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Art Across the Disciplines: How the Integration of Fine Arts Across the Curriculum Is Influencing and Changing Stem Pedagogy

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ART ACROSS THE DISCIPLINES: HOW THE INTEGRATION OF FINE ARTS ACROSS THE CURRICULUM IS INFLUENCING AND CHANGING STEM PEDAGOGY

by

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This manuscript has been read and accepted for the Graduate Faculty in Liberal Studies in satisfaction of the thesis requirement for the degree of Master of Arts.

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ABSTRACT

Art Across the Disciplines: How the Integration of Fine Arts Across the Curriculum is Influencing and Changing STEM Pedagogy

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Within the past decade several institutions have begun to investigate techniques that combine the fine arts and humanities into STEM (Science, Technology, Engineering, Mathematics) coursework and curriculums. The resulting trend STEAM (Science, Technology, Engineering, Art, Mathematics) indicates that the arts could comprise an important part of the critical thinking process leading to transfer across subject domains and higher order thinking skills. The purpose of this work will be to examine past trends in this area followed by an examination of methodologies developed during the formative years. This will be followed by an examination of the theoretical foundations of STEAM. The major portion will focus on four case studies reflecting some of these newer approaches. The thesis will conclude with evaluation of the case studies and thoughts on the validity of current methodologies and recommendations suggesting how academics might best apply several of these concepts to undergraduate studies.

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CHAPTER 1

Introduction

During the past decade educators have been examining the integration of arts imagery into classroom-based undergraduate instruction. One common approach was centered upon the humanities and social sciences where the arts could be added to course content allowing students further insight into the social customs, traditions, religious views, political movements and the ideologies in the context of these separate disciplines. Early studies, focusing on the work of Yenawine (2014), Housen (2001) and others, rested on a foundation, referred to as Visual Thinking Strategies (VTS) later verified through small and longitudinal studies. During this time there have been attempts to introduce additional innovative concepts into mathematics and the sciences - disciplines largely overlooked and considered widely dissimilar from such innovations up until this point. Recent trends, pioneered by several international universities now proceed upon a premise that wider cross-disciplinary studies are called for because *real world problems do not come in disciplinary-shaped boxes* (Koenig, p. 473).

Recently, several institutions have begun to investigate techniques that combine the fine arts and humanities into STEM (Science, Technology, Engineering, Mathematics) curriculums. These initiatives have contributed to the creation of separate programs of study (Masters of Creative Technology) consisting of a combination of research, art and design, humanities and technology modules. The direction of this approach aims to move the STEM curriculum into what university officials and faculty now refer to as STEAM (Science, Technology, Engineering, Arts and Mathematics). The desired result of such initiatives is to create a new generation of educators equipped to investigate, assimilate, and add validity to this integration into their respective disciplines. On a different level, one of the most impressive studies has another university taking a more aggressive approach as fine arts students, working alongside scientists, have developed classroom partnerships attempting to investigate how science constructs knowledge and how abstract ideas are visually communicated. This initiative is attempting to do what is seen as concocting a new language for the incomprehensible.

These two initiatives only reflect some of the newer trends in this ever-widening area of research. To date similar studies have produced results helping to demonstrate the use of visual arts should not be treated as a secondary component of the liberal arts and sciences curriculum. Rather this trend indicates that the arts could comprise an equally important part of the critical thinking process – one leading, not just to what in earlier studies described as transfer, but to higher order thinking enabling those outside of the humanities and social sciences to visualize and address complex problems and solutions.

Based upon these recent investigations, the purpose of this thesis is to examine past trends and methodologies and then proceed to further examine several of the newer initiatives being tested across academic institutions. The thesis will place emphasis on STEM subjects, areas that on most campuses continue to exist as a world apart from the arts curriculum. Included in this study will be an overview of earlier research consisting of the Columbia University, Housen and Yenawine studies in Visual Thinking Strategies (VTS). These studies supplied us with a theoretical basis serving as a starting point for later experimental studies. This will be followed with a theoretical overview and detailed examination of three significant and one ancillary case studiy further illustrating emerging trends and methodologies as described in the recent literature. Emphasis will be placed upon distinguishing similarities and differences common to the theoretical, methodological and educational concepts being applied to further advance the idea of STEAM pedagogy. The thesis shall conclude with thoughts on the validity of the current methodologies along with suggestions on how academics might work to introduce these innovative concepts into disciplines spanning the wider curriculum previously considered too remote for such considerations.

Rationale

Personal experience as a classroom teacher and instruction librarian has led to pursuing a hands-on and experiential approach to education. The idea of investigating the potential of art across the disciplines began as a PowerPoint lecture presented to our college faculty during a colloquium on library and classroom technologies. This approach was designed with undergraduates in mind although museum educators using primary and secondary school samples conducted earlier research in this area. Years as a college librarian, particularly one used to providing undergraduates with course-specific bibliographic instruction, made it possible to observe and evaluate how different literacies can be introduced across varied disciplines. Over time, it became evident just how adaptable the visual arts were in integrating them into core and liberal studies. Additionally, it became evident seeing just how useful and adaptable they might be on a broader pedagogical level.

Based upon these observations, a literature survey helped to illustrate that there are specific benefits derived from integrating the visual arts into other curricular areas. These benefits include: providing a visual supplement to lectures, the ability to associate images with spoken events and concepts, providing historical frames of reference and the development of interest using dramatic and compelling imagery. In addition, students could see how other liberal arts and the sciences often parallel the development of the visual arts, while benefiting from the idea that different disciplines share certain cognitive elements, dispositions, or ways of thinking.

Lastly, it became apparent that this type of approach, by its very nature, encourages students to think for themselves, a process essential for further academic and socio-political growth.

Much like the studies uncovered in the recent literature the early use of arts imagery was essentially object oriented and not exclusively geared towards the higher-level thinking seen in the current research. The use of imagery served the simple purpose adding works of art to enhance lectures and show how, through the eyes of artists, faculty could supplement a classroom narrative. Events depicted in the visual arts were equally effective as visual metaphors for specific social, historical and political events. From the start a more simplistic approach was used regarding the sciences, where assuming there was little connection, faculty used of the visual arts to focus on the history of science, and instances illustrating scientific achievement.

It became clear that the early use of art across the disciplines began in a simplistic manner. While there was no outcome assessment or statistical evidence regarding this use, positive feedback was received from faculty and students. Later it was discovered that other trends were slowly being introduced within this area. These trends were far removed from any conventional outlook or methodology. Although upon their discovery it become apparent that most of these innovations, aside from their modest origins with innovators such as Dewey, Vygotsky and Arnheim had their practical foundations in the earlier work of museum educators. From here it became important to further examine these and later attempts to add the arts into the greater curriculum.

CHAPTER 2

Preliminary Studies - Historical Foundations

One of the earliest and most comprehensive studies regarding learning through the arts and the question of transfer and critical thinking was conducted at Columbia University Teachers College by Burton, Horowitz and Ables (2000). This study, essential to the later and more comprehensive research of Housen and Yenawine, did not concentrate on an individual methodology and specific arts centered pedagogy. Instead it examined the development of higher order thinking skills from exposure to the arts in both students' private and public lives. Using a sample of 2,406 students drawn from cross-section of 12 elementary and middle schools over a period of several years, the sample was drawn from varied social and economic backgrounds from four states. Instructional staff consisted of faculty with diverse backgrounds and educational methodologies. Specialist and general classroom teachers, along with artists and outside educators made up the teaching component consisting of five phases and multiple variables that were quantified to achieve measurable results.

The first three phases explored potential sites, determined variables and developed quantifiable data. Data was collected in the fourth phase and, in the fifth qualitative phase, was interpreted to better understand the nature of these relationships. Before this a taxonomy of arts learning was created to serve as verifiable markers for the study. This consisted of seven areas: perception and inquiry, reflection and questioning, construction and layering of relationships, organization and appraisal of meaning, insight into alternative perceptions and imagining new possibilities and multi-sensory learning.

Each of these areas would be quantified and applied against two sets of variables as either a: potential indicators of outcomes from arts learning or b: characteristics of teaching and learning that might lead to results from arts learning. Potential indicators of arts learning consisted of cognitive, socio-cultural and personal learning. Characteristics of teaching and learning consisted of areas such as type of art, collaboration, comfort and competence in teaching, and other faculty-centered content.

Upon developing this model, the study was conducted using personal interviews consisting of an object-oriented approach with students discussing art and non-art items. Teachers quantified this by assigning numeric values to the discussions including the expression of ideas, layered relationships, imagining new possibilities and the use of multiple vantage points. Over time students were also tested using the Torrance Test of Creative Thinking, a Self-Description Questionnaire, and a Student Arts Background Questionnaire describing current and prior arts experience.

