merely recalling a concept. New learning moves through the conscious areas of their brains as they think; through their cerebellums as they sequence the information; and through their hippocampi as they make judgments, sort information, and form memories. This is why, once a concept is practiced and learned—understood, remembered, and stored back in the cortex—the student can apply this concept more quickly in the future.

Because humans are social animals, we have also developed survival skills that help us live as part of a group. Studies in the last fifteen years have identified a set of neurons that are located in front of the premotor cortex, connecting with the frontal cortex, and have been named mirror neurons (Kolb and Whishaw 2011). Mirror neurons, as the name suggests,
play a key role in an individual's desire to mirror the actions of those around her. They can be essential in social organisms, and were, in fact, discovered by accident during a neural study on macaques (Lindstrom 2010). While the monkey was attached to laboratory equipment that monitored brain activity during motion—specifically, picking up and eating food—one of the lab assistants entered the room eating something himself. As the macaque watched the poorly-trained assistant, its brain activity lit up the machine, indicating high activity in the same locations that became active when the macaque reached for and ate food himself. Needless to say, the focus of the study shifted after this accidental breakthrough!

The evolutionary benefits of mimicry in social animals have led to highly-developed mirror neurons in humans. Human mirror neurons not only initiate the desire to act the way an observed subject acts, but also enhance our understanding of that subject’s emotions and intentions while simultaneously considering context. Mirror neurons become active more often than motor neurons: they are activated when an action is carried out and when the same action is observed. In this way, students benefit from performing group activities where they can watch their peers and physically attempt the same actions.

The human brain evolved to gather information from the environment, move, and gather information from movement itself. Like the cortex-covered parts of the brain, the cerebellum evolved three levels of function that have become increasingly complex and involved with other parts of the brain. Neural routes established for the necessities of movement are also the pathways used to complete what people have previously
considered purely cognitive tasks (Jensen 2005). Many steps needed to initiate movement can be applied to cognition and the learning cycle. Both require planning actions, sequencing using the cerebellum and motor cortex, learning timing, mirroring modeled behavior, accessing previously learned memory, revising an action plan for another attempt, and turning thoughts into the actions.

At the end of the learning cycle, information becomes action. Without action, people cannot test their ideas and receive new input to hone concepts further; they cannot start the cycle again (see chapter 1). In addition to the direct action the brain must take to cause motion, movement in general (and exercise specifically) has extensive benefits for learning. Even in a relatively short lesson plan, body motion can increase learning potential.

The brain demands huge amounts of energy and oxygen, demands that are only matched by the entire digestive system (Evolve 2008). As with any organ, it works best when provided with all the energy and oxygen it requires, and performance flags when these inputs are reduced. The corollary to this statement is that when energy- and oxygen-flow to the brain are increased, the brain functions better. Teachers often forget these physiology basics when they enter the classroom.

First, students sit in a classroom. Sitting removes the stress of standing, which in turn reduces the energy spent by the muscles to maintain organs at their highest levels of functioning—something that happens naturally when standing up. By using less energy, blood flow is also reduced. This may not be a problem for the still muscles, but it can
become a problem for the brain. Exercise is the best way to increase blood flow to the brain. Studies have been highly effective at proving the importance of exercise in conjunction with classroom learning (Jensen 2005, Hannaford 2005, Sladkey 2009, Dennison and Dennison 1994). In most situations, a classroom teacher cannot oversee personal exercise and other life-style factors that affect brain function—such as early childhood development, sleep, diet, and hydration—despite the positive classroom effects of these behaviors. Teachers can use this information, though, to enhance their lesson planning. For instance, if a teacher notes the fact that simply standing up can increase the human pulse by 5-8% (Jensen 2005), she may initiate classroom designs that force students to move around the room to perform the assigned activities. Enough of these small activities throughout a classroom for a whole term may significantly enhance student brain function and learning.

Any moving organism learns its first lessons through body-learning—the movement of the body and its relation to the physical world. A typical child learns to balance, eat, and grasp before he progresses to the “higher” learning of language and non-physical concepts. Even our most basic mode of transportation, walking on two legs, has to be learned over the course of years before it can be completely mastered (Evolve 2008, Ulrich and Ulrich 1995, 2001). Walking involves balance, constant input processing, coordination, and the smooth timing of many sets of muscle contractions and releases. The mastery of these processes may in fact have been a key factor in human evolution, allowing the arms to remain free while walking and running (Nordlander 2008). Not surprisingly, these key behaviors and lessons are monitored and stored in some of the most basal parts of the brain, the
cerebellum and basal ganglia. All subsequent learning passes through these areas, which continue to link motor, sensory, and memory information to new tasks (Ratey, 2001).

The learning brain consistently activates more neural space than a brain repeating previous lessons that have already been stored in the cortex. This greater activity increases retention and stimulates the motor neuron complexes. These neurons, previously defined only by their role in controlling movement, run parallel functions with what one might call purely cognitive processes. As John Ratey (2001) states: “During physical activities, we not only exercise our muscles, we also exercise our brains, particularly our ability to sequence motor actions and information as well as access memory. [Therefore, when we use such simple techniques as mouthing words or counting on fingers,] we approach the task from different modalities, using shared neurons, increasing our chances of cementing the learning.” The processes involved in learning and moving are so linked that movement development has been shown to influence directly such cognitive processes as language acquisition and learning to walk (Acredolo and Goodwyn, Ulrich and Ulrich 1995, 2001).

Most teachers understand that the more modes with which you teach, the more likely students are to learn the material. Increased neural activity, as described above, presents a clear, biological explanation for this. When dealing specifically with body-based learning, some researchers have gone further, documenting the ability of the body to learn and remember without conscious thought. This issue often arises in relation to traumatic events, as described by Peter Levine in Waking the Tiger (1997), but its innate truth is also
so common as to be used in sayings such as “it’s like riding a bike.” Everybody understands that a person’s body remembers how to ride a bike even without practice. Integrating this aspect of memory into a lesson may increase retention and the learner’s ability to access and apply knowledge later.

While movement increases memory, effective learning cannot be defined as retention alone. It also involves the application of knowledge to new situations and the integration of these new situations back into a bank of knowledge. Kolb and Kolb (2001) discuss the importance of the “capacity to adapt flexibly to changing learning contexts” as a trademark of adult development and the basis for their experiential learning theory. For most students in school today, movement is a new circumstance to which they have never applied their “book” learning. When students transpose a concept from a drawing, text, or lecture onto a physical space, a group of students, or their own bodies, they must complete two tasks: first, they manipulate information while, second, they maintain its inner organization so that the meaning can remain in the new form. In this way movement lessons, themselves, can act as practice for applying knowledge to different situations and modes of communication. When a student completes a lesson, the new form information takes within the framework of movement must be integrated back into the student’s previous knowledge. This may encourage students to connect pieces of information into a network of understanding on which they can continue to build. It is the same process through which the cerebellum constantly corrects for greater accuracy in our movements (Thach, Goodkin, and Keating 1992). It is, in fact, the same “process of locomotion through the learning regions” that Kolb and Kolb define as “true learning,” (Kolb and Kolb, 2005).
Finally, one of the most essential but difficult skills to teach students is that of problem-solving in the external world. Dewey (1934) says that “nothing takes root in mind when there is no balance between doing and receiving” while discussing the constant loss and regaining of a learner’s integration with the environment. Kolb and Kolb (2005) echo this sentiment in their observations of the effective learning done at the Cleveland Institute of Art where students constantly receive information, process it, and place it back into the world again to be critiqued—which starts the cycle over. Zull (2002) points out that acting may be the most important part of the learning cycle because it completes the circle, bringing the learned material inside the student to the outside world of experience.

“Studies suggest that challenge and feedback are necessary to maximize learning” (Ratey, 2001), and working with a motion-based lesson plan involves the kind of quick feedback most beneficial for learners (Christophel 1990, Chesebro and McCrosky 2001). Students look around at how they fit into the system of the entire class; they hear the questions and directions of the teacher. Their brains are actively processing input and the relation of their output to the external world and getting feedback from both students and their teacher. Learning by standing and moving increases the number of active pathways in the brain and provides immediate feedback, a factor that has been shown to enhance learning (Mulder and Hulstijn, 1985; Ryan, Blakeslee, and Furst, 1986; Swinnen, 1996).

The more we learn about the brain, the more we understand the essential role that movement plays in its functioning and evolution. Movement-based lessons support purely
cognitive learning in two basic ways: first, students can use more basic types of learning, such as those required when learning to walk, activating deeper parts of the brain and cerebellum that manage balance, posture, coordination, and location. Second, students can use the parallel physical neural pathways to support cognitive pathways that may be weaker, compensating for and supporting cognitive function. Despite the large number of authors, scientists, educators, and researchers writing on this topic, there are very few analyses of lesson plans that evaluate how well movement-based lesson plans may increase learning. While many lessons have been proposed, I have yet to find a study that uses statistics and control groups to study the effectiveness of these proposals. The following chapters present a cell-division lesson plan I have developed that integrates the information above into an example classroom application and a review of data collected from students in classes where I have used this lesson.
Chapter 3: Mitosis and Meiosis Lesson Plan

This chapter outlines a movement-based lesson plan about cellular division. By acting out the roles of chromatids using their whole bodies and beads that pop together without string (often used in genetics classes), students get to leave their seats and work as a group while turning the lists of mitotic and meiotic stages into continuous action. They will leave the class with a greater appreciation for the order and logic of the stages of cell division and along with an understanding of why scientists find it useful to break down a fluid process into distinct phases that do not correspond to pauses in cellular action.

