Chapter 2: A Brief Review of Supporting Literature

" It is essential that the student acquire an understanding of and lively feeling for values. He must acquire a vivid sense of the beautiful and of the morally good. Otherwise he – with his specialized knowledge – more closely resembles a well-trained dog than a harmoniously developed person."

- Albert Einstein, editorial for the New York Times, 1952

"In this century, as we have seen in the cases of General Relativity and the electroweak theory, the consensus in favor of physical theories has often been reached on the basis of aesthetic judgments before the experimental evidence fore these theories became really compelling. I see in this the remarkable power of the physicist's sense of beauty acting in conjunction with and sometimes even in opposition to the weight of experimental evidence."

– Steven Weinberg, *Dreams of a Final Theory* (Pantheon Books, NY, 1992), p. 130.

Physics Education Research (PER) has revealed many difficulties with teaching and learning of classical physics, and with teaching modern physics after students have been ingrained in the paradigm of classical physics. Reform efforts which have concentrated on the methods of teaching, keeping the content fixed, have shown in general that interactive methods are superior to lecture-based instruction, however three main 'complaints' still prevail in the PER literature: that students do not understand the relationship between mathematics and physics (Redish, Saul, and Steinberg, 1998; De Lozano and Cardenas, 2002), that students who have become competent problem solvers may not be able to explain basic concepts (McDermott, 1993, 2001; Mazur,1997, 2007), and that there is still a dearth of women and minority students who major in physics (Ivy and Ray, 2005; Nelson, 2005; Zohar, 2006). The Relevance of Science Education (ROSE) study in Europe is beginning to reveal that there are indeed gender-related differences in contextual preferences, which, in the current curricular paradigm of physics with its emphasis on classical mechanics, favor males over females (Sjøberg and Schreiner, 2007). Simply putting females into mechanics problems – what Zuga (1999) called the 'add women and stir' approach - does not suffice to make physics appealing to girls (Zuga, 1999).

The content and organization of the current sequence of the introductory physics curriculum is traced to the 1957 launch of the Soviet satellite Sputnik, which sparked several physics education reform movements in the United States at the time (Brekke, 1995). In 2007, even though instructional methods have changed in many institutions from traditional lecture to interactive methods, the content and sequence of the introductory physics curriculum has remained constant over the past fifty years, and the population of physicists and physics majors has also been slow to change (Ivy and Stowe, 2003; Ivy and Ray, 2005; Nelson, 2005). One of the goals of this project is to ask whether changing the content and sequence to start with contemporary physics, and broadening the curriculum to include examples from art, music, and dance, can encourage diversity in physics, as well as make physics – with mathematics – more accessible to a wider population.

In this chapter I will first give a brief review of physics pedagogical reform efforts which began in the last two decades of the twentieth century, which have addressed teaching methods, but have not addressed the curriculum proper. I will then highlight several studies in Europe which indicate that curriculum reform which includes more contemporary physics and interdisciplinary approaches may be one way to redress the gender and cultural imbalances in physics, as well as modernize the curriculum. In section two I will touch on the discourse of physics as a way of maintaining a community identity which gives physics the appearance of being exclusive and perhaps intimidating, and in section three I will provide a brief background on one perspective of the need to provide opportunities for creativity in introductory physics.

2.1. A Quarter of a Century of Physics Education Reform

The university physics curriculum has its origins in the first medieval academies of Western Europe in the twelfth century, when scholars studied seven subjects: the trivium, consisting of grammar, rhetoric and dialectic, and the quadrivium which consisted of geometry, astronomy, arithmetic and music (Stuver, 2001).Physics became a separate topic in the undergraduate curriculum towards the end of the nineteenth century (ibid). The present curriculum, which starts with Newtonian mechanics, followed by electricity and magnetism, optics and sound, thermodynamics, and lastly (time permitting!) a few topics from "modern" physics, was established shortly after the 1957 Soviet launch of the Sputnik satellite (Stuver, 2001; Brekke, 1995). This curriculum is covered in one year for students who major in biological sciences, or two years for students who major in physical sciences or engineering. Physics majors, after the introductory sequence, study each topic in more depth; for other students, this introductory sequence may be their only opportunity to study physics. It is of interest to note that the topics which are called "modern" physics include the discoveries of Special Relativity, Quantum Mechanics, and

Heisenberg's Uncertainty Principle, all of which are now from seventy five to more than one hundred years old, and most introductory undergraduate courses omit any discussion of the Standard Model of Particles and Interactions, modern cosmology, or General Relativity.