Classroom teachers were given three questionnaires, the School-Level Environment Questionnaire, Classroom Teacher Arts Inventory and, based upon the student interviews the Teacher Perception Scale. They were also interviewed and given questionnaires focusing on curriculum and student art achievement. These were measured against existing national standards.

The most significant omission regarding this array of tests and questionnaires is the exclusion of a control group. As opposed to a control group students, based upon performance interviews as well as performance in the other areas were classified into *high-arts* or *low-arts* groups. This information along with family background, socio-economic status, race and ethnicity, prior arts experience and the distinctive qualities were included and evaluated in the study. The data was then quantified using third-party software.

After compiled and analyzed, the results appeared to favor the authors' thesis that the effect of arts education across other academic disciplines could be correlated with the development of higher order thinking skills and that learning in the arts can be both contiguous to and distinct from other subjects. Elements of transfer are seen in results of two variations of the Torrance Test (Number of Years of In-School Arts and Number of Years of Arts Lessons) where the results favor the High-Arts Group over the Low-Arts Group by double digits. Findings indicate that *when students have teachers who collaborate with other arts providers and integrate the arts, they are more likely to have higher creativity scores* (Burton, Horowitz, & Abeles 2000, p. 245).

The Teacher Perception Scale when compared against records of academic performance shows overall higher results. For this study the important factor to note is that these results, while stressing behavioral and other general issues reflect an increase in reading and mathematics skills, two disciplines that appear on the higher end of scores. This indicates that *when students have teachers who collaborate with other arts providers and integrate the arts, the students are more likely to have higher expression, risk taking, imagination-creativity, and cooperative learning scores* (Burton, p. 245).

The next measure of the influence of arts teaching variables, the Self Description Questionnaire, while showing increase in academic self concept scores and arts teaching variables, are categorized as *significant but weak* (Burton, p. 245). However, further analysis revealed that there were some positive differences in High-Arts Groups and Low-Arts Groups regarding reading, math, general school and total academic self-concepts. For the purposes of transfer, these differences are important.

Finally, the *School-Level Environment Questionnaire* revealed that schools with strong arts programs attributed several effects on school climate to the arts. These included changes that effected teachers by *enabling them to learn new skills and broaden their curriculum, encouraged them to take risks and be innovative, develop increased rapport with students and provide further insight into their personalities and potential* (Burton, p. 245). These findings also indicate that the overall enjoyment factor of the school and workplace was increased.

A second and highly significant study by Abigail Housen; a five-year longitudinal study used some of the elements of the Columbia study, particularly the incorporation of art and non-art objects as measurable variables in data collection. Consisting of five years of ten data collections per year, Housen's research significantly differs from the Columbia study through use of a control group. This would further clarify the results of visual thinking on academic transfer.

The sample consisted of a farming community in Byron, Minnesota and consisted of a consortium made up of the Byron School District, the Minneapolis Institute of Arts, and the independent research group Visual Understanding in Education. Philip Yenawine was the senior research associate in charge of the study consisting of two primary school age groups consisting of experimental and control groups. The study was based upon a methodology consisting of an in-school teacher who facilitated discussions about art, museum visits and teacher training. According to Housen, (2001) the curriculum grew out of her view that: *theory and research about aesthetic development [is] designed to match images and questions to aesthetic developmental needs and naturally occurring capacities of beginner viewers* (p. 100). This would provide a fertile and objective sample to establish and classify any incidence of critical thinking and transfer.

Three questions were posed in the study regarding art and non-art objects. What is going on here? What do you see that makes you say that? What more can you find? Response to the first question was effortless; the second asked them to examine the evidence more closely, and the third encouraged them to continue searching. Housen (2001) based much of her method on Dewey who championed, *effective habits of discriminating tested beliefs from mere assertions guesses, and opinions […] sincere, and open-minded preference for conclusions that are properly grounded, and […] methods of inquiry and reasoning appropriate to the various problems that present themselves* (Dewey, 1910/1997, p. 28).

The measurement criteria were intended to assess several variables of transfer traceable to evidence of momentum. Unlike the Columbia study Housen (2001) avoided what she felt was conventional measurement noting that *the conventional methods used in the earlier study would neither capture the elusive phenomenon of critical thinking nor yield data that would measure its growth or transfer* (p. 102). The team used two instruments of measurement. The first the Aesthetic Development Interview was combined with a second, the Material Object Interview. Unlike the art and non-art object interviews of the Columbia study, the Housen study focused on personal interviews and did not seek to include quantified data from an array of standardized testing. The classification of thought gathered through the two interviews was achieved through the earlier use of categories drawn from the Aesthetic Development Coding Manuel a method first developed and utilized in Housen's (1983) doctoral dissertation.

Regarding thinking in relation to VTS, Housen's study identified two types of transfer. Context Transfer looked for transfer within the Aesthetic Development Interview in the social or classroom context while Content Transfer would show that transfer occurred across subject domains. The resulting study put Housen's thesis to the test using five hypotheses. The first, Context Transfer would show that transfer occurs from classroom dialogues to monologues. Coding Aesthetic Development Interviews for critical thinking would test this hypothesis. The second hypothesis, Content Transfer would demonstrate that transfer occurs across content as well: from art to non-art object. In this instance, Material Object Interviews were coded for critical thinking.

The third hypothesis, Sequence Effects, would show that changes would occur between the experimental and control groups at distinct times. Developmental Effects would demonstrate that Content Transfer scores would increase along with developmental levels. In this instance, Aesthetic Development Interviews were coded for Aesthetic Stage Levels while Material Object Interviews were coded for critical thinking. Finally, the fifth hypothesis, Developmental Growth is intended to show that over time VTS learning will demonstrate that students had achieved higher aesthetic stages than those in the control group. Both groups began with similar mean scores regarding Developmental Effects. The control group scores were slightly higher, but this would eventually show that the experimental groups displayed significant gains over time. The final hypothesis shows that by the fifth year of the study the experimental group had a strong statistically significant distribution from that of the control group.

Findings of this five-year longitudinal study also reveal a significant increase in the mean score of the experimental group over that of the control group regarding Transfer across Social Context. This showed that the mean critical thinking score of the experimental group at the end of the fifth year of the study were more than twice that of the control group. Similarly, regarding Sequence Effects differences of Context Transfer scores were measurable within the second year of the project and continued a consistent regular basis to the end of the study.

Regarding these findings, Housen (2001) notes that, *at the most basic level; VTS appears to be teaching critical thinking skills that transfer across social context. By year II, we saw that experimental students use significantly more supported observations and speculations about their Aesthetic Development Interviews. Furthermore, when the content is shifted from art to artifact, the experimental groups outperform the control groups* (p. 116).

CHAPTER 3

Overview of VTS Methodology

It is through research such as the Columbia University and Housen studies as well as by educators such as Burton (1995), Gardner (1983), Greene (1995) and Perkins (1987) would enable educators such as Yenawine and Miller to collaborate with several other educators to develop a methodology leading to a student-driven VTS curriculum designed to deepen aesthetic understanding. This can be classified as the range of thoughts and feelings that occur when looking at art. Since its inception, the use of VTS has also been shown to enable students to transfer visual strategies into other subjects thereby further validating the earlier research proposed through these early studies. Educators such as Housen and Yenawine (2003), who through the creation of a methodical approach to arts learning attempted to implement this theory by further creating a system for categorizing the arts learner into three separate groupings from which specific pedagogies can evolve.

These groups (from least to most experienced) consist of Accountive Viewers, Constructive Viewers, and Classifying Viewers. These stages of aesthetic development will determine the choice of materials and level of instruction. Accountive Viewers are classified as storytellers, those who use personal associations, memories and their senses to make concrete observations about a work of art. Their judgments are drawn from what they know, what they like and their emotional reactions to the visual arts. The second stage, Constructive Viewers, go beyond that of the Accountive Viewers by approaching a work of art within a framework consisting of personal perspective, the natural world, social and moral values and conventional society. Often their sense of what is realistic is the standard used to assess value. The final stage, the Classifying Viewers, adapt the methods of art historians. They approach the work according to context: place, style, school, time and provenance. Based upon this approach the Classifying Viewer believes that the work of art can be classified and explained.

This classification of viewers was the starting point for a methodology consisting of specifics that can be adapted to the needs of the audience. In Jump Starting Visual Literacy (2003) Yenawine describes one of the most important factors in VTS; image selection. As the process object-oriented and based on discussion, the choice of art objects is crucial regarding the above classifications. Yenawine (2003) notes that *when we as parents and teachers choose books to engage early readers, we carefully consider both what the new readers are ready for developmentally and what captures and is likely to sustain their interest* (p. 6). The same can be applied to the art object keeping in mind that the choice of subjects becomes more complex for different classes of viewers. At a basic level, the educator must seek objects for their accessibility while also seeking to captivate the audience. Expressive content and narrative should be included to inspire comment and discussion. A historical diversity of subject matter as well as a diversity of media must also be a factor along with a sense of realism, as abstraction should be discouraged at earlier levels. Yenawine continues to include preferred types of subjects, sequencing, and the use of series and themes in the selection.