Part I: Common Difficulties with Mitosis and Meiosis

From my years of teaching and tutoring, I have observed that students grasp the beginning and end of cell division first, then struggle with what lies in between. These difficulties may develop from any number of causes—personal assumption, inaccurate prior learning, simple confusion—but they do tend to fall into several basic categories. Students often have difficulty learning the order of the phases, the similar-sounding vocabulary, and the differences and similarities between the two processes. Even when students cover this material in a class for a second or third time, the same problems arise. How can teachers in middle school, high school, and even college, teach this subject so that students retain the material correctly and thoroughly?
All of these common misunderstandings can be remedied with a better understanding of the basic process itself. Without the big picture, students are stuck with pure memorization. When learning a subject that is a physical, moving process, one of the best ways to learn is to understand the overarching concepts and use these as scaffolding for specifics. As students learn more vocabulary, labels, and specific aspects of the process, they can place each one within an already established framework—the big-picture scaffolding—so that the information remains organized in the brain and easier to remember.

When posed as a memorization problem, the order of the phases can cause difficulty for students. They miss the connections between phases that indicate their logical order. For instance, a cell cannot properly carry out anaphase if the metaphase plate has yet to form, but if a student only knows the basic facts and vocabulary, they may not make these connections. I have observed that shifting the focus from the labels to the process can benefit students. When scientists first observed cell division, they saw the process—not the labels. If a student understands the entire process, it becomes easy to create labels for specific moments within that process because she can draw on an understanding of the entire event to support her use of vocabulary and recall. If a student only understands the labels, he can easily miss the connections between steps in the process, making it difficult to conceive of the entire event.

Cell division vocabulary can be even more difficult. The same learning technique can be employed, and will help many students. If students understand the process and can point
out what needs a name and how each of these elements changes, their brains are more likely to remember the names once they are given. The vocabulary will be easier to remember when students first see the need for a biological element to have a specific name. For instance, when students learn that Down's Syndrome is often caused by two sister chromatids moving to the same pole, they begin to see that doctors and researchers need a name to describe this phenomenon. When understanding of the concept precedes memorization of the word in this way, the process of learning forces the student to internalize the need for a word. Her brain asks the question “What is this called?” thereby creating a context for the answer. When a teacher then presents the word, the student already has a context in which to place it. There is a need for the word to exist and a place for it in the biological process.

Having a framework on which to hang words helps, especially when the words still sound similar and are easily confused. Here, the larger connections made by physically modeling the process can be extremely useful. Movement-based models allow teachers to consistently use the same vocabulary in their directions and thereby familiarize students with the words while linking each cellular element to a physical person in the space. Soon, each word becomes more than a concept. For example “I am standing next to my sister chromatid, and we do this for a lot of the process.” “I am moving toward a centriole and away from my sister chromatid, so the centrioles are always at the poles.” Rich associations aid in memory retrieval, and hearing words used in directions forces students either to ask questions or reason out a word’s meaning on their own. Both of these processes allow the brain time and references with which to strengthen memory.
When tackling the differences and similarities between mitosis and meiosis, I have found it most helpful to focus on the reasons why the processes are different in terms of the outcome. For instance, when teaching the fact that all genes are only duplicated once, instruct students to run through the single and double cytokinesis phases in the two processes, and then work backwards to the DNA replication. Students will find that there are always four copies of the genes after the G2 phase, whether in a pre-divided cell, two diploid cells, or four haploid cells. The same can be done for crossing over. ‘Why does this happen?’ is innately tied to the question ‘When does this happen?’ Many of my students have also commented on how helpful it was to act out the process. They can easily remember standing in monochrome sets of two for mitosis metaphase (where crossing over was not possible) verses standing in multi-colored sets of four for metaphase I (where crossing over was possible). This also helps students clarify precisely crossing over happens. Students retain much more vivid memories of the experience in which they participate than they do of the pictures in the text or classroom posters.

Finally, students often reach a conceptual stumbling block when they try to turn the lists of steps for each phase into a fluid process. Phase labels help humans conceptualize important moments, but they also turn a series of linking movements into static outlines. Ironically, a sense of the moving process can aid in ordering and remembering the reasons behind each step because there is a logic to cell division. Turning each phase into a moving model links steps, connects phases, and helps students understand what must happen in each phase because they understand how each single event fits into the longer process.
Cellular division relates to many areas of biological study from mutation and evolution to cancer and other human diseases. While teachers should not overwhelm students during an activity to the point that they can no longer pay attention, they should bring into the lesson cell division’s connections to other fields. This often helps students find a foothold of interest in the subject. The more connections a teacher can reasonably make during the time when students are moving, the better. This forces students’ brains to connect these facts with the rest of the rich sensory experience of acting out cell division. See Appendix A for more relevant questions.

**Part II: Development**

After teaching cellular division units to high-school students for several years, I began working with college students as a TA at Northeastern University. When presented with the department's standard lesson plan, I knew that I wanted to add to the teaching material. The lesson presented to me involved diagrams, talking, and searching through slides to find the different phases of mitosis and meiosis in root-tips and testes. I anticipated my college students having the same difficulties my high-school students encountered, particularly those previously described. I set about trying to find additional ways to explain the information in a way that students would remember.

The first decision I made was to review, as much as possible, both processes at the same time. While explaining mitosis, I consistently preview aspects of meiosis. With many
classes I had the luxury of running the lab after they had been introduced to both processes in lecture and reading. For these students, moving back and forth between the two forms of cell division forced them to keep several sets of facts in their head at one time, emphasizing the connections between the two. In this way, the students first find consistency between the two types of cellular division, then integrate the differences in the process which reflect the different needs of somatic cells and gametes. Some of my classes had not heard or read about the processes since high school. For these students, I hoped that moving back and forth between the two processes would create one concept, “cell division,” that could then be categorized into somatic-cell or gamete creation according to specific differences.

The next decision I made was to involve movement. For this, I began to follow the suggestions of my peers and supervisors by reviewing videos of real cells and cartoons. I found the movement in these videos to be helpful, but the videos themselves rely on a segmented view of the processes. Because they are videos designed as lessons, they usually pause the process to explain a phase and its key elements. In addition, these videos rarely repeat words or wrote vocabulary on the screen, making the organization of similar words difficult, especially for visual learners.

Using the videos as a guide, I began to design my own lesson that could integrate movement, repetition of vocabulary, and fluidity between mitosis and meiosis. As a dancer, it immediately appealed to me to have students represent objects in the process as they physically move through the classroom. I had observed that people become more engaged
when they are asked to participate in the lesson. Making my students act the roles of 
chromatids would force them to view the process from within and, hopefully, understand 
the internal logic of the processes.

By acting as chromatids, students would also be forced to do the physical movement 
connecting each phase to the next. This was the most important aspect for me while 
designing the class. Instead of creating diagrams of phases or manipulating models, the 
students would actually look around, plan where they had to go next, move to that place, 
envision their next move. They would have to interact with the other chromatids, giving a 
sense of the crowded, three-dimensional world of a cell. They would also be engulfed in 
the movement of the whole class, sensing the need for uniform, organized movement 
among cell parts.

Finally, by moving students out of their seats and into a different orientation to each other 
and me, or into a different environment, I anticipated them remembering the experience 
more than if I simply explained the processes using diagrams and models. In short, I 
wanted to create a novel experience for my students. If it were novel, it would surprise 
them into paying more attention. With greater attention, students are more likely to learn. 
If it were a physical experience, it would require students to use more parts of their brains. 
As discussed in chapter 2, increased stimulation enhances episodic memory formation and 
the number of avenues students can take to access that memory later. As more sensory 
input is stored in a memory, the brain increases connections to that memory to be
triggered later. I wanted to guide students through an experience that would create this type of highly-connected episodic memory.

I taught my cellular division lesson several times before beginning the neurological and intelligence-based research for my thesis. As described in the previous chapters, I found that many of my ideas about movement were supported by modern research. Spatial orientation facilitates memory. Movement activates more parts of the brain. Therefore, full, physical, novel experiences provide massive and varied material for memory creation.

**Part III: Chromosomes on the Move**

The teacher will need two containers of different colored pop beads to carry out this movement-based lesson plan. The first thing she will need to do is count the students in the class to determine how many chromosomes she will have. Each chromosome will need to be a group of four students sitting near each other, two of one color—let us say yellow—and two of the second color—let us say red. Once the beads are passed out, go around the classroom and make sure students know where they are in relation to the rest of their group. They should be sitting next to their group member with the same colored beads and each one should be an A or a B. The four group members should know who is in their group and the number of their group/chromosome. This will be important during the meiosis model. Remember that each chromosome needs four students in order to carry out the meiosis model. Any left-over students will represent centrioles in the model with the teacher.
One of my favorite parts of this lesson plan is handing out the pop beads. At this point, students do not know what to expect or why the pop beads are important. They will be watching you intently, some waiting for answers and directions while many begin to pop the beads together. So use this time effectively. Explain that the class will be acting out mitosis and meiosis and that they should make themselves bracelets or necklaces of the beads before them. In my experience, this hint will engage most students. The specificity of the two people with red, two people with yellow pattern, along with the groups of four will usually trigger students’ memories of pairs of chromosomes or the two copies of DNA from mother and father. At this point, begin to discuss with the students what these beads might represent, something they are probably already thinking. For example, Why are there two colors? Start with student-generated ideas and only give answers if necessary. I tend to lead students through the scale of the model. The scale depends on whether or not the teacher plans to go outside. For example: If we know that the students are chromosomes, then what is the nucleus? The classroom, for an inside lesson, and the building for an outside lesson. What is the cell? The building, for an inside lesson, and the school for an outside lesson. What organism are we from? The school, for an inside lesson, and the town for an outside lesson. Why are there two colors of beads? Are we in a haploid or diploid cell?