The standard introductory curriculum has not changed in fifty years, however sometime in the 1980's, physics professors in a number of universities in the United States began to notice that their students did not understand the basic concepts, even if they could perform the calculations (Halloun and Hestenes, 1985; Van Heuvelen, 2001; Hake, 1998), and that this failure was independent of the professors' reputations. A reform movement in physics education in the United States began at that time, starting with the development of the Mechanics Diagnostic Test (MDT) by Ibrahim Halloun and David Hestenes at Arizona State University, which was published in 1985. Halloun and Hestenes studied undergraduates' "common sense" beliefs about the behaviors of simple mechanical systems, based on their direct experiences. They found that students' common sense beliefs, which are generally not correct in terms of classical Newtonian understanding, share features with older historically held beliefs of Aristotle and the medieval impetus theory. After Halloun and Hestenes released their diagnostic test in 1985, a number of educators began administering it, realizing that students could learn to solve problems in mechanics without understanding the concepts behind the formulas (Hestenes, 1987; Mazur, 1997; Savinainan and Scott, 2002).

Malcolm Wells, a high school physics teacher working with Hestenes at the time the MDT was published, was the first documented high school educator to administer this test to his students and, working with Halloun and Hestenes at Arizona State University, developed the pedagogical method called Modeling Instruction (MI). The goal of MI was to address the confusion of students by teaching them to mathematically model physical systems using sound Newtonian reasoning. Instead of lecturing to students and teaching them to solve problems, MI advocated helping students develop their scientific intuition by developing working models, and learning how to use equations to model physical systems (Wells, Hestenes, and Schwackhamer, 1995).

In 1992 Hestenes, Wells, and Schwackhamer published the Force Concept Inventory (FCI), a revised version of the original MDT of Halloun and Hestenes, in *The Physics Teacher*, the monthly magazine of the American Association of Physics Teachers. Since it was first published, the FCI has undergone several revisions, and has become the most widely used metric of classical physics instruction, having been translated into nine languages besides English, taken by tens of thousands of students, and is now available on the Internet from http://modeling.asu.edu/R&E/Research.html.

The results of giving the FCI as a pre- and post-course diagnostic have consistently shown that before instruction, most students hold naive beliefs about motion and interactions which are not compatible with a correct Newtonian analysis, and that traditional lecture methods do little to change such beliefs (Hestenes, 1996, 1998; Mazur, 1997, 2007; Van Heuvelen, 2001; McDermott, 2001; Hake, 1998, 2007). The FCI has been used to test graduate students' and faculty members' understanding of Newtonian concepts, and in a number of surveys, it has been found that often even graduate students and faculty score in the sixtieth to seventieth percentiles (Pride, Vokos, and McDermott, 1998). The general conclusions of the physics education community have been that traditional physics instruction does not guarantee correct Newtonian reasoning, but correct understanding of motion and forces according to the Newtonian paradigm is a predictor of success in physics (Hestenes, 1995, 1996). Interactive instructional methods, including the use of Socratic dialogue, which engage students as active participants during class, as opposed to traditional lecture methods, have been shown to cause significant improvement in Newtonian reasoning, as tested by the FCI (Hestenes, 1996,1998; Hake, 2007; Laws, 1991, 1997; Mazur, 1997, 2007).

Edward Redish, Jeffrey Saul, and Richard Steinberg published their Maryland Physics Expectations test (MPEX) in 1996, which was designed to be a companion metric to be used with the FCI. Whereas the FCI was designed to test concept development, the MPEX was designed to test whether students' attitudes towards the process of doing physics improved over the course of instruction. Their research, administering their test to over 1500 college students enrolled in introductory physics courses at six different universities, revealed that attitudes towards physics actually declined after instruction, regardless of the method used (Redish, Saul, and Steinberg, 1998).

The FCI and the MPEX have become the standard metrics in the United States for measuring the success of introductory physics courses, and are still widely used as diagnostics against which any new pedagogical methods are tested. One of the first teaching physicists to turn the FCI on his own students was Eric Mazur, of Harvard University. He described his shock at seeing the poor results of his students, which led him to develop the interactive method he called Peer Instruction (PI). PI emphasizes the Socratic method, whereby the instructor poses conceptual questions to the class at regular intervals during the lecture, which the students discuss first in small groups and then together as a class, instead of students passively listening to a lecture (Mazur, 1997, 2007). PI has been shown not only to improve conceptual learning via the FCI (Crouch, Watkins, Fagen, and Mazur, 2007), but also to eliminate the gender gap in introductory college physics, as measured by the FCI (Crouch, Oster, and Mazur, 2001; Lorenzo, Crouch, and Mazur, 2006).

The poor results on the MDT and FCI prompted a number of other instructional innovations in the 1990's, most of which include elements of interactive engagement from Peer Instruction as well as concept building from Modeling Instruction. The most widely recognized instructional innovations over the past decade or so have been Workshop Physics, developed by Priscilla Laws at Dickenson College, Physics by Inquiry, developed by Lillian McDermott at Washington University, and Learning Cycles, developed by Dean Zollman at Kansas State University. All three of these instructional methods emphasize the use of manipulatives, peer interactions, and discussions, and de-emphasize the role of lecture in physics instruction.

Workshop Physics is similar to the Modeling Instruction approach in that it seeks to help students develop mathematical models, but different in that these models all start with a physical experience. Every concept is first illustrated by an experiment or other practical activity, which is followed by the instructor guiding a mathematical derivation. This is followed by an “equation-verification experiment” (Laws, 1997).