Along with abstraction, the educator must avoid specificity as reliance on correct answers can the limit thought and expression of certain viewers. Illustrations, photojournalism, cartoons and advertisements should be avoided, as they tend to narrow interpretation. In addition, violent subjects and decorative arts and architecture are to be avoided as they present too little regarding interpretation.

Once the selection of materials is made the authors propose their application in a classroom setting. Yenawine and Miller (2014) along with Hailey (2014) have provided us with a template for VTS facilitators to apply in teaching situations. The basic steps in constructing a VTS discussion consists of five main components which according to Yenawine (2014) present *a carefully selected image*; *allow time for silent reflection*; *pose specific research questions*; *facilitate the discussion* and *conclude by thanking the students for their participation*.

The first step requires that the teacher select a subject of interest appropriate for the audiences' age and background. Imagery should have some relationship to the existing knowledge of the students. Meanings should be accessible and not intended to stump or confuse the students although there should be enough ambiguity to foster debate. Once an appropriate subject has been selected and the students have had adequate time to reflect the discussion should proceed using the same questions used in the Columbia and Housen studies: What is going on here? What do you see that makes you say that? What more can you find?

At this point the facilitator can move the discussion by listening to student replies and pointing to observations as students comment, what Yenawine (2014) defines as a *visual paraphrase*. Upon paraphrasing each comment, the teacher will take the time to reflect and then go over the reply making certain that the concept has been properly rephrased and fully grasped by the students. Related comments whether the students agree or disagree with the premise are then linked and possibly built upon one another. Within this procedure it will become imperative that the teacher remain neutral by treating each comment in a similar manner.

This process has had several successful outcomes across higher education and according to Yenawine (2014) has been used in the humanities, sciences and even on occasion by Miller (2014) in collaboration with the American Medical Student's Association in pre-medical clinical skills coursework. What becomes apparent is the idea that discussion was the more successful motivating factor behind the earliest use of art across the disciplines. While this can be proven in past studies, studies that are more recent establish that there are other variables to be addressed in the creation to a practical STEAM pedagogy. While these earlier studies promote transfer across content through discussion, newer trends are attempting to branch into mathematics and science through visualization, creative activity, and a redefinition of some of the ideas behind the VTS system.

CHAPTER 4

STEAM, Theoretical Foundations

At this point, we may assume that the origins of VTS and the idea of arts across the curriculum come from three philosophical sources. Dewey, with his idea of experiential learning could be considered first in this area. At the same time Vygotsky, although never directly approaching the subject, allowed us to view the value of thought, perception and individualized instruction. Perhaps one of the most important avenues of research into the nature of perception and high order thinking does not come from a scientist or educator but rather from an arts scholar. Noted art historian Rudolph Arnheim can be credited with being one of the pioneers in establishing that the visual is not a separate area of perception but rather an essential part of thought and cognition. Arnheim believed that the processing of images occurs throughout the thought process and must be included in the formation of high order thinking.

Arnheim (1969) notes that, *the arts are neglected because they are based on perception, and perception is disdained because it is not assumed to involve thought* (p. 3). He goes on to question (2004) this assumption this by adding that, *all perceiving is also thinking, all reasoning is also intuition, all observation is also invention* (p. 5). This leads him (1969) to conclude that, *once it is recognized that productive thinking in any area of cognition is perceptual thinking, the central function of art in general education will become evident* (p. 296). Although primarily concerned with the importance of including art education into the general education curriculum, Arnheim gives us a platform and a theoretical basis for shifting from the generalized VTS method to theories later advocating the creation of the STEAM curriculum. This movement, geared toward the inclusion of the arts into math and the sciences, also has an advocate who follows in the tradition of Dewey, Vygotsky and Arnheim.

Howard Gardner, a professor of education, in his groundbreaking study Frames of Mind: The Theory of Multiple Intelligences (1983) can, regarding STEAM, be the legitimate heir to the works of the earlier educators. At first, Gardner's work reflects many of the sentiments voiced by Arnheim. His work also expresses the idea that basic education should include an arts component that could enhance a person's level of perception using imagination, creativity, and physical and sensory involvement. Where Gardner differs and his work moves toward the theoretical framework of STEAM pedagogy rests on his theory of multiple intelligences. This theory stresses the idea that creativity is not limited to separate isolated areas of intellectual activity but rather across a variety of seven precisely defined intelligences. He believed that each of these intelligences could work through problem solving in different capacities depending on the individual's intellectual development.

This theory of multiple intelligences categorizes how we see our world. In Gardner's opinion the idea of standard IQ testing and measurement is inexact and that our minds consist of different areas of intelligence consisting of set criteria, all seven areas of intelligence can be used for problem solving on numerous intellectual levels. Gardner states that intelligence is not a single, fixed measurement as to *how smart the individual is, but rather how the individual is smart* (1983). These consist of linguistic, musical, logical-mathematical, spatial, bodily kinesthetic, interpersonal and intrapersonal intelligences. The idea that these intelligences are bridged in higher-level thought and problem solving provide a strong rationale for cross-discipline use.

According to Gardner each of these conform to eight strict criteria necessary for their classification as a separate intelligence (1983):

- Each can potentially be isolated by brain damage.

- Each, such as prodigies and savants, can exist in exceptional individuals.
- Each has a process of developing during normal child development and has a peak end performance.
- Each is evidenced in species other than human beings.
- Each has been tested using various measures not necessarily associated with intelligence.
- Each can work without the other being present.
- Each has a set of identifiable operations.
- Each can be symbolized or has its own symbol or set of symbols.

It is important to note that one-half of these intelligences have an artistic component that can also be used concurrently in individuals though in different capacities. According to Gardner (1990) *no two of us exhibit the same intelligences in precisely the same proportions and how they combine and work together are as varied as the faces and the personalities of individuals* (p.33). Gardner believed that is up to the educational system to either ignore these differences in intelligence, or create a system that attempts to exploit such differences. In exploiting such differences, he believed that, *the arts teach students to act and to judge in the absence of rule, to rely on feel, to pay attention to nuance, to act and appraise the consequences of one's choice, and to revise and then to make other choices* (p.8). This will enable students to *observe the relationships of the visual arts to the other arts disciplines, to their own world, and gradually, to the world at large* . . . [and] *understand that the visual arts do not exist in isolation* (p.8).

In more concrete terms, when we see that one-half of Gardner's intelligences have art components (linguistic, kinesthetic, musical, interpersonal, and visual) his ideas are the most probable and more exacting force behind the transition from STEM to STEAM. When we recognize that many of the world's mathematic/scientific advancements were not the results of large coordinated efforts but rather the work of isolated individuals we can glimpse an element of truth in Gardner's observations. The idea that one such as Einstein, who had a lifelong relation to the arts (music, visual arts), was also able to move from the inflexibility of experimental physics to imagining that he was traveling alongside a beam of light is the perfect example of using visualization in an otherwise rigid mathematical context. Through this visualization, Einstein would be led to his theory of Special Relativity and its resulting impact on how we see the world. This along with many other examples shows how the use of isolated visualization has been with us across the years.

While the theoretical foundations of STEAM pedagogy appear to be secure when seen in the light of the theories of Gardner and others, we must turn to more discerning examples of this theory. The earlier work of individuals such as the Yenawine, Housen and Columbia studies were effective in advancing the VTS theory in that they were longitudinal - each running for about five years. The problem lies in the fact that they were largely object oriented, outside of the classroom and driven by personal interviews with little thought toward combining disciplines. Since then there have been other studies have produced a variety of results. The results differ in the fact that they involve the creative process: an interaction between the student and the use of various artistic media. This movement toward the STEAM curriculum has, in the past decade, produced several relevant though limited studies; two of the most comprehensive were analyzed by Maryann Rachford (2011) while a doctoral candidate at Azusa Pacific University.

The sample consisted of an assortment of students from various social and economic backgrounds who were registered in degree programs at Citrus Community College in the greater Los Angeles area. The studies address some of these newer approaches to the formation of a STEAM curriculum. The first, a basic science class, focused on the integration of physics, chemistry and ceramics, while the second, an introductory art class, uses the Fibonacci equation (used to create the Golden Mean or 1:6:1 ratio) to demonstrate the relationship between art and mathematics. In addition to these composite examples, unlike the VTS studies, which were mostly object-oriented, there have also been several process-oriented non-longitudinal efforts at other institutions to further bridge the disciplines. This use of the creation of art objects to enhance transfer between the arts and sciences might possibly play a more important role in the STEAM curriculum than that observed in the original VTS studies.