If students do not provide answers themselves, the teacher should provide them, especially in terms of the scale so that students always know where they are in the model. This lesson plan can be used either way, but will be discussed as though it were taking place outside.
The colors reveal whether a chromosome comes from the mother or father. There are two colors in each group because the class is in a diploid cell. Each bead represents a specific allele of a gene, so different colors are different alleles. If students provide answers that are relatively close to your plan, alter your wording for the rest of the class. This increases student ownership in the project. So long as the scale and model make sense internally, anything can represent the cell and its parts.

Now, as students play with their beads, begin speaking through the process. What phase takes up the most time in a cell, and how many copies of each chromosome exist at this time? Begin in G1 interphase by having every person who is the A in their pair hold up his or her hand. These people do not exist. Have every B person hold up his or her hand. They do exist. Ask students why this is the case and when it will change. What phase is the class in now?

In S phase, sound very relieved as you let the A students know that they now exist; they have been synthesized. Review, again, how many of each type of chromosome there are in the cell (4) and how many chromosomes are exactly alike (2). Have students consider where each person in the group may end up after mitosis. At the end of interphase, have students explain what other organelles and substances should be duplicated in G2 interphase.

Bring students back to the beginning of M-phase by defining what has already happened that occurs in prophase. They have already condensed into chromatids by popping their
beads together. What must happen next? The nuclear envelope must dissolve in prometaphase. Because we cannot dissolve the walls of the classroom, ask students to file out of the classroom and the building into the nearest quad or playground area. This will be our cytoplasm, still inside the cell of the school, but outside the nucleus (the building). When you ask students to leave the room or building, they may be hesitant. Depending on the teacher’s style, he may decide to blame the movement on the rules of cell division, or he might show his own excitement about getting to go outside. The students will usually enjoy the movement. In my own classes, in which I have taught this lesson to over one-hundred and twenty-five students, only two have said the exercise was not helpful to them. I have never had students refuse to move.

With the class outside, ask them what will happen next. Depending on the numbers, line yourself up opposite a tree or other marker, or line up the student centrioles at least 5 yards apart. These are the centrioles. Ask the class what happens next. Have they each found their sister chromatids? Where should the pairs of sister chromatids go? Now, ask them to form the metaphase plate. It is important to let the students struggle with this as a group for a minute or two. With the centrioles in place, they should be able to form the plate in the right orientation standing next to their sister chromatids. You can even ask the sister chromatids to link elbows to help them orient themselves. I have had classes form the metaphase place perpendicular to correct orientation. At this point, I ask them what will happen next and how this could work in their current location. They often readjust themselves without any further direction, but, depending on the reading and introduction the teacher has provided on cell division, they may require more direction.
For anaphase, the centriole students and/or you will count down to anaphase. “Three, two, one, anaphase!” I do not give students any further direction. The counting down focuses them on their task, and the orientation of the metaphase plate will cue enough students to begin the process. They should separate from their sister chromatids and go toward their hemisphere’s centriole. A description of telophase and cytokinesis can usually be provided by the students at this point.

When each group is in its own space, run through a series of review questions. These questions help students organize the experience in their minds while helping them see which elements of the outcome are particularly important. How many cells are we? Are we haploid or diploid? Is your sister chromatid in the same cell with you? Is anybody from your original group in the same cell with you now? Do we each have the same number and color of chromosomes? Are we somatic cells or gametes? What happens next? Explain that nuclear membranes would now reform and you would unwind your DNA strands, but we are going to stay out here and walk through meiosis next.

For meiosis, reform the class into its original groups of four. Explain how the process begins the same way, and repeat some of the questions from the classroom section of the mitosis model. Raise your hands if you exist in G1. Now we are in S phase: how many of you exist now? How many times does DNA replicate for mitosis? For meiosis? What happens in prophase and prometaphase? Having students review what they just did step by step will help them connect prophase 1 with mitosis prophase. Also, reviewing the
motions quickly after executing them continues to organize the experience in the students’ minds.

For the rest of the lesson, the class will repeat the movements of the mitotic phases twice to represent meiosis I and meiosis II. Only a few key changes are necessary. Obviously, the first is that in meiosis II there will be two cells going through each process. Make sure that the centrioles are spaced far enough apart to account for both metaphase plates.

The second key change occurs during metaphase I. Here, the students will line up in columns of four so that all sister chromatids can stand side by side. Again, having sister chromatids link arms can be helpful if the class appears comfortable with the physical contact. Have the students describe the differences between this metaphase plate and the metaphase plate in mitosis. When I planned to have students look at slides of cells in different phases later in the course, I asked them to predict how the metaphases will look different from each other under a microscope. This sets an easy link in the brain between the movement experience and the slides or other pictures to which students will be exposed later. When anaphase begins, sister chromatids will remain together and separate from their homologous chromosomes as they move toward the centriole.

After meiosis I, ask one or two review questions that highlight the differences between meiosis I and mitosis. Where is your sister chromatid? Where are your other homologues? Having students locate people in space, raise their hands, and point reinforces the physical nature of the process.
Use the modeling of meiosis to draw attention to its key features. How many times do the phases repeat? What is different about metaphase I and II and anaphase I and II? How many daughter cells does one original cell create? Are they haploid or diploid? I have found that these questions are best posed to the class as a whole while they are still standing in their four daughter cells. Are there any homologues in your cell with you? Where is your sister chromatid?

Having each group raise their hands separately will show all students that one of each type of chromosome is in each cell. It will also give students the opportunity to double check their modeling work, since there should be one of each chromosome in every cell.

In the end, students should leave the lesson with a physical understanding of how chromosomes move throughout mitosis and meiosis. Their roles as sister chromatids and part of a tetrad tends to cement these often confused vocabulary words in their minds and clarify the logical order of the phases. Within each phase, students better understand what must happen to transition from the phase just completed to the next one. The body action and sensory experiences inherent in such an activity provides students with a rich store of sensory data that can strengthen memory and learning.

**Part IV: Useful Modifications to the System**
This lesson plan could be modified to become more complex depending on the teacher’s goals. While we consider the following suggestions or develop new ones, it is important to note the purpose of the lesson—student movement. If the lesson turns into a modeling practice on tables, even in groups, the purpose is lost. Students must stand, move their entire bodies, interact with fellow students, know where they and their classmates are in the space and in relation to each other, listen and carry out instructions with their whole bodies. Even students with movement-based disabilities can participate. Each individual almost always has a partner, and, if the teacher consciously places students who might need physical assistance with those who can help, the lesson should run smoothly. This lesson plan describes full-body modeling for reasons discussed in chapter 2, and this element should not be lost, even if students are unable to hold their beads themselves or must remain seated in a wheelchair. The following are proposed alterations that may be useful in themselves or as starting points for teacher-developed expansions.

First, teachers can integrate the spindle fibers into the process. This can be done relatively simply with a small ball of string for each student. Teachers will also need to make sure there is the right number of students so that each centriole can be modeled by a student and not an inanimate object. To keep the second set of student centrioles engaged while modeling mitosis, have them pair up with the active centrioles. Teachers can even discuss the accuracy of modeling paired centrioles.

During metaphase, when students begin to line up in the metaphase plate, they hand one end of their piece of string to the student performing the role of centriole and unroll the
rest of the ball until they are in place 2-3 yards away. Now, each chromosome or chromatid (depending on the stage) will be holding one end of a string, and each centriole will be holding the opposite ends of many strings. When anaphase begins, the centriole students will reel in all the strings at once, pulling the chromatids toward them. In the end, the correct chromosomes (or chromatids) will surround their centriole in the area of the new cell.

Second, if teachers use this lesson plan more than once, it can be instructive to keep a record of all the haploid daughter cells produced. This does demand a bit more prep work, but can have clear payoffs. In this scenario, each student chromosome quartet is given a chromosome number. At the end of the meiosis exercise, each daughter cell is documented on poster as containing one of each numbered chromosome which has either the maternal or paternal color as dominant. Crossing over makes an even more striking illustration using this technique. Here, the teacher must make sure that all four students of a given chromosome have the same number of beads, and, for simplicity's sake, that different chromosomes have different numbers of beads. When drawing on the poster, students can now specifically note which genes (beads) have been acquired through crossing over and where they are on the chromosome. Comparing their poster to the posters of previous classes allows students to see how their assortment into different cells varies. In clear colored diagrams, they can observe that even though each class began in the same way, the resulting gametes are never identical. The series of posters demonstrates how meiosis enhances variation. Some classes may even want to run the model twice to compare their own results a second time. If they try again, can they get it to be exactly the same? How
much effort and memory would this take? Could a cell ever do that? Discussions resulting from this exercise can be rich and informative.

The documents of the resulting cells necessary for this scenario can be best recorded and presented visually. Whether on a poster that each class fills in or on a computer through a drawing program, each class should be able to document their chromosome number, and color of their chromosome (aka maternal or paternal), and in which daughter cell they ended. This gives students a self-generated model of independent assortment and the effects of crossing over.
Chapter 4: In the Classroom

A lesson plan can be honed for years, but without students, a lesson is merely an intellectual exercise. I had the opportunity to use my cell division lesson plan in the laboratory sections of General Biology I and Principles of Biology I that I taught through my teaching assistantship at Northeastern University. In each of three semesters—Fall 2009, Spring 2010, and Fall 2010—I ran lab sessions on cell division, in which I used the lesson plan described in Chapter 3 to supplement the departmentally determined lesson based on slides.