Physics by Inquiry, developed by the Physics Education Group at the University of Washington, under the direction of Lillian McDermott, has been described as learning physics by guided inquiry (McDermott, 2001). McDermott's approach is similar to Laws' Workshop Physics in that each new concept is motivated by a short investigation, which could be an actual experiment or a thought experiment, but there is less emphasis on developing equations to model phenomena, and more effort spent on concept development. Physics by Inquiry also relies heavily on peer interactions, as all the experiments are done in cooperative groups, and the instructor poses questions for discussion rather than lecturing.

Zollman's Learning Cycles method incorporates elements of Physics by Inquiry and Peer Instruction, but utilizes a cyclic approach to learning concepts in physics (Zollman, 1996). Two inquiries are performed by students, at their own pace, outside of the regular class period: an exploratory investigation on Monday, followed by a more in-depth application on Wednesday. On Friday the class discusses the results, and the professor summarizes the week before beginning a new cycle the following Monday (Zollman, 1996).

"Just in Time Teaching" (JiTT) was developed by Evelyn Patterson (US Air Force Academy), Gregor Novak and Andrew Garvin (Indiana University – Purdue University), and Wolfgang Christian (Davidson College). JiTT emphasizes the use of the World Wide Web for near-real-time adjustments of an instructor's lesson plans to the current state of understanding of the class as a whole. The technique that is stressed is to have students read the text and answer questions via the Internet before class; the instructor reads their answers prior to class, and adjusts the lesson for the day accordingly. JiTT methodology makes extensive use of computers for modeling physical systems using simplified graphics called *"Physlets,"* which were first developed by Wolfgang Christian in the early 1990's.

Physlets - Java applications ("applets") which can be run over the Internet in the Java programming language, are useful with Modeling Instruction techniques, in that they allow students to change initial and boundary conditions in a simple system, make predictions, and test their predictions against the outcomes. Physlets are designed to be media-focused problems, as opposed to a passive, media-enhanced demonstrations of a system or process (Christian and Belloni, 2001). An extensive library of Physlets is now available on the internet (http://webphysics.davidson.edu/physletprob/) and instructions for how to code one's own Physlets are available in book form (Christian and Belloni, 2001).

More recently, Eugenia Etkina of Rutgers University has found that high gains in conceptual understanding, as measured by the FCI, are related to students' personal epistemologies - beliefs or views about how knowledge is constructed and evaluated. (May and Etkina, 2002). Students whose personal epistemologies are more appropriate to the methods of physics tend to show higher conceptual gains than others, even though they have all been taught using the techniques of Modeling Instruction and Peer Instruction (May and Etkina, 2002). Thus, in addition to promoting active learning, the next goal of physics education they recommend is to interrogate students' epistemologies – how they understand the process of acquiring knowledge and making sense of observations – and design strategies to help students learn the process of creating meaning from physical observations (ibid).

Etkina's work, and the research on student epistemologies of Hammer and Elby (2002), and diSessa (1993), while important, all center on understanding how students understand Newtonian physics, however Jonathan Osborne of King's College in London suggested that, although Newton's contributions were certainly revolutionary for his time, they represent a world view which is "relentlessly deterministic, linear and remote from human action or influence" (Osborne, 1990). Osborne suggested that the content of physics should be thought of in three basic realms of understanding: classical physics, from Newton to the end of the nineteenth century; modern physics, which includes discoveries of Relativity and Quantum Mechanics that occupied the first third of the twentieth century; and contemporary physics, which covers the recent advances in fundamental physics. Osborne suggested that the complete over-representation of Newtonian physics at the expense of contemporary physics presents a distorted view of the world, which fails to address what should be the goals of physics education: what do we know (ontology), and how do we know it (epistemology).

Thus physics education research in the United States in the past twenty years or so has shown that interactive methods are more effective than the traditional lecture method in promoting conceptual understanding in introductory physics. However, the content and sequence of the introductory curriculum has remained constant for the last fifty years, with an over emphasis on the deterministic Newtonian paradigm, so that the questions which motivate the practice of physics in the contemporary world are not being addressed in introductory physics.

2.2. Diversity and Equity Issues in Physics Education

At the same time as efforts to reform instructional methods in undergraduate introductory physics have been undertaken in the United States, women and minorities remain under represented in physics (Wertheim, 1996; Zuga, 1999; Fox-Keller, 2001, Tobias, 2003; Ivy and Ray, 2005). Blickenstaff (2005) examined thirty years of research on the gender imbalance in physics, and concluded that the very nature of science may be the largest contributor to what has been called the "leaky pipeline" whereby women have greater attrition rates than men, particularly in physics. A few studies in the United States have attempted to recontextualize Newtonian mechanics in terms of female scenarios, but with no conclusive evidence that such changes had any effect on increasing the numbers of girls in physics, nor improving their Newtonian reasoning (McCullough, 2001; Whitten, Foster, and Duncombe, 2003).