Although the efficacy of the following studies might remain in question, several are potentially significant and appear to have bridged the gap that was once believed to have separated the arts and sciences. What they share is an innovative quality that presents us with the premise that there exists a much wider dimension of practices available toward the development of an effective STEAM curriculum. The Citrus studies and two additional studies will be examined in the next chapter. Each of these studies address specific aspects of STEAM using different art forms. All were chosen because of their distinctive approach toward the integration of the arts and sciences. They are unique in this respect although it is certain that in the short space of time during which this trend has developed there can be found several other noteworthy examples.

CHAPTER 5

Case Studies

a. Science – Chemistry, Physics and Ceramics

Consisting of twenty-five students, this first Citrus study (Rachford, 2011) began as an entry-level course later used as a gateway to college level coursework. The students ranged from ages 18 to 45, with little or no art experience and from a wide variety of majors. Being from the Los Angeles area the ethnic and social makeup of these students was varied enough to provide us with a broad demographic selection. A confidential demographic profile was created for each student, and much like the Yenawine and Housen studies, the profiles listed such elements as name, gender, age, ethnicity, major and goals. In addition, like the earlier studies was the inclusion of a questionnaire completed by the students asking about previous art experience, opinions about art and its influence in their lives. It also asked if they could see any value in the mixing of art with other disciplines. Also comparable to earlier studies was data gathering that consisted of questionnaires, focus groups and individual interviews. Conspicuously unlike the Yenawine, Housen and Columbia studies there does not appear to have been any specific taxonomy or quantification process. This lack of quantifiable data, absence of a control group and reliance on subjective opinion appears to currently be consistent across these newer trends and must be a limiting factor.

Faculty consisted of art and science (chemistry and physics) professors each of who would lecture on their respective disciplines as applied to the physical nature of clay, glazes and the overall ceramic production process. A syllabus was created by each faculty member outlining the parameters and requirements for their portion of each of the three separate disciplines. Students began by working with clay while the science teachers spoke of the physical characteristics of the medium and the principles at work during the firing of objects in the kiln. The art teacher gave the students a cultural history of the ceramic arts and an overview of the universal principles of art, (i.e. line, form, color, three-dimensionality etc.). They then discussed procedures that students would use toward working in clay and creating their sculptures. The art and science teachers would describe the steps in the creation of their sculptures and the firing process within their respective disciplines. This would include the composition and characteristics of glazes and the physical defects contributing to the pitfalls of firing objects in the kiln without the proper preparation of materials. Each of the problems discussed was explained scientifically: describing the various negative reactions that might occur using a chemical or physical explanation. The object of this lesson was to enhance the student's understanding of the aesthetic qualities of ceramics along with the chemical nature of materials and their interaction through the laws of chemistry and physics. Upon completion the students were instructed in the use of glazes and the correct procedures regarding their use. The students then applied glazes to their sculptures and, once again, the pieces were fired. Throughout the process group discussions and personal interviews were held and additional questionnaires were distributed with the goal of their later being analyzed regarding four questions:

1. In this integration of subjects, how did students perceive the emphasis of disciplines?
2. What learning occurred within the integration of art and math/science?
3. Based on this experience, what expectations did students have regarding the process of transference?
4. How did students feel about additional integration of art with other disciplines in the curriculum to facilitate the learning experience?

After completing the project students, much like in the Yenawine and Housen studies, were given Likert questionnaires that focused on the above questions. In addition, to observe specific science transference, several questions regarding the physical effects of moisture and heat on the firing process were added to the questionnaires. This line of questioning would lead to further questions asking whether they felt that the integration of disciplines was an effective learning process. They were also asked whether a balance of disciplines was reached and if they believed that a similar cross-discipline approach was applicable to other areas of study. Questionnaires were broken down into categories each using either one or two sets of responses: always, sometimes, rarely, never or strongly agree, agree, disagree, strongly disagree.

Results showed that regarding faculty collaboration, student interaction and perception, a majority (92%) felt that faculty motivation was enhanced by cross-discipline instruction. Another majority (84%) sensed that faculty collaboration was now much more evident in their classroom.

The second question focused on the types and quality of learning that occurred through the integration of the disciplines. This questionnaire focused mainly on student involvement and collaborative learning. A majority (88%) felt that the integration of disciplines had a positive effect on student activity and interest. Another (88%) felt that they were more involved in the physics portion of the lectures when the instruction was centered on the art project. Ninety-two percent believed that student collaboration increased while an even greater percentage (96%) felt that there was a positive effect on student motivation. A similar number had a positive response regarding productivity (96%) finding that student morale and attitude were influenced through the integration of disciplines. In addition, they (88%) felt that through the increased involvement and collaboration had a positive effect on assessment and assignment of grades, student evaluations and outcomes. Overall, factoring in some additional questions the positive response regarding the types of learning that occurred averaged 92.7%.

The third question revolved around the process of transference, the central issue behind the innovative VTS studies. This questioned the students as to their perception whether the combination of art and science succeeded in increasing the application of knowledge from one discipline to another. Eighty-four percent felt that combining sculpture along with chemistry and physics had a positive effect on their expansion of knowledge through the ceramics lesson with a majority (76%) believing that they had developed a deeper understanding of the scientific process. A majority 86.3% based on eight questions ranging from personal perceptions to technical aspects of the ceramic firing process, believed that it enabled them to access and comprehend information about a discipline outside of their personal areas of study. A very large majority (96%) believed that combining curricula was beneficial to the learning process.

The fourth and final questionnaire asked the overall question whether the student participants believed that the integration of art with other disciplines helped to further motivation, learning ability and the future application of knowledge transfer. All the respondents believed that the integration of art and science could be integral to the transfer of knowledge. Eighty-eight percent felt that the applications from the lesson could be made in other areas of their life. In addition, the students felt (88%) that they were motivated to learn through the process of integrating art and science. In terms of transfer a large percentage (84%) believed that the knowledge acquired in this class would transfer across disciplines. Ninety-six percent of students enthusiastically believed that art can be applied to most areas of the curriculum and can assist in the transfer of knowledge from one discipline to another. The total of all responses to question four showed an 87% favorability rating.

b. Mathematics – Drawing and the Golden Mean

The mathematics case study (Rachford, 2011), done at the same institution and using the same criteria as the science study, addressed the same four questions namely - student perception, learning, expectations and whether they believed that the integration of art and the other disciplines facilitated learning. However, this approach centered on the integration of a small (20 student) beginning drawing class and the application of a single element drawn from classical mathematics: one that was cleverly drawn upon based on its universal practicality and applications.

The Fibonacci Equation is used to mathematically exhibit the numeric progression of the Golden Mean, a relationship used in the classical world as well as in the present that consists of a ratio of 1:6:1. Much of ancient and classical architecture, including the Pyramids and Parthenon were built upon this ratio that states that the relationship of the parts of a structure should exist within a proportion where the rectangular as well as other non-geometric proportions should be 1:6:1. This relation was to hold true to all subsequent parts of the structure. According to the Fibonacci Equation, all subsequent portions of a structure, when using adjacent areas of the same proportion, would conform to the Fibonacci Spiral a descending series of numbers (0, 1, 12, 3, 5, 8, 13, 21, 34, 55, 89, 144, . . .) and proportions all conforming to the same 1:6:1 ratio (Fig.1).

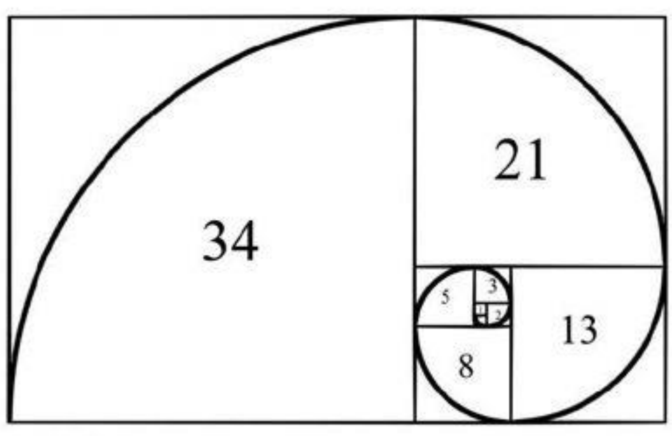

Figure 1. Fibonacci Spiral

Not exclusively limited to architecture, the equation has found its way into the visual arts and other areas as demonstrated in Leonardo's Vitruvian Man and other noteworthy works of two-dimensional art. The ancients believed that there was a spiritual basis to this ratio that would account for the balance, proportion, harmony and transcendent effect found in many fourth and fifth century structures. Because of the relationship of classical art and architecture to this mathematical progression, it becomes evident that this would be the perfect entry point for art and math faculties to attempt to combine disciplines.