The responses I received from students during and after the lesson were almost entirely positive. Of the eleven sessions I taught at Northeastern, only two students told me that they did not like or were confused by the activity. I assume that the actual number is larger, as not every student may have been confused enough or confident enough to voice her concerns. For this reason, I looked to the short, anonymous, in-class evaluation I ask students to complete at the end of each semester. In these surveys, many students referred to my movement-based mitosis/meiosis in their answers. Figure 1 shows that students had only positive responses to the lesson and enjoyed the cellular division lesson enough to remember it at the end of the semester as enjoyable, helpful, or educational.
Figure 1: The number of students who discussed my cell division lesson in their answers to one of the following informal class evaluation questions. All students were registered in a major other than biology at the time of the class. (n=33)

To gather more data about this lesson plan, I carried out two rounds of surveys designed to gather information about short-term and long-term memory/retention of my experimental procedure, my movement-based lesson plan. The long-term memory survey took place online with students I taught in 2009-2010 and their peers registered in the same lecture course. My students were the experimental group, and their peers who had different TA’s were the control group. The short-term memory survey went to students enrolled in Northeastern University’s General Biology I class in April 2012. I taught brief lessons in
their laboratory sections (using my method or a video as a control), and the survey was administered at the end of the lesson.

The survey I used (appendix C) contained eight content questions and one question about the student's personal response to the activity. The mitosis and meiosis questions were from quizzes given to laboratory classes by myself and other TA's. The personal response question gave students the options of fun, boring, interesting, annoying, confusing, and space for additional comments. The content questions highlighted some of the key elements of both mitosis and meiosis, including process and vocabulary. The personal response question allowed me a simple gauge as to whether the students found the experience positive or negative, useful or unhelpful, engaging or superfluous.

Due to the nature of my information gathering, I applied to Northeastern University's Human Research Institutional Review Board, completed human-research training, and received permission to continue with my planned data collection (Appendix F). I completed two rounds of surveys.

For each set of data, I ran two Welch’s t-tests (using the Welch-Satterthwaite equation to determine degrees of freedom) to answer the following questions: 1) Did the scores on the content portion of the survey significantly differ between experimental- and control-group students? 2) Did the answers to the opinion questions significantly differ between experimental- and control-group students? To quantify the opinion questions, I gave each
word a number to represent its positive or negative connotations: Fun = 5, Interesting = 4, Confusing = 3, Boring = 2, Annoying = 1. This scale was used in both sets of data.²

**Part 1: Short-Term Retention Data**

My second round of surveys took place in the classroom. Through Aaron Roth and Elizabeth Clark, I was granted access to eight sections of General Biology I at Northeastern University running during April, 2012. On April 5th and 12th, I joined two 11:45 am lab sections and two 2:50 pm lab sections studying heredity. The students were not biology majors and—in a lecture period one or two weeks prior to this lesson—had taken their test on cellular division. In the first 20-30 minutes of each experimental lab section, I ran my lesson and administered my survey directly afterwards. The experimental group, which was the larger group, consisted of the four classes taught on April 5th and the two morning classes taught on April 12th.

In the first 20-30 minutes of the control lab section, I lead a short discussion and had students view two videos, one each of mitosis and meiosis (Zabaaz, 5/12/2012). The control group consisted of the two classes taught on April 12th in the afternoon, making it the smaller group. For the control group, the videos served as the best control lesson available, as it integrated movement into the lesson without having students leave their seats. With these lessons, I attempted to separate the perception of movement (on the

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² Students were given the opportunity to check more than one adjective. Because each person could have more than one feeling about the lesson, I chose to count each response as a separate, valid data point. In this way, I did not reduce the validity of any response by making it into a fraction. This did lead to different, larger n values in some cases.
screen) from the act of moving (my proposed lesson plan). Both the control and experimental groups had the benefit of 20-30 minutes of review time before the surveys were administered. I analyzed my data in the same way as was done with the online data. Students significantly improved their scores on the content portion of the survey when they were taught with the movement-based lesson.

For my in-class lessons, the mean score of the 28 control-group students is 56.25% correct, and the mean score of the 71 experimental-group students is 69.01% correct. The means show the experimental group performing significantly better than the control group ($p < 0.01$, t-value: 2.78, df: 56.33). For all groups, the curve of the group peaks at or above 50% correct. The control group had fewer very low scores—possibly due to fewer data points—but grouped scores very close to the mean. The experimental group contained scores from 0% correct to 100% correct, with the majority of students earning a score of 62.5% or higher.
**Figure 4**: Content question scores for control group, experimental group, and both groups combined from in-class data collection. The experimental group (blue) showed significantly higher scores than the control group (red). Combined groups (green) given for comparison. (p < 0.01; control: n=28, experimental n=71; t-value: 2.78, df: 56.33)

While it is tempting to compare the short-term retention scores with the scores from the long-term retention averages, I have chosen not to do so for two key reasons. First, this was not the intention of designing the two surveys. My goal was to look at the affects of how I taught my lesson on both types of retention, not to compare the two. Second, the strengths, weaknesses, and designs of the two surveys vary so greatly that any comparison would not yield relevant numbers. Meaningfully comparing short-term and long-term retention would require both a different study design and a different series of questions to help delineate and isolate relevant factors.
In addition to the significantly higher scores than the control group shown in figure 4, the experimental-group students had a more positive reaction to the lesson (fig. 5). Again, I arranged the given adjective choices on a scale of 1-5: 1 being actively negative (annoying), 2 being passively negative (boring), 3 being engaging but not positive (confusing), 4 being positive (interesting), and 5 being actively entertaining (fun). The mean score of the control group was 3.44 (68.8% positive). The means score of the experimental group was 4.29 (85.8% positive). The experimental group had a significantly more positive experience in the review lessons of mitosis and meiosis that I taught (p<0.001, t-value: 3.95, df: 43.99).

The results for students who found the lesson interesting are worth discussion. The same percentage of students in both groups marked that they found the lesson interesting (52%). First, this indicates the similarity of the participating classes. Not only did the cohort share a class, lecturer, and TA, but they also shared relative interest in the subject. Second, and possibly more intriguing, the scores of these two groups diverged significantly, indicating that in my lessons, student interest alone did not increase content-question scores. While interest is often a pre-requisite for learning, here it was not a determining factor. Here it appears that the group of students who had more fun remembered more when taking their content quiz. There is no indication from the online data that this trend continues as years pass, although it remains a possibility. In future studies, I am interested in pursuing the difference between fun and interest in the classroom as applied to learning and both short-term and long-term memory. It is impossible to take the indications of
these results as proving that fun increases learning, but the data clearly point to this as a viable possibility.

![Short-Term Retention of 2012 Students: Control Group's Opinion Answers](chart.png)

- Annoying: 9%
- Boring: 15%
- Fun: 12%
- Confusing: 12%
- Interesting: 52%

Short-Term Retention of 2012 Students:
Control Group's Opinion Answers
Figure 5b: Answers to opinion question for control group and experimental group from short-term retention data collection. Responses from experimental-group students were significantly higher than those from control-group students. This difference can be seen in the amount of “fun” the group reported having, 12% in the control to 41% in the class taught with a movement-based lesson plan. (p < 0.001; control: n=34, experimental n=94; t-value: 3.95, df: 43.99)

With a small-scale experiment such as this one, one consistent teacher for both the experimental and control groups is a controlled variable, reducing the possibility of confounding between an experimental-group teacher and a control-group teacher, a probable bias of the of the long-term retention survey. Yet, even from an educational perspective, this control could confound the data. For my personal teaching, the in-class data are profoundly informative, but I am not the only teacher! How would students be affected if another teacher taught the same series of lessons? When applied to other
teachers, my data may be a less applicable, a less convincing argument to change their teaching habits. For this reason, the fact that I taught all the classes comes to light as a weakness in the experimental design and possible confounding factor. Given the time and money to complete a fuller investigation—such as those described below—I would train other TA’s to teach my movement lesson and have them teach half of their students with movement and the other half with video. However, my statistically significant p-value should imply that, despite possible confounding, there is still a significant improvement in student learning and classroom experience when cell division is taught with a movement-based lesson plan.

**Part II: Long-Term Retention Data**

My long-term retention surveys went to my students of 2009-2010 and their peers in the lecture sections of the course. This online tool included a question about when they took this class and whether or not I was their teacher. In this way I was able to separate students who received the same lectures who experienced my movement-based lesson from their peers who experienced the departmentally determined lesson based on slides. I was also able to determine how long ago they learned the material. Part of my hypothesis about movement-based learning was that it facilitated memory formation. By surveying students who may not have been in a science classroom for two years, these data helped me gain an understanding of the long-term memory responses to, and effects of, my lesson plan.
Online surveys were completed during March and April, 2012, with a total number of 60 students responding (Fig. 2). The mean score for the 16 students in the experimental group was 59.37% correct. The mean score for the 44 students in the control group was 58.25% correct. These means showed no statistical difference between the data sets (t-value: 0.179, df: 28.64). These data appeared to indicate that students retain the same amount of information about cellular division long-term (over eighteen months) no matter if their TA used a movement-based lesson or a traditional, slide-based lesson. Due to the small and inconsistent numbers of surveyed students from any particular semester, at this point I was unable to draw conclusions about the students’ scores in relation to the length of time since their cell division class. To draw more useful conclusions about retention of information presented in movement-based or traditional lessons, I suggested a proactive, long-term study in which surveys are administered consistently over the course of years. In my proposed follow-up study, detailed at the end of this chapter, I included a series of demographic questions about the students’ areas of study since their introduction to biology course. I anticipated that the students’ current major, more recent biology courses (especially genetics and microbiology where cellular division is revisited), and planned career path may all affect memory of this lesson.
Figure 2: Content question scores from long-term retention survey administered in March and April 2012 to students registered for General Biology I or Principles of Biology I at Northeastern University from 2009-2010. The experimental group was taught using the movement-based, cell division lesson plan in their lab sections. The control group was taught using the traditional, slide-based lesson plan in their lab sections. (control: n=44, experimental: n=16; t-value: 0.179, df: 28.64). There is no statistical difference between the two data sets.