In Europe, the Relevance of Science Education (ROSE) project has revealed that girls and boys in high school do indeed have different interests regarding content and orientation in physics. In a study of high school students in thirty four countries Sjøberg and Schreiner (2007) found that boys report interests in electrical, mechanical, spectacular and violent phenomena, while girls' interests are more directed toward biology, health, caring, ethical, aesthetic, philosophical issues. On the other hand, they found that both girls and boys reported similarly high interests in topics from contemporary physics, including black holes, supernovas and other spectacular objects in outer space, stars, planets and the universe, unsolved mysteries in outer space, and phenomena that scientists still cannot explain (Sjøberg and Schreiner, 2007). Angell, Guttersrund, and Henriksen (2004) interviewed Norwegian high school students in physics in grades twelve and thirteen, and found that both boys and girls reported much greater interest in topics such as relativity and quantum mechanics than classical physics. Interestingly, these same students also reported that the topics from contemporary physics were much more connected to their every-day experiences than topics from classical physics, because these were often topics of conversation among their friends.

Kessels, Rau, and Hannover (2006) studied negative attitudes toward physics of high school students and undergraduates in Germany. When they tested the high school students using an implicit association test, they found that high school students associate physics with difficulty, masculinity, heteronomy (lack of opportunity for self expression), and unpleasantness. They then compared a control group of undergraduates who were given a passage to read from a traditional physics text book with a treatment group who were given a passage by Thomas Kuhn that emphasized the importance of discourse and creativity in physics. They found that the negative associations with physics of the treatment group were significantly reduced compared to the control group (Kessels, et al., 2006). They found that the avoidance of physics as unpleasant, although more pronounced in high school girls, was also present in boys. They recommended that educational strategies which seek to overthrow stereotypes of physics can be effective in reducing the perceived barriers to studying physics (ibid.). This recommendation supports the findings of the present study, in which art students with initially negative impressions of physics and physicists reversed their attitudes as a result of this course.

Zohar (2006) compared connected knowing, which was originally described as "women's ways of knowing" (Belenky, Clinchy, Goldberger, and Tarule, 1986), with feminist epistemology of science, which is characterized as an interconnected knowledge system. She defined four ways in which interconnected thinkers are characterized: seeing connections between phenomena to be understood and the contexts in which they occur; seeing connections between the phenomena to be understood and themselves; connecting their mental representations of knowledge with their emotions, bodies, and actions; and seeing knowledge as a collaborative construction among people. It is interesting to note that the attributes of connected knowing, ascribed to feminist epistemology by Zohar, are essentially not different from the practices of contemporary physics, in the following ways: In contemporary physics, it is understood that an observer cannot observe a system without influencing its behavior (phenomena connected with contexts in which they occur), which is the opposite of the Newtonian paradigm which divorces the observer from the observed. Experimental physics research is becoming increasingly connected with other disciplines, for example: biophysics, nanoscience, and media arts technology (phenomena connected with different 'selves'). All branches of physics encourage and require collaboration (phenomena connected with people), from theoretical physics to international experiments in particle physics and space science. Lastly, although in traditional physics instruction, understanding physics has not been associated with emotions and physical sensations, one has only to read personal accounts of Einstein and other famous scientists to understand the role of emotions, images, and intuition in their accomplishments (Wallace and Gruber, 1989; Miller, 1989; John-Steiner, 1997). Thus, I would like to suggest that instead of labeling connected ways of knowing as "feminist epistemology," that we instead look at them as "humanist epistemology," and consider the possibility that starting the introductory physics sequence with contemporary physics, especially with contextual applications from nature and fine arts, may have a positive effect in attracting a more diverse student population.

Conventional science instruction, Zohar concluded, is based on the dualistic conceptions of science that grew out of the Enlightenment of Western Europe, in which reason and objectivity were identified with science and masculinity, and emotion and subjectivity were identified with art and femininity. Other scholars of the history of science have also associated science, especially Newtonian physics, with objectivity, which has come to be associated with conventional masculinity (Wertheim, 1996; Zuga, 1999; Traweek, 1988). Zohar recommends that the goal of science education should be to challenge the conventional dualistic mode of thinking by developing ways of interconnected knowing (Zohar, 2006).

Symmetry and Aesthetics in Introductory Physics combines features of each of the above recommendations for improving introductory university physics: starting with contemporary physics rather than Newtonian mechanics as more interesting and meaningful for both male and female students; utilizing connections with art and nature to illustrate concepts from math and physics; utilizing alternate learning strategies of drawing and visualization to enhance mathematical and logical understanding; encouraging discussion, collaboration, and self reflection; reading literary works by theoretical physicists instead of a standard text book; and a final project connecting physics with an art form of personal relevance to each student, thus allowing for freedom of expression (the opposite of heteronomy) within the correctness of the discipline.