The students participating in this study ranged from 18 to 50 years of age. Again, this being in the greater Los Angeles area, the ethnic makeup of the study group was wide and varied and background information, including arts related experience was collected. Much like the science study the methodology revolved around the same four questions and the results were drawn from questionnaires, focus groups and individual interviews. The evaluation process was also done in the absence of a control group, specific taxonomy or quantification process outside of the above referenced methods of data gathering.

The project consisted of students being randomly assigned a letter of the alphabet. Upon receiving their letters, they transferred the letter into a large drawing after which they were asked to assemble and incorporate into their drawing's items beginning with the same letter. The authors of the study referred to this as the creation of an illuminated letter. After completing this first stage of the assignment the students were given a series of lectures, by a mathematics faculty member, on the Golden Mean and Fibonacci Equation. After the lecture students were given a large sheet of paper conforming to the 1:6:1 ratio, upon which they were required to transfer their illuminated letter into the larger version, while also adding their interior illuminations (done in color) based upon the Fibonacci equation. Although the literature failed to detail steps in the process, one can assume that the objects selected for the letter that were not of a geometric nature would have been inscribed within a rectangular area conforming to the equation. This would have given them a type of grid positioned within their chosen letter consisting of illuminations all based upon descending variations of the Fibonacci Spiral. Upon completion the students gave presentations along with critiques after which they were also required to complete questionnaires. Smaller focus groups were then formed to further discuss the projects.

The outcome, based upon the original four questions, generally reflected that of the science project. Based on the always, sometimes, rarely, never response the first question (emphasis of disciplines) the students perceived that faculty motivation, assessment and grading (100%, 95%, 95% respectively) were influenced through the integration of disciplines. Another Likert questionnaire examined student perceptions regarding the degree of faculty engagement and the reliability of assessment. Results showed that 95% of the students agreed that faculty engagement was increased while 100% agreed that assessment was more accurate though course integration. These factors, when combined, give us an overall 96.5% favorably rating. This total is greater then that of the science project which gave us an 88% rating, keeping in mind that the science group used a 20% larger selection of students and more detailed and scientifically oriented questions.

The second question, much like in the science survey, asked what learning might have occurred within the integration of art and math. Responses to this questionnaire showed that 100% believed that combining the courses increased student motivation. Also increased were collaboration (95%), productivity (100%) and attitude (95%). Overall 98% of students believed that learning was increased the result of which again indicates a greater favorability rating than that of the science group (92.7%).

The third question, focusing on transference, showed that 95% believed that the application of math to the art project was effective toward the learning process. One hundred percent felt that it had increased their understanding of the separate disciplines - with the overall total of 97% agreeing that the cross-disciplinary approach was positive regarding the transference of knowledge. The results of the science project were similar in one respect as 96% of the students believed that the combination of curricula was beneficial. However, much like the earlier questions, when compared against the math project the overall total of the science project only came to 88.3% a considerable difference, although we must again factor into this result the smaller population and that a larger number of questions were added to the science questionnaire.

The fourth question, concerned with student's feelings about integrating the arts with other disciplines, appears to have both positive and slightly negative responses. Although 95% of students were intrigued to find how the Fibonacci equation could be found in art and nature, only 70% of the 20 students felt that they had a better understanding of math through the combination with design. Despite this discrepancy 95% felt motivated by this process with 100% believing that knowledge gained through the lesson would transfer to other curricular areas. Ninety-five percent went on to state that they felt that art could successfully be applied to other academic disciplines, with the result registering a 90.7% favorability rating. Once again, the math favorability rating comes in as a slightly higher rating over the science project (87%). The result shows that the overall favorability of the math project was larger than that of the science project by 6.3% - although when considering the science project's larger sample and additional questions it could be less of a factor and probably not significant in student perceptions regarding the combination of disciplines. A comparison of the favorability ratings of both case studies appears in figure 2. This and a closer examination of the efficacy of these and the following case studies will occur in the Discussion section of this thesis.

Study	Question 1	Question 2	Question 3	Question 4	Average
Mathematics	96.5%	98.0%	96.0%	90.7%	95.3%
Science	88.0%	92.7%	88.3%	87.0%	89.0%

Table 1. Favorability Ratings of Math and Science Projects

c. Physics – Black Holes, Energy Transformation and Schrödinger's Cat

Referenced earlier in the introduction, this case study (Koenig, 2015) was chosen primarily because it was one of the most unusual amongst the many studies discovered during the research. Its uniqueness tends to show just how wide and varied the use of art across the disciplines can be as well as how it tends to demonstrate or touch upon Gardner's hypothesis of multiple intelligences. Unlike the earlier two examples this case study, much like the ideas behind quantum physics, relies much less on qualitative and quantitative analysis and much more on intuition, perception and the idea of the thought experiment. In addition, unlike the earlier studies it does not rest upon a select group of students who receive formal cross-instruction from several faculty members but rather the on-site interaction of students from Canada's Emily Carr University of Art and Design with graduate physicists from the Canadian National Laboratory for Particle and Nuclear Physics (TRIUMF).

The participating students, who also have the option of entering other scientific cross-institutional partnerships, are required to take an active part in scientific inquiry from the point of view of what Koenig (2015) refers to as a cultural nomad. To avoid isolated disciplinary thinking the overall approach to these partnerships expects the student to function as authors, creators and collaborators who *query a range of questions and approaches that conjoin the relationships between art and science* (p. 472). Theoretically this should result in observations as to how science constructs knowledge and how abstract ideas are visually communicated – a premise that owes much to Arnheim and his theory that images are not outside of the thinking process but rather make up an important part of memory and cognition.

Similar in one way to the Citrus studies, the theories and analysis of subjects such as black holes are done through the creation of art works in a further attempt to answer the question, *what does it mean to know things that are not physically perceivable to us through our senses?* (Koenig, p.472) The key operative element here is the idea that the artist's view, after a thorough examination of the subject matter with the physicists, remains outside of the discipline and mostly objective. What lacks is any quantitative evidence of student outcomes or transfer but rather the presence of creativity and vision. The most important contribution of this process lies in the idea that both the scientist and artist are working with unknowns through an interconnected but disparate network of knowledge areas.

German artists, Elvira Hufschmid and Margit Schield, in the creation of the Transformation Art Lab at Emily Carr University summed this up with their premise that there exists a fundamental idea that, *every creative work operates in a system of relationships to other fields and disciplines* (Koenig, p. 473). This premise lies behind Gardner's theory of multiple intelligences but also becomes much more evident in works such as Leonard Shlain's (2007) Art and Physics where the author tracks the side by side development of both disciplines throughout the centuries while revealing what is referred to as an astonishing correlation of visions.

The process begins when students from over fifty countries; many possessing a basic knowledge of the sciences are taken on a lengthy tour of the institute's cyclotron which accelerates trillions of particles through its spiral structure at 75% of the speed of light. This remarkably complex structure's function is used to address many different scientific areas each of which are explained to the students. The creation of medical isotopes, the replication of celestial events, questions concerning quantum physics and the creation and decay of matter are all discussed. Outside of the classroom students attend daily lectures in which staff physicists and post-doctoral researchers explain how experimental physicists attempt to explain physical phenomena through laboratory methods. Throughout the process the physicists explain the experimental process while also detailing the plus and minus factors either contributing to or acting as an obstacle to the experiment's intended purpose. During this experimental process, which can involve such varied areas such as astrophysics and quantum mechanics the physicists maintain a continuous informal dialogue with the students who are encouraged to ask questions. At the same time the physicists encourage the students to consider creating a parallel response through different artistic mediums.

The results of these exchanges and inquiries are very creative. When imagining the physical properties of particle forces and degeneration one student created huge colossal webs made of various materials. The physicists were highly impressed by this approach and the student was surprised to learn that his project closely mirrored the visual trails that are recorded when particle collisions are created within the cyclotron. These random and often violent patterns resulted in a map visualizing the uncertainty of sub-atomic quantum mechanics.

This idea of the randomness of quantum mechanics was also demonstrated by students on an international basis through gaming in which three separate groups of students, through different artistic approaches, examined the theories of black holes. Referred to as the *broken telephone exercise* this enabled the students to create transformations of each other's works across disciplinary boundaries. These transformations were described as *like meteors, intruding into the galaxy of others, causing an impact then disappearing again* (Koenig, p. 473).