The online data collected also included a question in which students gave their opinions about their cellular division laboratory class. Control group and experimental group responses to the opinion question also showed no statistical difference (Fig 3). When the adjectives were placed into a numerical scale, the mean for the 22 experimental group answers was 3.82, indicating a 76.4% positive response to the movement-based lesson. The mean for the 56 control group answers was 2.75, indicating a 55% positive response to the traditional cell division laboratory class. Despite the trend of positive responses to the
movement-based lesson plan, the means showed no statistical difference between the data sets (t-value: 3.258, df: 0.00021).

![Long-Term Retention of 2009-2010 Students: Experimental Group and Control Group Opinion Answers to Cell Division Lesson](image)

**Figure 3:** Opinion question responses from long-term retention survey administered in March and April 2012 to students registered for General Biology I or Principles of Biology I at Northeastern University from 2009-2010. The experimental group was taught using the movement-based, cell division lesson plan in their lab sections. The control group was taught using the traditional, slide-based lesson plan in their lab sections. (control: n=56, experimental: n=22; t-value: 3.258, df: 0.00021). There is no statistical difference between the two data sets.

In addition to the given answers, students had the opportunity to write in additional or clarifying responses. All collected responses can be found in Appendix C, along with the responder’s score on the content questions, response to the opinion question, and
experimental group/control group status. Of the ten students who wrote in a response, six were in the experimental group. Some trends present in these responses were that most students referred to their TA in their comment (five of my students, one of another TA’s students) and all experimental-group responses were positive, while only one control-group response was positive. The following four examples showed a range of the type of comments, although they do not account for the range of scores (37.5%-100%). A control-group student, who earned an 87.5% and said the class was interesting, added, “Took molecular genetics as well.” Another control-group student who earned a 75%, and said the class was boring, added, “Had it online [took the laboratory class through an online computer program] and I didn’t learn anything.” An experimental-group student, who earned a 62.5% and said the class was fun, added, “I remember it was helpful in visualizing the process.” Another experimental-group student, who earned a 75% and said the class was fun and interesting, added, “Alma made it enjoyable.” This last comment highlighted one of the possible confounding factors of my experiment, the fact that I taught all of the experimental classes.

This retroactive, online method of collecting data showed two key weaknesses separate from the confounding factor of having only one teacher teach experimental lessons. First, the response to the online survey contained a self-selecting group and, therefore, a sampling bias. I received responses from just over 5% of the emailed students (students still enrolled in Northeastern University at the time of the study). Second, many of the students surveyed were freshman in 2009 and 2010 and planned on pursuing a major in biology or biology-related field (psychology, neuropsychology, health sciences, nursing). In
these cases there was no guarantee that the students surveyed continued to work in or study the field of biology. This would weaken memory, as it is not frequently accessed or used to solve problems. When accessed more frequently, memories become more certain because the brain determined that they are important.

This second weakness of students’ varied courses of study could also be an asset. The data collected from these students was more typical of students who—at the time of taking this class—did not anticipate using the information later in life. Students without a major had less at stake in their class because they were working for a grade and not to gain a baseline of understanding in their field of study. The level of personal interest may have lowered students’ ability to remember the material because their brains did not register that this was important information at the time of learning.

For this reason, data collected here may apply to a wider population, the group that did not plan to pursue biology throughout life. This population takes biology because it was required, and a person taking a required class often responds differently than when he takes an elective class. This tends to be the most difficult population to reach, and further research into whether or not movement-based techniques engaged students not personally interested in a subject may be the most valuable.

**Part III: Analysis of Assessment Tool and Future Studies**
My short-term retention study supports my hypothesis that learning cellular division through full-body movement modeling is more effective than lessons in which students remain seated. With this support, I find myself asking further questions about the lesson and experimental design, especially as it relates to my long-term retention study, which showed no difference in learning. Would a more carefully designed long-term study show different results? What role do positive and negative responses play in long-term retention? Do these responses change over time? For this reason, I have reviewed my own work, researched student assessment techniques, and propose the procedure below as a way to answer some of these questions.

The first and possibly more important re-examination I completed was a review of the effectiveness of multiple-choice assessment as an accurate tool for collecting data on student learning and understanding. My first question was whether or not my assessment tool accurately mirrored the tools I use in my own classrooms to evaluate students’ understanding of the exercise. If I were teaching a class, I would be interested in my students’ participation, attitude, and attention to help me judge their progression over the length of a course. Because my proposed study would evaluate a single lesson—not the lesson's role in a whole course—I do not propose collecting data on these aspects of student engagement. If I were teaching a class and wanted to figure out whether or not my students understood a specific lesson plan, I would review their quizzes, homework assignments, and other written assessments.

Deciding on a written assessment, I then had to determine the best way to gather accurate
information in this format. The education trend over the last several decades has been away from limited questions (i.e., true/false and multiple choice) and toward the use of “more open-ended problems, essays, hands-on science problems, and portfolios of student work. Collectively, such measures are frequently referred to as ‘authentic’ assessments (e.g., Archibald & Newman, 1988; Wiggins, 1989) because they involve the performance of tasks that are valued in their own right” (Linn, Baker, and Dunbar, 1991).

As American education philosophy began to shift at the end of the twentieth century, scholars and teachers have raised concerns about historically-dominant evaluations of learning and teachers’ lackadaisical use of whatever assessments have come before. Allan Collins summarizes this view clearly and eloquently:

First, there is the tendency for testing to drive teaching down to the level of our testing technology away from learning and reasoning skills toward more easily measurable skills that can be tested by multiple-choice items. Second, testing encourages students to adopt memorization rather than understanding as their goal: knowledge is learned in a form that it can be recalled rather than in a form that it can be used in real life tasks. Finally, there is a kind of test-taking mentality that takes over and helps turn many students against school and learning more generally. (Collins, 1987)

Fifteen years later, another aspect was added to the argument against traditional assessments when President George W. Bush enacted “No Child Left Behind.” The implementation of large-scale, high-stakes standardized tests in schools instilled opponents of this testing with an urgency to prove that learning could not be quantified so easily. Euphemia Maclellan has studied and written extensively on the role and power of
assessment over the experience and quality of learning for students.

“The power of assessment to determine the quality of learning has been established for quite some time (Ramsden, 1997) with the evidence clearly concluding that the quality of student learning is as high (or as low) as the cognitive demand level of the assessment tasks (Crooks, 1988; Gibbs, 1999). In other words, if students perceive a need to understand the material in order to successfully negotiate the assessment task, they will engage in deep learning but if they perceive the assessment instrument to require rote learning of information, they will be unlikely to engage with the higher level objectives which may well have been intended by the program of study. . . . assessment practices, then, play a subtle, complex, and enormously important role in the students’ experiences of learning.

“Assessment itself, however, is undergoing a paradigm shift (Gipps, 1994) with a movement from the measurement model to a standards model (Taylor, 1994). Such a movement comes from an increasing recognition that the assumptions of traditional learning theory are now very questionable. Learning is now more commonly recognized as a process of knowledge construction (rather than of knowledge reproduction), as being situated in particular contexts (and therefore not necessarily transferable to other contexts) and as being knowledge dependent (Resnick, 1989). The realization that learning is not linear and atomistic and that it is not decontextualised, has led to the desire that assessment should represent meaningful, significant and worthwhile forms of human endeavor and accomplishment. In other words assessment tasks should reflect the ways in which knowledge and skills are used in real world contexts (Newmann & Archbald, 1992).” (Maclellan 2001)

Analysts generally manage the difficulties arising from the need for “direct assessment of complex performances” (Linn, Baker, and Dunbar, 1991) by recommending a series of varied evaluations. Even Thomas Haladyna, Steven Downing, and Michael Rodriguez—
proponents of the multiple-choice format—acknowledge the changing trends in classroom assessment:

“Perceived overreliance on the MC format to measure the recall of knowledge instead of higher level learning has resulted in disenchantment with MC testing. A natural aftermath is the increasing use of performance testing that seems better suited for testing complex mental abilities like writing and mathematical problem solving. The standards-based movement has also promoted an approach to teaching and testing in which we recommend a greater variety of assessment approaches” (Haladyna, Downing, and Rodriguez, 2002a).