2.3 How Discourse Shapes the Physics Community

The discourse of physics sets physicists and physics students apart from other discipline-based communities, thus any reasonable attempt to understand the lack of diversity in the physics community should include an investigation of the role of the discourse of physics in maintaining the boundaries and borders of that community. A male English major from the College of Creative Studies, who was enrolled in an astronomy course for which I was a teaching assistant in 2004, after attending a meeting of the Society of Physics Students at UCSB said to me, "They TALK different from most of the rest of us.” This language difference between the physics and art students was apparent in the course Symmetry and Aesthetics in Introductory Physics (CCS-120) in the present study, in the way they spoke, wrote, communicated, and represented themselves.

Traweek (1988) described the culture of physics as "an extreme culture of objectivity; a culture of no culture, a world outside human space and time," and the knowledge represented by physics as “a certain kind of privileged knowledge, a way of knowing that is profoundly gendered and cultural” (Traweek, 1988). Bazerman (2000) described the discourse of physics in the following way:

> Unfamiliar words signify objects and phenomena from the microscopic and macroscopic limits of the universe, objects distinguished from each other and classified with a precision and taxonomic care having little to do with our everyday fuzzy naming of the objects of domestic life *(*Bazerman, 2000, p. 293*).*

He further said that these practices give physics discourse “special status separate from the turbulent, murky, and illusion ridden language of the rest of the human world” (Bazerman, 2000, p. 296). This obscurity of language, he says, often leads to a general mistrust of physicists. The art students in CCS-120 expressed similar resentment towards this usurping of familiar terms from everyday parlance into physics usage, as will be discussed in Chapter Five.

Sociolinguistics scholar John Gumperz' (1968) definition of a speech community provides a more objective definition which can be applied to the community of physicists:

> any human aggregate characterized by regular and frequent interaction by means of a shared body of verbal signs and set off from similar aggregates by significant differences in language usage (Gumperz, 1968. p.381).

Dell Hymes (1997) defined a socially constituted linguistics as one which has both social as well as referential meaning. Thus, even setting aside Bazerman's rather emotionally charged condemnation of the discourse of physics, it is conceivable that the specialized language of physics is a socially constituted linguistics in that it has referential meaning, and also serves to identify members of the physics community as separate from others. The language of physics and mathematics did present a boundary between the art and physics students, which had to be overcome, even in this group of students who were otherwise culturally homogeneous. Thus, if we are to increase the diversity in physics, one important aspect to consider, which is suggested by the present study, is to find ways to make the language of physics and mathematics more accessible to a wider population.

2.4. Discourse of Physics as a Barrier to Minority Culture Students

The problems of accessibility with the discourse of physics and language of mathematics are magnified for minority students in the United States (Aikenhead, 1999; Aikenhead and Jegede, 1999; Lee, 2003). According to the Multiple Worlds Theory of Phelan, Davidson, and Yu (1993), students from minority culture home worlds must make a transition to the dominant culture of the school world. The theoretical framework of border crossings between multiple worlds has been applied to understand the combined difficulty of minority-culture students both with the dominant white culture of school itself, and with the additional difficulty imposed by the culture of western science, particularly physics. Not being part of the dominant culture language group, learning the language of physics is even more problematic for minority culture students (Lee, 1998, 2003; Aikenhead, 2002, 2003). Not surprisingly, recent studies by the American Physical Society (Ivy and Ray, 2005; Ong, 2007) reveal the persistent lack of people of color in physics. Thus the physics education reforms cited above, which address pedagogical strategies for introductory physics, but do not consider the role of the discourse of physics and mathematics in maintaining the unseen boundaries around the community of physics, do not automatically benefit minority culture students who may be reluctant to enter a physics course at all. The problem of under-represented groups in physics continues to be both monolithic and implacable (Burciaga, 2007), and the physics education community has been slow to address issues such as discourse, which fall outside the arena of mainstream physics education research.

The rationale for a paradigm change in the introductory physics curriculum as being necessary for a change in the physics community can be found in Thomas Kuhn's *The Structure of Scientific Revolutions* (1962, 1970, 1996). To change the structure of the physics community requires a change in the way we educate our students, which necessitates the acceptance of a new paradigm – which, it seems, the physics community is reluctant to do. Why is it so important to the community identity that everyone be trained first to conceptualize the phenomenological world in terms of strict Newtonian determinism, when the axioms of the Newtonian paradigm, absolute space and universal time, are not those of the contemporary world view? Perhaps, according to Kuhn, we maintain this paradigm because it is a cultural outgrowth of western Europe. Thus it unconsciously acts as a barrier which prevents cultural diversity: unless a student is prepared to first adopt the Newtonian world view prescribed by the introductory curriculum, he or she cannot progress to the higher level, where the contemporary issues and technologies are taught. Thus the system of physics education, which begins with a strict adherence to Newtonian mechanics may function as a tacit filter, which is so culturally embedded as to be invisible to mainstream Physics Education Research, yet which acts to prevent cultural diversity from changing the face of the physics community.