The results of this black hole project gave rise to several additional questions to be used to further examine the relationship between the arts and physics:

> What was referred to or emphasized? Where does an idea pull itself through? When has a subject been dropped? How does an idea expand? Looking back at the original subject, what was its impact? How do we apply these disseminating and scattering processes to the interface between art and physics? (p. 473).

Another student developed a beam sketchbook by using the cyclotron's particle beam accelerator to generate art. He described his thought experiment by asking the question, if a pencil were attached to a particle beam, what would it draw? He further elaborates on this question by asking what kind of traces would the beam leave, if it were used as a recoding tool or if its motions were traced on a photosensitive plate? In answering this question, he developed software that allowed him to translate beam data into a visual model. One elegant example of his results can be seen in figure 2.

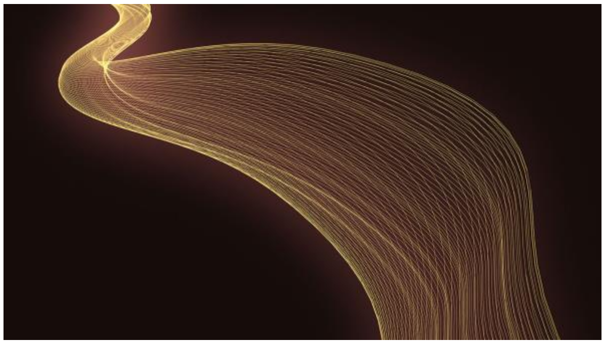

Figure 2. Proposed Image of Particle Beam Path

Equally as compelling, on a conceptual level, was the work of one student who attempted to visualize one of physics most famous theories, the thought experiment known as Schrödinger's Cat. Schrödinger's Cat is simply defined as: a thought experiment, described as a paradox, devised by Austrian physicist Erwin Schrödinger in 1935. It illustrates what he saw as the problem of the interpretation of quantum mechanics applied to everyday objects. The scenario presents a cat that may be simultaneously both alive and dead, a state known as quantum superposition, by being linked to a random subatomic event that may or may not occur. The though experiment is also often featured in theoretical discussions of the interpretations of quantum mechanics.

Schrödinger described a list of all possible states of matter to be found in quantum mechanics. This he described as the state vector. Several students applied this concept to everyday life. By creating a large grid of cue cards, they listed all the actions that might take place in a single day. After doing so they proceeded to cross out all the actions that did not take place by the end of the day. This produced a visual array the potential behavior of particulate matter amounting to what is described as collapsing the state vector. While many would find such concepts hard to visualize, the physicists who were clearly able to see the parallels of quantum mechanics with human experience, were so impressed that they have since included the project as a permanent installation at TRIUMP.

Later after the semester's completion the students and physicists gathered to discuss the various projects. One of the more interesting aspects of this meeting was that the physicists were asked to read art, allowing the participants to see whether there occurred any recognizable connections and transformations. Although highly speculative this unique collaboration shows us just how versatile the use of art across the disciplines can be and how such diametrically opposed areas can be bridged to produce moderately relevant results. This becomes even more evident when we examine our next case study that examines a collaboration falling outside of the visual arts - between engineering and dance - areas that appear even more dissimilar than those of our earlier case studies.

d. STEM, Engineering and Dance – An Unlikely Collaboration

> An artist will approach a problem in a completely different way than an engineer. They have certain sets of skills and knowledge that they bring and the designers or the artists will bring a human-centered approach. You are beginning in two different places and my argument is that you need as many points of departure as possible to be truly innovative. STEM is not enough. It's a start, but it's not enough. What's smart about contemporary curricula in STEM-based fields is many educators are realizing they must reach this in different ways. It's more like design thinking based on problems and based on solutions, rather than abstract models (Payton, et al., 2017, p.39).

This portion of the thesis starts with this quote because this final case study falls distant from the conventions and applications that were examined in the earlier examples and those of innovators such as Yenawine and Housen. Indeed, it reaches outside the restrictions of Koenig's disciplinary shaped boxes. In previous studies this thesis attempted to illustrate the process of STEM to STEAM using practical project-based examples in science and mathematics as well as in the highly theoretical area of quantum mechanics and astrophysics. This later section moves from an object or process-oriented approach and focuses on a different path as it examines some of the intangible aspects that might be observed and advanced through this integration of disciplines.

Examined in this case study (Payton, 2017) are issues of duality, academic rigor, inclusion and other emotional factors that do not specifically involve specific STEM plus art projects, but rather look at how the combination of science and the arts, in this case dance, enhance student's emotional performance, self-identity, efficacy and contributes to problem solving. It also addresses the physical and emotional demands of the science curriculum by examining a STEM discipline through the eyes of STEM majors who also possess artistic temperaments - sharing different thoughts, ideas and opinions. In the case of dance these ideas and opinions can seem quite contrary to STEM disciplines so clearly and intellectually delineated as science and engineering.

Based at North Carolina State University, a national leader in data analytics, engineering and bio manufacturing, the participants in these focus groups were drawn from STEM (mostly engineering) majors who also displayed an interest in the arts and participated in dance curricula. Also included were several STEM and several non-STEM majors who had actively been involved in either of the University's two dance programs before the formation of the study. The number of students involved in the program can only arguably be significant as the authors state that *students participating in the university dance program are mainly matriculating STEM majors,* numbering only twenty-five. (Payton, et al., p. 39).

The North Carolina State dance program is composed of the University Dance Company a nationally renowned establishment and the Panoramic Dance Project, which is devoted to intercultural dance projects both traditional and contemporary. Courses offered consist of Dance Performance, Current Trends in Afrocentric and World Dance, Dance Composition and Independent Study in Dance. There is also a master class centered on three annual concerts. Despite such a concentration of dance-oriented instruction there exists no formal dance major in North Carolina State University.

While the researchers' initial ProQuest search criteria returned a surprising number of relevant articles, most of them dealt with primary and secondary institutions. A more concentrated criteria search produced 45 results. The focus of the initial large number of search results concentrated on VTS-based ideas of multi-sensory methods of pedagogy and transformative experiences leading to improved student outcomes regarding pre-college work. The difference between the returned results considered relevant to the university project and that of the former centers upon the idea that in the university study the arts are not used to demonstrate practical outcomes and uses in other academic areas. Instead, the university study treats the arts as separate entities consisting of unique intrinsic qualities that contribute to higher level thinking across the academic spectrum; once more recalling the theory of multiple intelligences.

Excluding the demonstrated competencies of the former, this line of thought was used to gain insight into the thoughts and perceptions of students concurrently involved in STEM and the arts. Making this study even more interesting is the overall idea that the relationship between science, engineering and dance is so disparate as compared to the three other case studies that were project-based and centered upon the creation of actual physical objects.

Conducted through focus groups, interviews, and Likert surveys, the coded criteria and questions were based on four themes: Academic, Personal, Institutional, and Career Workforce Preparation. These four major themes were further broken down into sub-themes.

The sub-themes consisted of, for Academic: Program Rigor, Commitment to Academic Major, Problem Solving Skills, and Emotional Engagement and Self-Efficacy. The sub-themes for Personal were: Stigma/Peer Perceptions, Identity and Safe-Zone issues. Institutional Issues covered: Diversity and Inclusion, STEM Public Relations, Competition and Storytelling. Career Workforce Preparation, dealt with: 21st Century Skills, Creativity, and how the combination of how the Arts and STEM helps in these areas. One of the most sought-after results (according to the authors) with relation to these themes and sub-themes, were currently widespread inquiries into how the students' experiences might have contributed to and highlighted aspects of human diversity including ethnicity, race, gender identity and class. It also asks how dance might contribute to the establishment of safe-zones that might stand in contrast to the rigorous demands of STEM coursework.

The research methodology was conducted through focus groups that began by attempting to understand why STEM and other non-STEM majors also participated in dance or arts programs. Included were inquiries to identify their assumptions regarding their awareness as to how they perceived and were perceived by others by their participation in each group. Added to this were issues of race and gender although care was used to ensure anonymity so that identity markers were not used as a contributing factor within any of the groups.

Twenty-five students from various STEM majors, with the majority being from either chemistry and engineering, were selected for the study. Also included were a small number of students from majors outside of STEM disciplines. These students were to be used on a comparison basis for exploring similar educational experiences and motives across academic and STEM disciplines. Those outside of STEM majors could act as a control group assisting in and helping to investigate students' rationale for entering into dance along with cultural diversities, ethnicity, course of study, regionalism and prior study and training.

Ranging from ages 18 to 22, on top of their academic and STEM studies, the students spent between 8 and 12 hours weekly in the dance studio. Of the twenty-five students all were female; a distinction that might be useful regarding gender assumptions but one that must be problematic regarding the usefulness of responses when drawn from a purely homogeneous sample. Of the twenty-five students, fifteen majored in STEM fields such as applied mathematics, animal science, biochemistry, or statistics. Eight of the group majored in either engineering or chemistry. The remaining students were drawn from areas such as social work or marketing.