Malcolm Cox and David Irby (2007)—also proponents of diverse testing formats—review the pros and cons of several different forms of evaluation used throughout medical school. They highlight what each form tests best and, therefore, when each is appropriate to use as medical students. Because these students complete internships and residencies, their work is a perfect example of learning that cannot be fully evaluated with any type of written question. The following table (Cox and Irby 2007) summarizes their review of different types of written assessment (underlines to highlight statements relevant to cell-division lesson):

<table>
<thead>
<tr>
<th>Written Question Method</th>
<th>Domain</th>
<th>Type of Use</th>
<th>Limitations</th>
<th>Strengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-choice questions in either single-best-answer or</td>
<td>Knowledge, ability to solve problems</td>
<td>Summative assessments within courses or clerkships;</td>
<td>Difficult to write, especially in certain content areas; can result</td>
<td>Can assess many content areas in relatively little time, have high</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Format</th>
<th>Description</th>
<th>Reliability</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended matching format</td>
<td>National in-service, licensing and certification examinations in cueing can seem artificial and removed from real situations</td>
<td>reliability can be graded by computer</td>
<td></td>
</tr>
<tr>
<td>Key-feature and script-concordance questions</td>
<td>Clinical reasoning, problem solving ability, ability to apply knowledge</td>
<td>Not yet proven to transfer to real life situations that require clinical reasoning</td>
<td>Assess clinical problem-solving ability, avoid cueing, can be graded by computer</td>
</tr>
<tr>
<td>Short-answer questions</td>
<td>Ability to interpret diagnostic tests, problem-solving ability, clinical reasoning skills</td>
<td>Reliability dependent on training of graders</td>
<td>Avoid cueing, assess interpretation and problem-solving ability</td>
</tr>
<tr>
<td>Structured essays</td>
<td>Synthesis of information, interpretation of medical literature</td>
<td>Time-consuming to grade, must work to establish inter-rater reliability, long testing time required to encompass a variety of domains</td>
<td>Avoid cueing, use higher-order cognitive processes</td>
</tr>
</tbody>
</table>
The multiple-choice, short answer, and structured essay questions appear to relate most closely to the goals of my study and the context of an undergraduate or high-school classroom. With this in mind, I returned to the literature to find ways to minimize the limitations of multiple-choice questions. Are they a valid form of testing on their own, or are they only considered valid by teachers because they are used by large-scale testing programs? Craig Berg and Philip Smith (1994) raise an even more important reason to review carefully multiple-choice items. In their study of how accurately multiple-choice tests described middle- and high-school students’ understanding of graphs, they state that “insights into students’ thinking about graphing reveal that some multiple-choice graphing questions from prior research studies and standardized tests do not discriminate between right answers/right reasons, right answers/wrong reasons, and answers scored ‘wrong’ but correct for valid reasons” (Berg and Smith, 1994). With this potential downfall in mind, how does a teacher write good multiple-choice questions?

Literature on multiple-choice tests usually centers around reviews text-book questions and makes recommendations to text-book writers, editors, and publishers. The most comprehensive work on how to write multiple-choice questions was completed by Haladyna and Downing in a series of papers in 1989 and by Haladyna, Downing, and Rodriguez in 2002. They argue that, “despite the increased emphasis on performance testing, the MC format continues to play an important role in classroom and large-scale assessments,” (Haladyna, Downing, and Rodriguez, 2002a).

Measurement experts as well as testing organizations prefer the MC
[multiple-choice] format for many reasons:

1) Sampling of content is generally superior when compared to other formats; the use of MC formats generally leads to more content-valid test-score interpretations.
2) Reliability of test scores can be very high with sufficient numbers of high-quality MC items.
3) MC items can be easily pretested, stored, used, and reused, particularly.
4) Objective, high-speed test scoring is possible.
5) Diagnostic subscores are easily obtainable.
6) Test theories (i.e., item response, generalizability, and classical) easily accommodate binary responses.
7) Most kinds of content can be tested using this format, including many types of higher level thinking.

For these reasons, MC is the preferred format for virtually every standardized cognitive test in the United States, including elementary and high-school achievement tests, college and graduate-school admissions tests, personnel tests, and certification, licensing, competency, and proficiency examinations in education and other professions. (Haladyna and Downing, 1989a)

Haladyna and Downing continue to lay out 43 multiple-choice item-writing rules in the categories of General Item Writing, Stem Construction, and Option Development. In 2002 they reviewed their guidelines, moving to a set of 31 rules that had been reviewed in the literature since 1990. In this more recent review, Haladyna, Downing, and Rodriguez reaffirm the importance of multiple-choice item-writing skills and guidelines, even in the changing world of diverse assessment. Like Berg and Smith, Haladyna, Downing and
Rodriguez support the use of well-written multiple-choice items, especially when used in tandem with options that check the reasoning behind students’ answer choices.

Their research validates the use of multiple-choice questions as a useful way to assess student skills and learning in a variety of areas. It also confirms the continued use of multiple-choice questions in large-scale assessments on which students will need to perform well in order to continue in a science career. Despite these validations, my questions do not completely fit their best-practice rules of item writing. Therefore, rewriting multiple-choice questions to fit Haladyna, Downing, and Rodriguez’s revised rules will be necessary in any future study, such as the one I propose here.

I propose to study at least one thousand undergraduate students from several universities by way of their laboratory classes. By working within the lab-class time period, the lecture, assignments, time spent on discussion, reading, and general preparation of the material will be controlled for throughout large groups of the study population due to the high enrollment numbers of introductory biology courses. Students will be given information on the study and must provide consent to participate in the long-term study before their unit on cellular division begins. Students will also be asked a series of demographic questions—including current area of study—and will need to complete a series of learning-style questions to identify the students’ learning styles on at least two scales—Kolb’s learning spaces and Gardner’s types of intelligence. I will also require that each student

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3 Despite my personal reluctance to support Gardner’s work, his labels for different types of thinkers are widely used and understood. They create an easy shorthand for people in the field who need a vocabulary to use in their day-to-day and communications. I recommend using it here because it is simple to test and
share his or her grade in the course and on the test that includes cellular division.

Each participating teaching assistant will be trained on my movement-based lesson plan by me and will need to adhere to guidelines on the length of the lesson, between fifteen and twenty-five minutes, so as not to create disparities in time spent on the material. The first assessment will be administered after the lesson is taught during the laboratory class. The following assessments will be administered at set times after the lesson was taught: two weeks, six months, one year, two years, and four years. Each assessment will contain a new essay question and different multiple-choice items each time it is presented to a student. Each assessment will also request additional demographic information—such as number of biology courses taken and current area of study or work.

I propose a two-stage assessment for this study. First, students will be asked to write a short essay describing the processes of mitosis and meiosis, making sure to include key differences and similarities. Once they have handed in their essays, students will be asked to complete a series of multiple-choice items—written to adhere to Haladyna, Downing, and Rodriguez’s revised rules—one problem-solving, short-answer question, and several personal response questions. While correcting multiple-choice questions will be simple, correcting the essay should be completed by at least two different biology teachers who will need to follow the same grading rubric. Having reviewed the lesson, student difficulties, the goals of teaching cellular division, and the literature on test-questions, I

an effective way to categorize people. Because I am looking for relationships between types of learners and success with this lesson plan, I suggest Gardner’s multiple intelligences as a good place to begin my investigations.
propose the following rubric:

1) Accurate use of the names and order of the stages of mitosis and meiosis:
   interphase, G1, G2, S-phase, prophase, metaphase, anaphase, telophase, prophase I,
   metaphase I, anaphase I, telophase I, metaphase II, anaphase II, telophase II (15 pts)

2) Clear explanation of at least one key event that happens during each phase (15 pts)

3) Accurate use of key terms: replication, chromatid, chromosome, centriole,
   centromere, spindle fiber(s), cytokinesis, metaphase plate, tetrad, haploid, diploid,
   gamete, somatic cell, sister chromatid(s) or homologous pair(s) (14 pts)

4) Discussion of at least two similarities between the two processes, such as:
   the function of spindle fibers, the G2 phase, the concept that chromosomes must line up
   before they can be pulled apart, the process of cytokinesis

5) Discussion of at least two differences between the two processes, such as:
   the differences between mitosis, meiosis I, and meiosis II; the different types of
   daughter cells; the rearrangement of genes; where each process happens in the
   body

The goal of this essay is to assess the accuracy of their mental model of cellular division and
their ability to utilize and contextualize relevant vocabulary. Mitosis and meiosis may be
the basis for many complex processes and problems in biology, but most introductory
biology classes, in high school or college, aim to secure a student’s baseline understanding.
The essay question will require students to correctly use labels and vocabulary in context,
connect different phases of cellular division in a logical order, and use critical thinking
skills to identify and describe similarities and differences between mitosis and meiosis.
Despite the effectiveness of multiple-choice and essay-based items, assessment literature supports application-based questions that mirror the problem-solving and end products of professionals in the field (Maclellan 2001, Newman and Archibald 1992). For this reason, the second stage of assessment will include at least one short-answer question that asks students to explain a biological phenomenon using their knowledge of cellular division. One option for this question is as follows: explain which stage of cellular division supports the following statement and why: “Sexual reproduction increases variation in a population.” While biology teachers integrate these types of alternative assessments into their curriculum, traditional written assessment remains the baseline for grading and a variety of large-scale testing schemas (Cox and Irby 2007; Halady, Downing, and Rodriguez 2002a/b; Linn, Baker and Dunbar 1991, Shumway and Harden 2003), which is why it remains the dominant form of assessment here.

I am also interested in alternative questions designed to gather data on student responses to the lesson itself. I plan to include the question from the current study, “What word best describes your feelings about the cell division lessons? Please leave any additional comments/responses,” in order to connect with this study and because it is sometimes necessary to give students prompts for descriptive responses. In addition, questions involving a 1-10 number-scale response will be included to provide quantifiable data to more specific aspects of the lesson plan. Possible questions include:

- Did you find this lesson helpful?
- Was the instructor engaging?
- Could you follow the directions?
- Could you connect this lesson to your previous knowledge of cellular division?

Completing this experiment will help answer questions arising from my previous study, such as—but not limited to:

- What role do positive and negative responses to the lesson plan play in long-term memory?
- Did negative responses indicate that students already understood the material or that the lesson is not reaching students who would benefit from a different style of teaching?
- Is there a relationship between learning style (defined on a variety of scales) and information retention? Personal response to the lesson?
- Does the field of study or work affect the student’s memory of material?

With some of these questions answered, along with a more detailed series of personal-response questions, I will be able to complete two important tasks:

1) Support my hypothesis that learning cellular division through movement is more effective for a wide variety of students than learning it through reading, lecture, diagram, or video.
2) Continue to hone in on the key aspects of the lesson plan that support learning so that they can be utilized in creating lessons for additional units in biology courses.
Chapter 5: Conclusions

The brain is a key factor in the survival and dominance of the human species and, as such, has been subjected to high selective pressure. Many of the traits that evolved in response to this pressure are taken for granted in modern life, especially memory and learning. Despite the ancient and complex roles these skills have played in our evolution—and the huge investments of time, intellect, and money that society makes in education—it is only in the later half of the twentieth century that the neuroscientific understanding has existed to support the field of brain-based education.