In a recent editorial in *Physics Today*, “Rethinking the Content of Physics Courses” (February, 2006), Diane Grayson of the University of Pretoria, South Africa, recommended changes in the scope, sequence, and content of the introductory physics curriculum, based on proposals from an international conference on physics education that took place in Durban, South Africa, in July, 2004.

A physics curriculum for the 21st century should include the human dimensions of what is a very human activity, the generation of knowledge about the physical world. That knowledge generation does not take place in a vacuum; it is always embedded in a time and place, influenced by history and culture, passion and prejudice. Students should come away from their physics courses with an increased sense of wonder and excitement at the marvels of the physical world and the ingenious ways in which human beings have tried and continue to try to understand them. (Grayson, Physics Today, Feb., 2006)

The curriculum, teaching strategies, and goals of Symmetry and Aesthetics in Introductory Physics support and are supported by the proposal of the international conference on physics education summarized by Grayson. This interdisciplinary introductory physics and fine arts curriculum takes into account the research in mainstream physics education, incorporating elements of Peer Instruction and Modeling Instruction; addresses students' epistemologies by interrogating students' beliefs about the role of mathematics in understanding the physical universe; reframes the curricular paradigm from Newtonian determinism to a contemporary, post-Einstein world view; and attempts to make physics accessible to a more divese population by including ways of knowing that are connected to nature, art, and music. The results of the present study suggest that including art as a way of understanding concepts in physics may provide a way to open up access to the discourse of physics and mathematics to a wider population, thus ameliorating the negative perceptions of physics described by Bazerman.

An additional goal of this curriculum is to foster creativity while maintaining mathematical rigor and developing sound physics reasoning by exploring the connections between art and physics, through the common principle of symmetry.

2.5. Creativity theories and Interdisciplinary Curriculum

In a recent editorial in *Physics Today* (July, 2006, p. 10) the ability of physicists to “imagine new realities” was correlated with what are traditionally considered non-scientific skills, including imagination and creativity, qualities which are usually associated with fine arts. Sheila Tobias (Research Corporation, Tucson, Arizona) commented in another editorial in *Physics Today* that the physics education community needs to seek alternate ways of teaching physics to overcome “America’s lagging production of physics majors” so as to recognize a talent for physics that is “differently packaged from the norm” (August, 2006, p. 10). The present study is addresses the need for an introductory physics curriculum which promotes the ability to imagine the new realities as revealed by contemporary physics, and encourages students who may be differently packaged from the norm to excel in physics via the similarities between physics and the arts. Research on intelligence, creativity, education theory, and the nature of physics as it is practiced, supports the rationale for such an interdisciplinary curricular paradigm for introductory college physics.

2.5.1. Creativity and Intelligence

What is creativity? Creativity theorists, such as Mihaly Csikszentmihalyi, Howard Gruber, and Vera John-Steiner, have shown that creativity is defined by a product and a process, often a very long process, which is defined within a socio-cultural system, of which the individual is one component. Creativity does not occur in a single insightful moment, nor is it possible without being situated within a cultural system. Csikszentmihalyi interviewed famous people who are considered creative, who came from a wide variety of disciplines, ages, and cultures, including physics, literature, art, music, and dance, as well as hundreds of college students, in a multi-year study. Based on his findings, he defined a systems approach to creativity:

> Creativity occurs when a person, using the symbols of a given domain such as music, engineering, business, or mathematics, has a new idea or sees a new pattern, and when this novelty is selected by the appropriate field for inclusion into the relevant domain. (Csikszentmihalyi, 1996).

Thus we can understand from this definition that creativity requires training in one or more domains. What about intelligence? As Gruber (1989), Csikszentmihalyi (1996) and John-Steiner (1997) have shown that there are many different ways in which creativity is expressed, Howard Gardner (1985) has shown that there are several different ways in which intelligence is expressed. Gardner (1985) identified five main types of intelligences that involve cognitive skills: linguistic / verbal intelligence; musical intelligence; logical/mathematical intelligence; spatial intelligence; and bodily/kinesthetic intelligence. Moreover, Gardner showed that people express intelligence in more than one mode simultaneously (logical, kinesthetic, musical, e.g.). Gardner founded "Project Zero" at Harvard University to study the cognitive aspects of the arts, or *artistic intelligence* (Gardner, 1983). Artistic intelligence, Gardner proposed, involves the production and recognition of symbols (ibid).

Since Gardner's Multiple Intelligence model was published, several programs have explored the incorporation of arts in science education in universities (Walton, 1998; Korey, 2000; Nikitina, 2003; Hertzberg and Sweetman, 2004),which have shown that people simultaneously express themselves intellectually as well as creatively in more than one realm, for example: engineering and dance, engineering and photography, or math and art. These studies will be discussed in Chapter Three.