The focus groups averaged seventy-five minutes. Each session was recorded and later transcribed. Once transcribed, the researchers reviewed each of the transcripts to pinpoint any themes and sub-themes related to any of the research questions. After identifying any relevant responses, they proceeded to exchange their thoughts and opinions regarding the sessions. Upon analyzing the initial inquiries into the session and their perceived responses, the researchers turned the transcripts over to independent examiners who coded the transcript data according to the research questions and an existing taxonomy. This taxonomy was based on Wilson's (2014) study linking co-curricular activities and academic engagement in engineering education.

Results showed that the range of responses varied from moderate to substantial with the greater number of undergraduate STEM majors noting that the dance classes were an equally important part of their matriculation. In addition, the students all believed that the combination of arts and STEM coursework were complementary and felt that the study of each is best served when curricula is geared toward their dual participation. The rigors of both areas were well recognized by the participants who equated the demanding choreography and physical memorization of the dance studio with that of the exacting laboratory time required of STEM coursework.

All students understood both disciplines involved long hours, the need for continuous improvement, and the demands of teamwork. Based on this duality of rigor most of the participants indicated that an academic minor in the arts would work best for STEM students. They believed that a dual major would be far too restrictive in terms of physical and intellectual demands and limit the student's participation in the broader curriculum. Obvious to all was the obvious implication that the dance studio provided students a greater avenue for self-expression - one where their contributions were more apt to be valued and accepted by their peers.

Of the students, a majority expressed satisfaction with their academic performance and believed that the combination of academics and co-curricular activities contributed to their overall self-efficacy. However, when the question of peer acceptance was brought up several of the participants felt that their peers did not accept dance as a viable academic discipline and believed it to be far less important then STEM. Because of this several of the evaluators perceived a sense of academic elitism that was compounded by a sharp distinction between the sexes with their male peers equating STEM with masculinity and dance with femininity. This would contribute to what one evaluator referred to as a gender identity complex. While, the focus groups appear to have questioned this notion, the majority felt that the co-curricular introduction of the arts into the STEM curriculum appears to have fostered the perception that the sciences are a male-dominated culture. Aside from this many of the students marginally felt that dance contributed to a flexibility, creativity and diversity that migrated into their STEM studies and affected the attitudes of their STEM peers.

Regarding the now prevalent area of diversity, the students believed that the inclusion of arts courses running alongside the STEM curriculum contributed to institutional diversity although they also believed that this was not the case regarding STEM coursework excluding the arts complement. Dance was contributing to diversity in areas such as race and ethnicity, choice of majors, demographics, first-generation college experiences and geographic backgrounds along with prior dance experience. Further, the focus groups recognized that the combination of disciplines promoted multiple approaches to problem solving, creativity, innovation and collaboration. Later one-on-one interviews with six STEM and non-STEM graduates routinely indicated that in their professional lives their problem solving frequently drew upon and benefitted from the rigors of their STEM and dance experience. They stated that their approach to hypothesis testing was likened to their exploration of movement in the dance studio. Their systematic approach to data driven research and investigation was also drawn from both disciplines. In addition, their ability to transition theory to practice also appears to have been affected by the combination of STEM and dance. Finally, the idea of applying thought to action (think + do) in dance performance was viewed as being like the presentation of results in STEM disciplines.

While a great many ideas and observations were recorded through the examiners' interaction with the focus groups and interviews, their most cogent observations can be summed up through five considerations. The first notes that STEAM can foster inclusion, broaden participation and nurture persistence. These ideas were supported by the fact that the students recognized such possibilities even though they were not dual majors and that their dance studies were not the focus of their academic goals. Therefore, the idea that a duality of rigor coexisted and complemented laboratory pedagogy becomes more apparent. Secondly, despite the above referenced benefits, they also reached the conclusion that the inclusion of dance might have heightened the stigma of being a female in a male dominated discipline, giving the false impression of a lack of commitment on the part of the dancers in the STEM curriculum.

The third conclusion notes that problem-solving skills were enhanced through co-curricular activities. This conclusion is based on the idea that interdisciplinary, data driven thinking results from the *Think+Do model in STEM paired with a Performance +Presentation model in the arts* (Payton, 2017). In addition, a fourth conclusion notes that the STEM and arts curriculum is a vehicle for diversity inclusive of thought, disciplines, backgrounds and dance forms. Regarding these observations, the authors continue to note that:

> The challenge of this work is for higher education to find a blend of where the arts and STEM can co-exist while enabling students with multiple interests to navigate curricula and engage in experiences to strengthen what STEAM has to offer and what does it mean in co-curricular environments (Wilson, 2014).

They also note that the idea of major and minor offerings and course enrollments are a simple indication of academic intent but not enough characterization of either [type of] student.

The fifth and conclusion notes that such an approach can effect and contribute to what they refer to as the place and space ethos, (Matusovich, 2010). This is the idea that a physical locale and the social culture within the specific locale can impact student achievement across the disciplines by fostering engagement *among students to seek interdisciplinary connections to societal and innovation problems, that can prove to be more relevant to the learning process* (Payton, p. 45).

This study closes with the authors expressing the need for longitudinal studies in this area with the purpose of understanding how curricula is moving toward meeting the needs of STEM and arts students. Also called for is further examination of student performance and responses as to how this combination is found in traditional STEM coursework. Finally, they note the obvious fact that a need for diverse methodologies across larger sample sizes is called for. Similar thoughts have been present from the beginning of this research into the case studies. These will be further examined within the discussion and conclusion portions of this thesis.

CHAPTER 6

Discussion

These four creative approaches to STEAM are impressive and challenging on a practical as well as a theoretical level. The faculty and students were able to create highly innovative approaches in their attempt to integrate STEM and the arts. The case studies chosen for this work were some of the most significant of the many studies available that centered upon this type of integration, specifically in higher education. Based upon the research there seems to be some promise regarding the introduction of the arts into STEM pedagogy. However, we should qualify these assumptions with some contrasting ideas and opinions observed during this research. These additional considerations are not trivial. They pose questions that move us to examine the current direction of STEAM when assessed against the results of the selected case studies.

The case studies first make it obvious that the thrust of research in this area currently diverges from the foundation approaches taken by Yenawine, Housen and the VTS methodology. We observe that the Yenawine and Housen studies were successful as they concentrated entirely on primary and secondary school students. Their samples existed apart from any relation to higher education other than the students' possible future aspirations. In addition, they did not attempt to integrate the arts into the formal curriculum and essentially remained (as in the case of Yenawine, a museum educator) outside of structured classroom and credit-bearing coursework. Rather than seeking curricular integration they concentrated on exposing students to the arts during their formative years to enhance future academic performance through a combination of context and content transfer.

The efficacy of the Yenawine and Housen studies was well demonstrated in that their longitudinal studies produced several verifiable results. These results showed that, based on their levels of exposure to the arts, students were able to later progress across the curriculum. A longitudinal approach along with random sampling, quantification, and the use of control groups helped to back up these studies. Outcomes became even more convincing when positive results, comparing the sample and control groups, could also be seen in the disparate areas of science and mathematics. This emphasis on early education resulted in a logical recommendation by educators such as Yenawine, Housen and Arnheim to simply broaden arts education. However, outside of these similarities and unlike that of VTS, a similar systematic methodology for the realities of college level classroom pedagogy is not as easily attainable.

The case studies used in this thesis, while paying attention to Yenawine, Housen and Gardner on a broad philosophical level, diverged from them on an application level. This occurred because the differences in curriculum and realities regarding the cost and time constraints of higher education favor immediate context over content transfer. These limitations could also be seen to have prevented the educators from developing useful controls and outcome assessments that could have been used as a basis of comparison against sample groupings. Because of this there were no comparisons between the community college samples and those of their fellow undergraduates. This becomes more problematic when we note that, in both Citrus studies, data would have been available from prior and concurrent classes taken outside of the STEM component. They also lacked a precise reliance on quantification, depending only on Likert scales to produce and arrive at arguably measurable results.

Although not mentioned, their reason for this approach probably rests on the premise that the studies were short term and centered on specific coursework – an approach not entirely based upon or favorable to earlier developmental models. This is the most significant and exclusionary difference found between the case study methodologies and the VTS studies. These differences resulted in the case studies showing a lack of the continuity seen in their VTS counterparts. Much of this can be traced to their necessary use of course-specific materials. This emphasis on specific materials differs from the universal focus of Yenawine, Housen and the first generation of educators working in this area.