The field of brain-based education asks teachers, students, administrators, and parents to view education through the lens of functional neurobiology. Brain-based educators look to the brain—its functions, evolution, and processes—as a guide toward a closer match between how they instruct and how the organ of learning naturally processes information. They argue that the more educators can manipulate instruction to suit—and not fight—the powerful abilities and limitations of the brain, the more permanent, interesting, and functional student learning will become.

With a broader perspective on the variety of brain functions that contribute to learning, I anticipate continued movement toward the experiential, hands-on, problem-solving based education advocated by such visionary thinkers as John Dewey and Maria Montessori, and supported by current neuroscience research. The sparsity of existing data on the effectiveness of movement-based lesson plans indicates how early we still are in the
understanding and implementation of neuroscience in the classroom. Education literature reveals growing interest, application, and techniques for utilizing movement in the classroom as a useful way to bridge the gap between current methods and the ideas emerging from neurology research (i.e. Sladkey 2009, Summerford 2009, Jensen 2000). One of the greatest benefits of brain-based education is it can be applied to variety of learners and in a variety educational environments, from helping young children to college students, from managing learning disabilities and ADHD to developing highly complex problem-solving skills. The interest within education fields is mirrored in the scientific literature, where research indicates increasing interest in finding statistically significant data to support this shift (i.e. Vasquez-Cropper 2005).

It is within this context of brain-based education that I advocate for the inclusion of movement in teaching biology. Movement activates multiple areas of the brain, including those related to spatial-relations, previous knowledge, and memory. Whole-body and whole-class modeling allow students to view biology as a process in physical space that contains its own logic and interlocking pieces. Through movement, students can move through Kolb’s experiential learning cycle while cementing and using vocabulary. They can use all lobes of the brain (Zull 2002), and must move through many different learning spaces (Abbey, Hunt, and Weiser 1985), skills that all learners must develop in order to problem-solve in different situations (Kolb and Kolb 2005). Once relegated to athletes, mechanics, and kinesthetic learners, movement should take a more dominant role in education that reflects its dominant role in the evolution of human cognition.
The neuroscience of movement becomes even more applicable to brain-based learning theories when we relate cerebellar function to the Kolb learning cycle. The cerebellum’s role in the self-correction of movement—as described by Thach, Goodkind, and Keating (1992)—indicates that it carries out the same processes of concrete experience, reflective observation, abstract hypothesis, and active testing as the cortex carries out during the Kolb’s learning cycle. In the cerebellum, the abstract hypothesis is the theoretical plan for movement, active testing is the action itself, the concrete experience is the perception of this action, and reflective observation is the cerebellar process of comparing the actual outcomes with the hypothetical plan, which leads back to a new abstract hypothesis—a revised plan of action.

The neurology of memory also relates closely to key aspects of movement, spatial location and three-dimensional environments. It is easy to imagine the importance of location on memory for early humanoid species. As we evolved, we built upon this spatial basis for memory. Journalist Joshua Foer, in his 2012 book *Moonwalking with Einstein*, emphasizes this point when he discusses what he calls “the art of memory,” which he used to win the 2006 U. S. Memory Championship. This set of techniques, developed by the orators and storytellers of ancient Greece, centers around the idea of creating a complete, three-dimensional location in your mind in which you physically place the objects (or representations of objects) you need to remember. It is the conversion of symbols (words) into visual ideas located in a complete environment that facilitates extreme feats of memory. Eleanor Maguire and her team have documented the physical changes that extensive spatial memory causes in the brain in their studies of London taxi drivers’
enlarged hippocampi (Maguire et. al. 2000). The brain clearly responds positively to this type of stimulus.

In this thesis, I have developed a lesson plan that integrates these aspects of movement into a lesson about cellular division—a topic which often confuses students as they maneuver through a fluid, physical process by using static vocabulary, lists, and diagrams. In comparing the correct answers and personal responses of students who were taught using my lesson and students who were taught using lecture and video, I demonstrated a significant increase in testing scores on a multiple-choice assessment and in student engagement and enjoyment. My assessment data indicate the short-term, academic benefits of studying mitosis and meiosis through movement. My student response data indicate the potential for long-term effects, as engagement and enjoyment both increase retention of material. My long-term trial data did not indicate significant differences between types of instruction, but the potential remains and will be further investigated in my proposed next experiment. My research into executive function and the power of engagement over memory convinces me that the significant increase in “fun” for experimental groups holds the potential for long-term retention benefits.

Finally, my research into educational assessment emphasized the complexity of learning and the difficulties in quantifying it. In this series of experiments, I could only study one lesson at a time. This meant that I only had one assessment event and could not observe students in difference scenarios, tasks, assignments, and learning environments over the course of days, weeks, or semesters. This would limit most studies’ ability to assess
student learning as well as how different lesson plans affected different students or types of students. In addition, my own study focused on factual understanding and memorization, which are not the most important aspects of good learning, although they are the easiest to quantify. I worked to address this problem in my proposed study by including written as well as multiple-choice questions over the course of several months.

My proposed study still succumbs to the most obvious trouble of assessing learning through research; an investigator can only assess one lesson or set of lessons at a time. Problem-solving and intelligence often rely on connections between huge sets of input from more than one source. This makes single-lesson research useful as a starting point for educators, not an end point. I hope that my data will help teachers extrapolate how they can use movement in their own classrooms and will inspire new movement-based modeling lessons that fit their subject, style, and students.

My experiment and literature research has also inspired my own teaching. I consistently develop movement-based lesson plans and find them increasingly effective in the classroom. Neuroscience supports the knowledge I acquired during my work as a special-education teacher and counselor as well as my own student experiences which have informed my teaching instincts. I can now support my teaching decisions with biology and evolution, and increasingly look to the brain for answers to lesson planning and questions of how to help struggling students. My understanding of brain processes has become necessary and invaluable to my teaching.
Appendix A: Mitosis / Meiosis Movement-Based Lesson (Lesson Plan Format)

Class Objectives:

Understand the process of Mitosis:
what happens during each stage
traits of cells at the beginning and end of the process

Understand the process of Meiosis:
what happens during each stage
traits of cells at the beginning and end of the process
how the physical movements in meiosis allow for independent assortment, genetic variability, and sexual reproduction

Common points of confusion:
Only 1 duplication of chromosomes in both processes (how those chromosomes are distributed makes the difference of haploid v diploid daughter cells)
Terminology: chromosome (active and inactive), chromatid, gene, allele, etc.
All cells do not go through these processes at the same time or rate.

Additional Tie-Ins:
Who in the class is currently going through mitosis? Meiosis? Why?
Why is sexual reproduction important in evolution?
Why are eggs and sperm shaped differently?
How can evolution be described in terms of alleles/genes? (Hardy-Weinberg)
Why do bodies need to do mitosis?
How and where do different organisms use mitosis?
What is a genotype? A phenotype?

Connection to Course Goals:
Cellular reproduction applies to studies in:

- genetics
- evolution
- cloning
- cancer (and other human diseases/disorders)
- human reproduction

**Materials:**

- Pop beads in two colors
- Room to move outside or in a large hallway
  (Optional material: a small ball of string for each student)

**Anticipatory Set (hook):**

- Hand out the pop beads
  
  IMPORTANT: hand out pop beads to sets of four, color A, color A, color B, color B if student numbers are not divisible by four, extra students will be centrioles with you

- Begin to discuss what they might represent

- Establish the room as the nucleus once beads are understood to be genes and decide on the size of the cell and organism
  
  if you are going to go outside, make the school grounds the cell, and the town or school system the organism
  
  if you are going to work in a hallway, make one floor of the school the cell, and the school the organism

- Explain that they are going to be the chromosomes in order to act out mitosis and meiosis

**Introduction:**
As students begin to put the bead together, explain/review the terms
   establish each color as either maternal or paternal DNA
   describe that each gene has two different versions in our organism: alleles

Discuss the difference between a haploid and diploid cell
   using humans as an example, students will be able to volunteer a “half mom, half dad”
   scenario which can then be used to transition into a question of how organisms get both
   haploid and diploid cells from diploid cells

Describe the stages of mitosis and meiosis:
   use board drawings and/or posters so students can see what you are talking about
   as you outline the basic process
   ask questions about where in organism each process takes place
   here is a good place to expand beyond the human example
   discuss who is currently going through each process and why

**Procedures:**

**PART 1 - MITOSIS:**

Begin by having one person in each color pair raise their hands; then say that they do not exist.
Yet.
Ask: What stage are we in now, if half the class does not exist?
Answer: G1, where the cell continues to grow.
Ask: what happens next?

*S phase*: use the word synthesis to allow students a language foothold on the term
Tell the “non-existent” students that they now exist, to their relief
Make sure students know who all their homologues/replicates are (their set of four)

Ask: What happens next?
G2: explain that the cell now needs to create everything else it will need to furnish two cells
   (use this as a review of cell organelles)

Prophase: chromosomes condense, centrioles begin to migrate and form spindle fibers
   If students have not already, make sure they have created bracelets or necklaces
     for themselves out of the beads, aka condensed their DNA strands.
   If there are student centrioles, bring them to the door in preparation of
     prometaphase. (If using string, have them hand it out now.)

Prometaphase: nuclear envelope dissolves
   Take all of the students out of the classroom.

Metaphase: sister chromatids pair up and form the metaphase plate
   Direct each student to find their exact match (the same color from their set of four)
   Situate the centrioles at two ends of the space being used
   Tell students to form the metaphase plate
     IMPORTANT: let them figure out where to stand, and in what relation to
     the centrioles, on their own; this might take a minute or two. If longer, give hints,
     i.e. “What will you be doing next?”
   Have them note the long, skinny nature of the plate (different from metaphase 1)
   (If using string, have the centrioles collect on end of each student’s string.)