The implications for education are clear: the intelligences defined by Gardner are avenues by which creativity can be expressed, and people naturally express both intelligence as well as creativity in more than one area simultaneously. It is the suggestion of the present study that symbolic representations, whether in visual arts, mathematical symbols, movement arts, or musical notation, share the common feature that they communicate ideas via representations that tap into concepts more efficiently than words, although they are ultimately reducible to verbal description. Thus, it may be possible to utilize, for example, a cubist painting to communicate the idea of what the world might look like to a traveler undergoing a Lorentz boost, movements from dance to communicate concepts from dynamics, or – as one of the art students in CCS-120 expressed, translational symmetry as wallpaper.

> The passage about Morris (p.21-22 in reader), which some may consider an irrelevant tangent made me instantly get what translational symmetry is – a concept I have been struggling to see before my mental eye thus far. Wallpaper - of course! It makes complete sense!

Elliot Eisner of Stanford University has discussed the separation of arts and sciences in education as having originated in the Enlightenment of western Europe (Eisner, 2002a, 2002b). Natural science - which later became known as physics – represented the epitome of knowledge as being rational, objective, deterministic, universal, and reducible to mathematical relationships. Episteme, or true knowledge, was independent of beliefs and values (ibid.); such is the basis for the Newtonian *weltanschauung*. The viewpoint of practicing physicists, on the other hand, is that while acknowledging the ultimate universality of the laws of physics as constant under translation, rotation, or Lorentz boosts, for example, physics is ultimately a creative and cultural endeavor, which shares experiential features with arts and literature. Quoting theoretical physicist Lawrence Krauss (*Fear of Physics)*, physics is a creative endeavor.

> I want to stress that physics is a human creative intellectual activity, like art and music. Physics has helped forge our cultural experience. … it is a grave mistake to ignore the cultural aspect of our scientific tradition. … And the chief virtue of a cultural activity – be it art, music, literature, or science – is the way it enriches our lives. Through

> it we can experience joy, excitement, beauty, mystery, adventure (Krauss, 1993, p. xi).

Eisner (2002b) proposed that the choice of symbolic forms of representation influences not only what one is able to say, but also what one is able to see. "We seek what we are able to find" (Eisner, 2002b, p. 380). Just as narrative is a form of discourse in which the way in which something is told conveys a deeper meaning behind that which is being said, images make it possible to "apprehend that which we wish to comprehend” (ibid., p. 380). Thus it is logical to conceive of bringing art and other forms of symbolic representation into physics education. These two statements, one from a theoretical physicist and the other from an education theorist, if understood together, lend support the model of interdisciplinary arts and physics education, at least at the introductory level, before specialization in the more advanced courses narrows a student's focus. The reactions of both physics and art students in CCS-120 support this view as well.

Csikszentmihalyi proposed that creativity is best nurtured at the intersection of different cultures, where beliefs, lifestyles, and knowledge structures permit the free exchange of ideas and points of view. “*Creativity is more likely in places where new ideas require less effort to be perceived*” (Csikszentmihalyi, 1996; p. 9). The interdisciplinary course, Symmetry and Aesthetics in Introductory Physics, which combined arts and physics was certainly an environment which encouraged the exchange of ideas and points of view, in a classroom culture that was neither uniform nor rigid.

Further support for the idea of interdisciplinary arts and sciences education can be found in the work of Vera John-Steiner (1997), who studied the cognitive aspects of creative thinking. She investigated the similarities, across cultures and across disciplines, in the way people who are publicly recognized as highly creative think about what they do. She proposed that between the external object and the internalized conception of the object, there is the translation through some set of symbolic representations. She called these representations *languages of the mind* – how people think in images, music, patterns, words, numbers, algebraic symbols, mnemonic techniques, and spatial relationships. Her interviews revealed a wide variety of symbolic representations that people use to translate from the external world to their understanding of it, via their own internal symbol systems, and in turn, how they communicate their internal understanding with the outside world through creative processes of literature, music, dance, science, and mathematics. She found, for example, that physicists and mathematicians often think in images, as in the following quote from Einstein:

> The words or the language, as they are written or spoken, do not seem to play any role in my mechanisms of thought. The physical entities which seem to serve as elements in thought are certain signs and more or less clear mages which can be voluntarily reproduced or combined (John-Steiner, 1997, p. 4).

Combining the research of Gardner on multiple intelligences, Csikszentmihalyi on the nature of creativity, and John-Steiner on the creative process, it is logical to consider that perhaps intelligence is the ability to understand sensory input from the outside world, and creativity is the ability to express one's understanding in one or more symbolic forms so as to stimulate new ways of understanding in others. Thus, we can see how physics and mathematics embody creativity, and arts express intellect. Combining these ideas leads us to try new paradigms in undergraduate education, such as the interdisciplinary course, Symmetry and Aesthetics in Introductory Physics of the present study.

2.5.2. Optimizing the Educational Experience

One final element that is missing from traditional introductory physics courses, which was cited by John-Steiner as being important to the creative people she studied, has been cited as important by scientists and artists, and was cited as important to the students in CCS-120, is *passion.* John-Steiner reported that the creative people she interviewed had the common experience of school as being "sparse and lifeless" (1997, p. 45), while both art and physics students in CCS-120 reported that it was the passion of the other students and the instructor which made the class important to them, and inspired them to attend. Csikszentmihalyi developed a *theory of optimal experience,* based on people's personal accounts of what it felt like to be doing what they most enjoyed (Csikszentmihalyi, 1990). He defined the *"flow*" experience as "the state in which people are so involved in an activity that nothing else seems to matter" (ibid., p. 4). Qualities of the flow experience include the loss of a sense of time as measured by a clock, and the loss of the sense of self, yet the self concept emerges stronger as a result. There is the sense that the task can be completed, there are clear objectives and the opportunity to concentrate, and there is a sense that the task is worth while for its own sake. Several experiences with the interdisciplinary course CCS-120 had qualities that embodied those of the flow experience, particularly the final project, which students said did not feel like an assignment at all, and the class discussions, which often went on for an hour or more after class. Thus, the suggestion of incorporating arts into physics, and of starting introductory physics with contemporary physics instead of Newtonian mechanics, should be taken seriously by the physics community as a way of improving the introductory physics experience for all students.

2.5.3. Emerging Support for Symmetry –based Curriculum

Finally, to become accepted as a creative contribution, a new idea must be accepted by those in power who function as gatekeepers of a discipline (Csikszentmihalyi, 1996). Evidence that the combination of arts and physics is gaining acceptance by some of the gatekeepers of physics is apparent in the support for this curricular model by Professor David Gross, the director of the Kavli Institute for Theoretical Physics (KITP) and 2004 Nobel Laureate, who gave a guest lecture for the class (Gross, personal communication, March 9, 2007). The KITP has supported Dr. Jean-Pierre Hebert as Artist in Residence for several years, and maintains two informal art galleries within the KITP itself. The School of Engineering at UCSB began a graduate program in Media Arts Technology several years ago, which encourages interdisciplinary research in art, music, and computer technology.

Outside of UCSB, support for a symmetry-based integrated physics and fine arts curriculum comes from Dr. Leon Lederman, 1998 Nobel Laureate and former director of the Fermi National Accelerator Laboratory in Illinois, who has designed a high school based on these principles (the Illinois Math and Science Academy).

2.6. Summary of Supporting Research

In summary, research in physics education in the past twenty years has shown that interactive methods are superior to straight lecture in promoting understanding of physics concepts. At the same time, while the methodology has changed from traditional lecture to interactive classroom environments, the prevailing view that Newtonian mechanics should dominate the introductory curriculum has been very slow to change. The physics community continues to be characterized by a lack of diversity, with both women and minority cultures being under-represented. Research in Europe is beginning to show that the gender bias may be maintained by the introductory curriculum due to its over emphasis on Newtonian mechanics and contexts which address the specialized interests of traditional masculinity. The perspective of contemporary physics is more aligned with what has been called feminist epistemology, or connected ways of knowing, which suggests that reframing the introductory physics curriculum so as to begin with contemporary physics may have a positive effect, at least on redressing the persistent gender bias.

From a sociolinguistic viewpoint, the specialized discourse of physics serves to create and maintain the boundaries of the physics community, which set physics students apart from others even in otherwise culturally-homogeneous groups. The discourse of physics as a marker of physics identity is even more problematic for minority culture students. Most of the mainstream physics education research in the United States still focuses on improving students' understanding of Newtonian mechanics, yet the effectiveness of this approach at increasing diversity of the physics community has not been demonstrated. The number of women graduating with PhD's in physics is still under 20%; for minority culture students this figure is much lower.

At the same time, practicing physicists are calling for the undergraduate curriculum to encourage greater creativity in the next generation of physicists. Theoretical support for the combination of creativity and multiple intelligences from the work of psychologists Howard Gardner, Howard Gruber, Mihaly Csikszentmihalyi, and anthropologist Vera John-Steiner can be used to help design interdisciplinary curricula which can encourage the development of creativity in physics. Education theorist Elliot Eisner of Stanford University has advocated for greater emphasis on the arts in education.

The goal of this project, then, was to design a new curriculum for introductory physics, which starts with symmetry and math as a language of nature, and utilizes symmetry as the natural connection between physics and fine arts, and to test whether such a curriculum could make physics appealing and accessible to a wider population of undergraduates, without sacrificing the mathematical way of knowing which is the foundation of physics. The enthusiasm of the students and their progress in learning concepts in physics are testaments to the success of this model with these students, and suggests that this model deserves further development and testing with a wider population.

In the next chapter I will present the results of several interdisciplinary arts and sciences courses at other universities which support the idea that such curricular paradigms can make physics accessible to a wider student population, without sacrificing mathematical rigor. I will also present the results of a survey I conducted in 2006 of recreational folk dancers who have jobs in physics or math-related fields. The reports by these people, from the United States and Europe, demonstrate that indeed connections do exist for many people in their approach to dance and physics.