The focus on coursework and absence of quantifiable data in the case studies gives us an idea as to the direction and challenges of introducing STEAM into the greater higher education curriculum. Based on the results of the case studies we cannot rule out that the STEAM approach to higher education is, at least according to the students' reactions, an effective process. This however only rests upon the fact that according to Likert scales it increased faculty involvement, student motivation and possibly, some content transfer. The greater contribution, acknowledged by the students, was that it helped to make a difficult subject easier to comprehend. This does not necessarily indicate transfer and, in the absence of precise quantifiable and longitudinal data, the overall efficacy can be questioned.

This leads to the idea that the specialization and increasing levels of difficulty that we find in the higher education curriculum implies that one direction of the integration of art and STEM will have to be done on an individual classroom level through methods introduced by faculty and focused within specific disciplines. At this early stage STEAM will probably be more of a selective approach driven by separate faculty along with gathering interest and support from academic interest groups. This is reflected in the case studies and research in the current literature where most of the more determined efforts appear to have come from consortia. Several such considerations found in most of the case studies show that this is where we currently stand. Added to these considerations is the diversity of materials, methods and intangible problems that can be found in the process of transferring knowledge across higher education disciplines.

Considering these reflections, the first study, Chemistry, Physics and Ceramics, comes closest to a more practical model in that it utilizes the act of creating a work of art, in this case a ceramic, to create a link between both disciplines. While most of the other case studies found in the readings also use this process, this study differs in that it occurs in a remedial, non-credit bearing course. This makes the sample somewhat like that of the VTS process where arts education occurred on the front end of credit-bearing academics. The Chemistry course used a diverse sample of students who upon completion would be eligible to move on to progressively more difficult and credit-bearing studies in the sciences. Since it is a remedial course, outside of the general curriculum, it relies much more on a timely transfer and use of information across context and the creation of a specific course centered academic foundation.

The second study, Mathematics – Drawing and the Golden Mean, done at the same community college, used a similar, although smaller sample and criteria. However, although similar it differs from the former in one significant aspect. The Chemistry course imbeds the art component in a science course while the Mathematics component is imbedded within a credit-bearing art course. One must keep in mind that the pressures involved in a science course, usually directed toward an eventual science major or curricular requirement, are far greater than those in an art course where the mathematics portion is not as relevant or used as a prerequisite to progressively more difficult studies. This might count as one aspect contributing to the overall higher favorability rating (96.5% to 88%) of the mathematics project. It also displays a motivation behind the mathematics problem much closer to the foundation theories in which the process is developmental and marginally outside of well-defined time constraints. In addition, it addresses future content transfer as opposed to a more precise methodology used as a prerequisite to course advancement. This type of transference is not as immediate as the benefits gained from the Chemistry case study but rather one that mimics the VTS model, and better prepares the foundation for future cross-discipline academic performance.

The third case study, Physics – Black Holes, Energy Transformation and Schrödinger's Cat foregoes the methods employed in the preceding two studies. Rather than being a preparation for grades leading to more difficult future coursework this approach is an exercise in visualization – an exercise in the expansion of the boundaries of the visual arts. Much like the Mathematics case study this also approaches the physics applications from the vantage point of the art student or artist. However, the desired results are much different – challenging the students to envision complex problems while also seeing if their results coincide with the thoughts of working physicists. Being an exercise in visualization this case study does not address transfer – however is does provide the groundwork for an additional avenue; a largely creative approach to STEM.

The fourth and final case study, the engineering/dance combination, while not focused on the academic results of the participants, considers some of the less tangible and psychological aspects. While it does not coincide with the quantifiable methods and results of the other case studies, it does examine questions that have become widely discussed in the modern college and university. The article's examination and conclusions regarding issues such as diversity, peer pressure and self-image that academic circles currently see as important, can provide us with insight into the feelings and emotions experienced by students, familiar with the arts, who have decided to enter the demanding fields of science and engineering. It also gives us insight into their relationship to the arts and the relationship between the arts and technical problem-solving skills. Also emphasized in this study is the parallel function that the arts can play within the sciences and subsequent later technologically based employment. From this we can surmise that some of the benefits of STEAM do not only exist within the classroom. Most important this study attempts to address some of the psychological issues that might be encountered by students as they attempt to navigate through cross-discipline studies.

These and other factors must be considered regarding future approaches to STEAM. By examining these factors, we can safely assume that there is no single approach to STEAM but, regarding higher education, a series of uses and applications that can be applicable across many disciplines and capable of benefitting different levels of student. These applications can be either general or specific and each has the potential to be effective in higher education. However, we must also keep in mind the realities of fiscal sustainability and effectiveness in the time and cost-driven environments of colleges and universities.

CHAPTER 7

Conclusion

The readings indicate that three (excluding the engineering/dance combination) methodologies can be identified in the integration of STEM and the arts. While all three are viable on some level, they differ in application and audience. The first method, the remedial Chemistry course, focuses on using a methodology to act as a transition to more specific and difficult coursework. It is in this method that we find the most promise and cost-effectiveness regarding undergraduate education. It is most effective as it lends itself nicely to the ever-growing population of students who enter undergraduate studies deficient in essential academic areas. Specifically, this approach appeals to those already in the college system who are taking remedial or pre-requisite coursework. It also favors this population as it is less open-ended regarding the lengthy periods that are found in the VTS process. While excluding the overall content and subject domain transfer seen in the VTS studies, this approach enables transfer within a specific context (math, science, et al.) and would give students the opportunity to advance one step closer to credit bearing work and ultimately a college degree. Perhaps this approach could help to ease the burden of the overcrowding created by the sudden influx of remedial students into American colleges and universities.

The second method, illustrated in the Mathematics study, attempts the Yenawine, Housen and Gardener ideas of transference described and demonstrated in their longitudinal studies. This VTS method is a non-specific approach by which students, through arts instruction, use multiple intelligences to prepare groundwork for future academic performance. While this approach is proven effective through well-coordinated testing and evaluation, it is fundamentally a longitudinal process best serving students at the start of their education. The idea that significant multi-disciplinary content transfer could occur during the brief four years of a college education is questionable considering that the foundation studies results were done over a ten-year period. Its value to higher education lies in the fact that it is a proven theory with the potential to yield concrete results - but to date only outside of higher education and under much different circumstances.

The third process, as seen in the Physics case studies speaks to students well-entrenched in their major areas of study or pursuing graduate degrees. These case studies appear as intellectual exercises that can help them to gain insight into advanced areas or abstract problems within their studies. The TRIUMF case studies display some of these insights but only through the eyes of artists as opposed to advanced physics students. How such an approach would play in the sciences remains to be seen. This has relegated these studies to an exercise in visualization while not (much like the mathematics study) addressing any specific coursework in the physical sciences. It also might be assumed that as research and coursework become more advanced and difficult that the integration of the arts would be less likely to occur as scientific and mathematical concepts become increasingly abstract. This would probably limit such attempts to a small number of uses in the advanced science and mathematics curriculums. Beyond this it would be most appropriate in hard sciences and mathematics and well outside of the visualization process to all but a few well-entrenched individuals. Regardless, there should be some room for similar projects useful for scientists and mathematicians in developing visualization techniques. Outside of this usefulness, as seen in the Mathematics and Physics case studies, these approaches will probably remain on the margins of classroom instruction. While some might become entirely relevant and useful in the future their promise lies in advanced undergraduate and graduate studies and outside of the general education curriculum.

Finally, the results of the research tend to indicate that STEAM's primary potential lies in the world of remediation. It is in remediation where, as in the Chemistry study, results will be more immediate. We must also consider that if results are like the Chemistry study the transition from remedial to credit-bearing work might possibly happen sooner. In addition, while the transfer might not be as significant as the longitudinal studies, the context transfer should suffice and support the move to credit-bearing studies. In addition, to be considered is the idea that the move to credit-bearing work might lessen the time spent in remediation. This should be brought into account considering the current *college for everyone* approach to higher education. This approach has filled up classrooms and has exponentially increased the number of remedial sessions. It has also influenced the monies allocated for credit-bearing sessions along with funds for grants, research and the improvement of facilities. Should future studies indicate that the integration of art and other disciplines is successful, this might go toward the reallocation of such funding to the originally intended areas.

Despite the above referenced promise, projects such as the Chemistry study must still be verified through longitudinal research and answers might not be forthcoming for a considerable period. During this time, newly formed creative technology programs under the guidance of graduate education departments, will continue to graduate specialists working in this area. From these specialist educators will come the initiatives and the statistical confirmation needed to verify the efficacy of STEAM pedagogy. Such factors require much room for experimentation and, outside of current individual initiatives - the rush toward cross-discipline integration and the focus on transfer across subject domains might still face a limited if not uncertain future.

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