Anaphase: sister chromatids separate
   Count down “Three, Two, One, Anaphase!” with as many students as will join
     you. Students should move away from their partner and cluster at the centrioles.

Telophase and Cytokinesis: cell splits, nucleus reforms
   Talk through the cell splitting and the reforming of the nucleus
   Sample Questions:
     Do you see your sister chromatid in the other cell?
     How many copies of the genes are in each cell? Haploid or diploid?
Is there another person from your set of four in your cell? Same color?

Nuclear membranes would now reform and you would unwind your DNA strands, but we, are going to stay out here and walk through meiosis next.

**PART 2 - MEIOSIS:**

Everything that happened at the beginning of mitosis happens at the beginning of meiosis.

Sample Review Questions:

- How many of you exist in G1?
- How many times does DNA replicate in meiosis S-phase?
- What happens during early prophase? Late prophase?

Repeat the processes in order for all phases: metaphase 1 and 2, anaphase 1 and 2, telophase 11 and 2, and cytokinesis.

Lay particular emphasis on **metaphase 1**.

- Observe that the metaphase 1 plate is shorter and wider than mitosis metaphase.
- Ask who the sister chromatid pairs are next to.
- Have students cross over by switching colored beads with their homologous chromosomes across the plate.

When there are four cells, ask some review questions.

Sample Review Questions:

- What kind of cell are you? (haploid or diploid)
- Is your partner in the same cell as you?
- Are you and your partner still the same as each other?
- Where are the four homologous sister chromatids? Is there one in every new cell?

From here, it is easy to bring in diversity, population genetics, evolution, and Punnett squares.
ADDITIONAL MODELING:
Students (or teacher) designated to be the centrioles are given small balls of string at the beginning of the process. This works only if there are four centrioles in total. During prophase, they hand these balls of string to half the students. Once the students are in the metaphase place, the centrioles take one end from each student on their side. The chromatids then roll up the string again as they move toward the poles OR the centriole can pull the strings and chromatids toward them (each models one of the two current possible explanations of chromatid movement).
Appendix B: Diagrams of Lesson

Interphase → Prophase

Metaphase
Anaphase

Telophase / Cytokinesis
Metaphase I

Anaphase I
Telophase I / Cytokinesis I

Metaphase II
Anaphase II

Telophase II / Cytokinesis II
Appendix C: Survey Questions

1) Meiosis and mitosis both include
   a) 1 duplication of chromosomes
   b) 1 division
   c) 2 duplications of chromosomes
   d) 2 divisions

2) The process of detaching and exchanging identical segments of any two non-sister chromatids in a tetrad is called
   A. anaphase
   B. mutation
   C. crossing over
   D. forming a metaphase plate

3) In which meiotic phase are the centromeres pulled apart and the sister chromatids separated and pulled towards opposite poles?
   A. Anaphase I
   B. Anaphase II
   C. Metaphase I
   D. Metaphase II

4) In which mitotic phase do the duplicated chromosomes line up on the cell’s equator?
   A. Prophase
   B. Anaphase
   C. Telophase
   D. Metaphase

5) Sister chromatids share
   a) alleles
   b) genes
   c) both
   d) neither

6) Mitosis creates
   a) haploid somatic cells
   b) diploid somatic cells
   c) haploid gametes
   d) diploid gametes

7) When do tetrads line up along the cell’s equator?
   a) metaphase
   b) metaphase I
   c) metaphase II
   d) both A and C
8) During prophase,
   a) spindle fibers begin to form
   b) sister chromatids separate
   c) chromosomes condense
   d) both A and C
   e) all of the above

9) Which semester did you take Bio I? CHECK “ALMA” too, IF she was your TA for your
   cell division lab. (for long-term retention survey only)
   a) Fall 2009
   b) Spring 2010
   c) Fall 2010
   d) Alma

10) What word best describes your feelings about the cell division lessons? Please leave any
    additional comments/responses.
    e) fun
    f) boring
    g) interesting
    h) annoying
    i) confusing
### Appendix D: Long-Term Retention Write-In Responses to Question 10

<table>
<thead>
<tr>
<th>Percent Correct</th>
<th>Experimental Group Status</th>
<th>Marked Opinion Response</th>
<th>Write-In Opinion Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>Experimental</td>
<td>Fun, Interesting</td>
<td>I enjoyed my lab with Alma as my TA. She was very enthusiastic and was always available if I ever had any questions. P.S. Did you watch Frozen Planet Sunday night?!... awesome</td>
</tr>
<tr>
<td>62.5%</td>
<td>Experimental</td>
<td>Fun</td>
<td>I remember it was helpful in visualizing the process.</td>
</tr>
<tr>
<td>37.5%</td>
<td>Experimental</td>
<td>Interesting</td>
<td>Alma you were a great TA! I think the best one that I've had yet at Northeastern, your classes were interesting and you were a fair grader and accommodating to our needs. Thanks for doing such a great job and Good Luck! Lauren</td>
</tr>
<tr>
<td>75%</td>
<td>Experimental</td>
<td>Fun, Interesting</td>
<td>Alma made it enjoyable</td>
</tr>
<tr>
<td>100%</td>
<td>Experimental</td>
<td>Fun, Boring, Interesting, Annoying, Confusing</td>
<td>I am no longer a bio/science-related major, my lack of knowledge on this topic should reflect this. Alma was my favorite TA out of every TA I had while studying biology/environmental science/science in general. She was easily the most relatable, informative, and enjoyable.</td>
</tr>
<tr>
<td>100%</td>
<td>Experimental</td>
<td>Interesting</td>
<td>Alma was an awesome TA, great way to start off my college bio career!</td>
</tr>
<tr>
<td>87.5%</td>
<td>Control</td>
<td>none</td>
<td>I can't remember</td>
</tr>
<tr>
<td>87.5%</td>
<td>Control</td>
<td>Interesting</td>
<td>Took molecular genetics as well</td>
</tr>
<tr>
<td>37.5%</td>
<td>Control</td>
<td>Annoying</td>
<td>I don't remember much about this class or the lab, I do remember my TA, Matt, was the best.</td>
</tr>
<tr>
<td>75%</td>
<td>Control</td>
<td>Boring</td>
<td>Had it online and I didn't learn anything.</td>
</tr>
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### Appendix E: Short-Term Retention Write-In Responses to Question 9

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<tr>
<th>Percent Correct</th>
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<th>Marked Opinion Response</th>
<th>Write-In Opinion Response</th>
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<tr>
<td>87.5%</td>
<td>Experimental</td>
<td>Fun, Interesting</td>
<td>Helpful, useful</td>
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<tr>
<td>100%</td>
<td>Experimental</td>
<td>Fun</td>
<td>Awesome</td>
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<tr>
<td>87.5%</td>
<td>Experimental</td>
<td>Fun</td>
<td>Informative</td>
</tr>
<tr>
<td>25%</td>
<td>Experimental</td>
<td>Boring, Annoying</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>62.5%</td>
<td>Experimental</td>
<td>Fun</td>
<td>fun way to learn complicated subjects making stages easier to visualize/learn and understand</td>
</tr>
<tr>
<td>50%</td>
<td>Control</td>
<td>Fun, Interesting</td>
<td>It was interesting but I get confused between mitosis and meiosis and the 2 parts of meiosis</td>
</tr>
<tr>
<td>37.5%</td>
<td>Control</td>
<td>Confusing</td>
<td>Frustrating</td>
</tr>
<tr>
<td>87.5%</td>
<td>Control</td>
<td>Boring</td>
<td>not as boring as a book</td>
</tr>
<tr>
<td>50%</td>
<td>Control</td>
<td>none</td>
<td>I haven't found any good videos: the voices aren't animated enough</td>
</tr>
<tr>
<td>62.5%</td>
<td>Control</td>
<td>Boring</td>
<td>It was a bit blank, but effective</td>
</tr>
<tr>
<td>50%</td>
<td>Control</td>
<td>Interesting, Confusing</td>
<td>confusing sometimes</td>
</tr>
</tbody>
</table>
Appendix F: IRB Approval

Northeastern

Notification of IRB Action

Date: February 13, 2012
IRB #: 12-01-14
Principal Investigator(s): Kostia Bergman
Alma Baumwoll
Department: Biology
Address: 413 Mugar
Northeastern University
Title of Project: Efficiency of Learning Cell Division Through Movement
Participating Sites: N/A
Informed Consent: One (1) unsigned consent form for online survey

As per CFR 45.46.117(c)(2) signed consent is being waived as the research presents no more than minimal risk of harm to subjects and involves no procedures for which written consent is normally required.

DHHS Review Category: Expedited #7
Monitoring Interval: 12 months

Approval Expiration Date: FEBRUARY 12, 2013

Investigator’s Responsibilities:

1. Informed consent form bearing the IRB approval stamp must be used when recruiting participants into the study.
2. The investigator must notify IRB immediately of unexpected adverse reactions, or new information that may alter our perception of the benefit-risk ratio.
3. Study procedures and files are subject to audit any time.
4. Any modifications of the protocol or the informed consent as the study progresses must be reviewed and approved by this committee prior to being instituted.
5. Continuing Review Approval for the proposal should be requested at least one month prior to the expiration date above.
6. This approval applies to the protection of human subjects only. It does not apply to any other university approvals that may be necessary.

C. Randall Colvin, Ph.D., Chair
Northeastern University Institutional Review Board

Natalie Regina, Director
Human Subject Research Protection

Northeastern UniversityFWA #: 4630
Bibliography:


