TEACHING METHODS FOR A HOLISTIC COMPUTER GRAPHICS CURRICULUM INCORPORATING ACTIVE LEARNING TECHNIQUES

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ABSTRACT

This paper presents various concepts and techniques for creating an educational pipeline targeted at the field of computer graphics. This proposed pipeline focuses on the teaching of core concepts, core methodologies and finally core techniques employed within the field of computer graphics. Each component is then paired with an example of an active learning strategy used to enlighten and reinforce the abstract ideas behind these components. Throughout this document outlines the importance of supporting a holistic and platform agnostic approach, which sets the foundation for learning of all core computer graphics concepts, methodologies and techniques. The end result is a collection of concepts, techniques and example strategies, which are supported by active learning exercises.

DEDICATION

I dedicate this thesis to my loving wife Allyson, who pushes me to pursue my dreams no matter how outlandish they may be.

ACKNOWLEDGMENTS

First and foremost, I would like to thank Dr. Donald House for his patience, wisdom and guidance during my journey to complete this thesis. Additionally I would like to thank all of my thesis committee members: Dr. Brian Malloy and Prof. Tony Penna. I could not have completed this thesis without the love and support of my family and friends. Finally and most importantly, I would like to thank my loving wife Allyson for hours, weeks and months of patience and support.

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CHAPTER ONE

INTRODUCTION

The field of computer graphics is one of ever-changing technology and technique in which the boundaries of what is currently possible are being expanded upon continuously. To this end, educating individuals who wish to enter this field of study have a diverse, eclectic and growing set of concepts and skills to master. While many different types of higher education institutions have attempted varied approaches to address the educational requirements for individuals entering this field, the currently solutions often do not address the entire problem. This thesis provides a subject matter outline and educational pipeline methodology for a holistic curriculum within the field of computer graphics.

We begin the discussion with a brief survey of the most common programs currently offered in higher education. The institutions discussed will include traditional public college and university undergraduate and graduate models, community college and technical college models, and finally non-traditional online and private colleges. This discussion is not intended as a criticism of the listed institutions, but rather to present a methodology that could possibly be applied in part or as a whole to a computer graphics program offered through any type of institution.

A core driving principle with the aforementioned educational model is the application of a holistic approach to computer graphics education. This holistic approach covers the traditional disciplines from which concepts of computer graphics evolved while at the same time addressing the contemporary concepts and techniques derived directly from within this field of study. Topics derived from the traditional disciplines include a diverse spectrum spanning the visual / performing arts, physics, physiology, psychology and computer science. Topics derived from the contemporary study of computer graphics include numerous concepts such as two dimensional graphics rendering and animation, three dimensional surface simulation, lighting, rendering and animation. Additionally general techniques, which correspond with the underlying concepts of computer graphics, are outlined.

There are two primary pedagogical goals. The first being to connect the concepts of computer graphics with the student's existing knowledge. This is an iterative process, which identifies the current knowledge of the student and builds upon it with the end goal being a holistic understanding of computer graphics. This is why an educational pipeline is critical in order to set the student on this path. The second goal is that, the student must be able to problem solve using active learning techniques in order to continuously adapt to the ever-changing field of computer graphics.

Finally a system of rubrics is discussed in order to address the need for assessment. This assessment is employed in order to benchmark the subject specific competency of the student as well as the institutional effectiveness of the applied educational methods. Here again, an iterative approach is used on both the micro (student) level and the macro (institutional) level in order to adjust teaching methods for optimal results.

CHAPTER TWO

BACKGROUND

2.1 Traditional Computer Graphics Educational Pipeline

Typically, computer graphics education is either overly simplified or specialized. While either approach is not inherently flawed, it does allow for an incomplete understanding of computer graphics. In the case of the overly simplified curriculum, the knowledge imparted to the student may be too theoretical in nature with little emphasis on the execution of technique. When the curriculum is more specialized, the student may focus on the application of technique, while neglecting to understand the fundamental concepts that drive the technique. Conversely a holistic approach focuses on three major components: subject matter core concepts, application of technique, and performance-oriented problem solving skills.

Additionally, the traditional computer graphics curriculum may create a disjointed curriculum layout. A holistic approach must balance the pace and sequence of the subject in a way that emphasizes continuity and flow. By building off of the traditional disciplines from which concepts in computer graphics are derived and then layering on increasingly more specific knowledge, a holistic educational pipeline can provide depth and breadth of knowledge.

Within the industries that make use of computer graphics technology, the emphasis is on performance-based problem solving skills. So whether the individual is an artist with a technical bent or a technician with an artistic eye, the skill set needed is one that requires at least an understanding and appreciation of all of the interconnected elements within computer graphics. In this way the arts and sciences are inseparably connected different approaches to the same problem [SHLA07]. A holistic computer graphics educational pipeline is neither to generalized, nor to specialized, but rather a blend of both that builds from fundamental concepts to problem solving application.

2.2 Holistic Computer Graphics Educational Pipeline

An educational pipeline exists in order to create a procedural methodology for conveying and assessing knowledge. Similar to a manufacturing process, an educational pipeline defines the input needs (content), output product (assessment), and sequence (flow) that produce an effective, efficient and repeatable methodology for success [NATI04]. By creating an educational pipeline, a course or program can be more effective in its overall goal of producing students who are well prepared for careers in the industry.

A holistic education is typically considered to address a much broader spectrum of influences, such as philosophy, nature and the soul. In the context of this paper we will be primarily focusing on the concept of holistic as the comprehension of the interconnected parts of computer graphics as they relate to the whole. To that end, we will define the educational pipeline content areas and how they relate to the overall flow and the subcomponents within each content area and their corresponding flow. Additionally a model of assessment is needed to authenticate the effectiveness of student outcomes within the pipeline. The assessment model should focus on the understanding of fundamental concepts, the understanding and application of technical procedures used with computer graphics, and the student's ability to problem solve using both the fundamental concepts and technical procedures.

2.3 Teaching Methods and Learning Strategies

In order to organize, execute and validate the structure of the proposed holistic computer graphics pipeline we use several methodologies. The methodologies that address how the pipeline is organized and how information is presented include elements of Bloom's taxonomy, cognitive load theory, and the application of active learning strategies. A simplified rubric will be applied to each area of content in order to help validate the content and methodologies for both the overall program and student outcomes.

Bloom's taxonomy purposes that categorizing educational objectives into hierarchical domains can form a holistic view of education, where each domain addresses an increasingly advanced application of higher order thinking skills. The three domains are: cognitive, affective, and psychomotor. Each domain focuses on learning for mastery within the domain and also within the overall subject. The cognitive domain focuses primarily on the knowledge of the subject matter itself and employs skills of memorization, comprehension, application, analysis, synthesis, and evaluation. The affective domain focuses on the emotional awareness of subject matter. While the psychomotor domain primarily focuses on the hands-on act of doing an action related to the subject matter [ANDE00]. In this paper we will approach the conceptual knowledge content of the holistic computer graphics education with an emphasis on the cognitive domain, but we will reinforce and highlight the artistic execution or the subject matter with the affective and psychomotor domains.

Cognitive load theory suggests that the control of human working memory is limited and that in order to process information in a manner that will move the information from working memory to long term memory, this load should be balanced. The theory proposes that information processing revolves around the association of working memory information with schemas in order to make meaningful connections to information within existing long term memory. Within the theory there are three types of information sources: intrinsic, extraneous, and germane. Intrinsic information deals with the complexity of information while extraneous information is any unnecessary distracting information. In general, we want to avoid intrinsic information that is too complex to grasp as a whole and rather break it down into subschema, which are easier to comprehend individually and then reconfigure into the whole at a later time. Extraneous information is to be avoided at all times as it disrupts cognitive flow. However germane information processing focuses on the association and creation of schema [CLAR06]. The goal of creating an educational pipeline is to optimize the association of schema while continually building new schema.

An excellent example of Bloom's taxonomy and cognitive load theory is Paul Hewitt's "Conceptual Physics" textbook series [HEWI11]. In his books, Hewitt breaks complex physics topics into simple subschema, which are illustrated through examples that are relatable to the average adult. In this way he is able to guide the reader through simple and relatable concepts, to an understanding of physics concepts that are rather complex.

Active learning is a methodology for in-class activities that invoke the concepts of both Bloom's taxonomy and cognitive load theory. Additionally, one of the core principles of active learning is the institutional focus on moving the responsibility of learning to the learners [CHAN09]. In the context of a holistic computer graphics education this concept of learning responsibility is exceedingly important due to the fact that the very nature of the computer graphics industry is one of constant improvement and change.

Two forms of active learning that the hands-on methodologies in this paper focus on are project based learning and problem based learning. Project based learning is structured around an open question or project that is addressed by groups of students and without strict guidelines, where the teacher operates in more of a facilitator role. Similarly problem based learning allows the student to answer a question or complete a project without strict guidelines or oversight. Problem based learning differs, as it can be more self-directed and executed by an individual student rather than a group. Both of these forms of active learning promote student ownership over their own learning as well as the skills for research as well as creative and critical thinking.

Assessment of the quality of knowledge retention can be more complex when employing active learning strategies as opposed to testing or other methods where a binary right or wrong assessment can be made. To address the diversity and granularity of executable knowledge, we must employ rubrics, which define a center point and concepts clustered around that point that must be mastered to fully comprehend a subject. The general concepts for defining a quality rubric should include the outline of the material encompassed, a clear hierarchy of the range of optimal and sub-optimal student outcomes, and how the outcomes are to expressed by some form of execution [STEV13].

In this paper, all example rubrics are intended as as a general outline and by no means attempt to cover all possible subschemas of the holistic computer graphics educational pipeline.

2.4 Background Conclusion

The industries that make use of computer graphics have a heavy focus on creative thinking, problem solving, and execution. These industries need decision makers who can validate the choices they have made and critique the choices of others. Additionally, it is not star individuals, but rather teams of people with diverse specialties who do most of the professional work in the fields that employ computer graphics. Individuals on a team must be an expert in their area of specialization, but must understand and or appreciate the work being done by others outside of their specialization. To this end, a holistic computer graphics education will prepare an individual to work well in team, and also to see the large picture and approach problem solving with a more complete toolset of skills and understanding.

In order to address this educational need, a curriculum must take a wide array of subject matter and align it in a way that enables an optimal consumption of the information. Additionally, this curriculum must not only address the information from a theoretical point of view, but also emphasize proper execution of this knowledge in order to forge a concrete product. This blend of mastery of both theoretical knowledge and application of that knowledge is critical to the long-term success of an individual in the ever-changing field of computer graphics. Through a holistic educational pipeline and active learning strategies, this balance can be achieved.

CHAPTER THREE

TEACHING METHODOLOGY

3.1 Content Roadmap

The components of the holistic computer graphics educational pipeline content roadmap should include a consideration of cognitive flow and active learning strategies. As a whole and individually, the components should address: Bloom's cognitive domain as it pertains to the understanding and memorization of conceptual content, a technical application of concepts that utilize Bloom's psychomotor domain, and a use of active learning elements to address problem solving skills within computer graphics. By achieving this balance a program can be both holistic and robust at both the coarse level and the curriculum level.

The specific content included within the proposed holistic computer graphics educational pipeline can be broken into four primary groups: art, physics, psychology, and computer science. The following is an outline of the primary groups and their related subcomponents:

- Art
    - 2D design
    - Color
    - 2D perspective
    - 3D design

    - Geometry
    - Traditional rendering
    - Human form
    - Photography
    - Cinematography
- Physics
    - Light emission
    - Light interaction with media
    - Light phenomena
    - Rigid body dynamics
    - Soft body dynamics
    - Fluid dynamics
- Psychology
    - Visual system
    - Color
    - Functions of light
- Science of computer graphics
    - Mathematical models
    - Color systems
    - Raster graphics
    - Vector graphics
    - Compositing

- 2D transforms
- 2D animation
- 3D structures
- 3D transforms
- 3D modeling
- 3D surfacing
- 3D rigging
- 3D animation
- Dynamics / simulation
- 3D rendering

The application of the concepts of Bloom's taxonomy, cognitive flow, and active learning on a per lecture basis is difficult due to the time restrictions that most traditional education allots for an individual topic within a course. In order to address this, we can employ a handful of strategies that allow for the time inside and outside of the class to be maximized and yet balanced for optimal cognitive flow. These strategies include: a flipped classroom, minimal in-class lecture, guided activity, and assisted problem solving activities.

A flipped classroom is one where the students have a resource to expose them to the lecture material outside of class. Ideally this material would be either a video or an interactive. Ideally this material would be either a video or an interactive application that would illustrate the lecture concepts. A flipped classroom allows for in-class time to be spent less on intense lecture and more on instructor-facilitated hands-on activities. A flipped classroom does not replace lecture, but rather it allows for the in-class lecture to be more of a review, reinforcement and clarification of topics covered.

Our goal with a holistic educational pipeline that focuses on active learning is to get the student to begin to problem solve as soon and often as possible. To this end, the flipped classroom allows more in-class and out of class time for problem solving activities. These activities vary in their degrees of problem solving freedom and instructor assistance. The degrees of difference fall into two categories.

The first is an activity that is heavily guided. This type of activity is structured as step-by-step hands-on experience where the student follows the steps in order to complete a task. This type could be completed outside of class, but if it is done during class time the instructor can play an active role in facilitating student progress. Here the focus is on the technical understanding of software and hardware tools and techniques.

The second type of activity is one that has multiple ways to solve a problem. In this case, the instructor gives the students a problem to solve and possibly some guidelines to facilitate progress. For this type of activity, the instructor acts as a facilitator who helps the student maintain momentum while addressing the problem. It is important to note that however the students choose to answer the problem, they are not right or wrong, but rather the solution can be evaluated and critiqued from multiple perspectives. Here the focus is on the technical application of software and hardware in order to solve a problem.

It is important to note that while the holistic computer graphics educational pipeline creates a solid foundation for the understanding and application of concepts within this field, the need for further specialization in a specific area is necessary for student success. This paper does not address the focus on specialization that a student must undertake. However, if an educational institution were to employ the curriculum outlined within, they could add classes within an undergraduate or a graduate level program in order to achieve the necessary instruction in one or more computer graphics specializations.

3.2 Art

The content to cover within the category of art includes: 2D design, color theory, 2D perspective, 3D design, geometry, traditional image rendering, human form, photography, and cinematography.

2D Design Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of 2D design principles, matching terms to definitions and terms to graphical examples.	Identify more than 70% of 2D design principles, matching terms to definitions and terms to graphical examples.	Identify less than 70% of 2D design principles, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to assemble a composition using all 2D design principles.	Follow step-by-step instructions in order to assemble a composition using most 2D design principles.	Follow step-by-step instructions in order to assemble a composition using few 2D design principles.
Problem Solving	Accurately compose an image using 100% of 2D design principles.	Accurately compose an image using more than 70% of 2D design principles.	Accurately compose an image using less than 70% of 2D design principles.

Table 1.1

Example Activity

Conceptual: Students must identify each principle within a series of images.

Application: Students must follow steps in order to place colored shapes to match a existing work of art.

Problem Solving: Students must use colored shapes to form a composition for each principle.

Color Theory Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of color models, color wheel components, examples of color temperature, types of color harmony types, and the components of color matching terms to definitions and terms to graphical examples.	Identify more than 70% of color models, color wheel components, examples of color temperature, types of color harmony types, and the components of color matching terms to definitions and terms to graphical examples.	Identify less than 70% of color models, color wheel components, examples of color temperature, types of color harmony types, and the components of color matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to assemble a composition using all color theory principles.	Follow step-by-step instructions in order to assemble a composition using most color theory principles.	Follow step-by-step instructions in order to assemble a composition using few color theory principles.
Problem Solving	Accurately compose an image using 100% of color theory principles.	Accurately compose an image using more than 70% of color theory principles.	Accurately compose an image using less than 70% of color theory principles.

Table 2.1

Example Activity

Conceptual: Students must identify each color theory concept within a series of images.

Application: Students must follow steps in order to place colored shapes in order of hue, saturation and brightness.

Problem Solving: Students must use colored shapes to form an example of each type of color harmony.

2D Perspective Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of 2D perspective principles, matching terms to definitions and terms to graphical examples.	Identify more than 70% of 2D perspective principles, matching terms to definitions and terms to graphical examples.	Identify less than 70% of 2D perspective principles, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to assemble a composition using all 2D perspective principles.	Follow step-by-step instructions in order to assemble a composition using most 2D perspective principles.	Follow step-by-step instructions in order to assemble a composition using few 2D perspective principles.
Problem Solving	Accurately compose an image using 100% of 2D perspective principles.	Accurately compose an image using more than 70% of 2D perspective principles.	Accurately compose an image using less than 70% of 2D perspective principles.

Table 3.1

Example Activity

Conceptual: Students must identify each type of perspective within a series of images.

Application: Students must follow steps in order to overlay perspective lines on a series of images.

Problem Solving: Students must use shapes to form a composition for each type of perspective.

3D Design Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of 3D design principles, matching terms to definitions and terms to graphical examples.	Identify more than 70% of 3D design principles, matching terms to definitions and terms to graphical examples.	Identify less than 70% of 3D design principles, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to assemble a 3D composition using all 3D design principles.	Follow step-by-step instructions in order to assemble a 3D composition using most 3D design principles.	Follow step-by-step instructions in order to assemble a 3D composition using few 3D design principles.
Problem Solving	Accurately compose a 3D sculpture using 100% of 3D design principles.	Accurately compose a 3D sculpture using more than 70% of 3D design principles.	Accurately compose an image 3D sculpture less than 70% of 3D design principles.

Table 4.1

Example Activity

Conceptual: Students must identify each principle within a series of sculptures.

Application: Students must follow steps in order to place 3D shapes to create an example of each principle.

Problem Solving: Students must use 3D shapes to form a sculpture that displays all of the principles from different angles.

Geometry Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of geometry concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of geometry concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of geometry concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to assemble all geometric shapes.	Follow step-by-step instructions in order to assemble most geometric shapes.	Follow step-by-step instructions in order to assemble few geometric shapes.
Problem Solving	Accurately create all geometric primitives.	Accurately create most geometric primitives.	Accurately create few geometric primitives.

Table 5.1

Example Activity

Conceptual: Students must identify the components of geometry within a series of images.

Application: Students must follow steps in order to create geometric primitives from sticks.

Problem Solving: Students must recreate an existing artwork using a collection of sticks, junctions, and primitives.

Traditional Image Rendering Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of traditional rendering concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of traditional rendering concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of traditional rendering concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to create all traditional rendering techniques.	Follow step-by-step instructions in order to create most traditional rendering techniques.	Follow step-by-step instructions in order to create few traditional rendering techniques.
Problem Solving	Accurately create an example of all traditional rendering techniques.	Accurately create an example of most traditional rendering techniques.	Accurately create an example of few traditional rendering techniques.

Table 6.1

Example Activity

Conceptual: Students must identify each type of traditional rendering within a series of images.

Application: Students must follow steps in order to create an example of each type of traditional rendering.

Problem Solving: Students must recreate a photograph with each type of traditional rendering.

Human Form Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of human form concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of human form concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of human form concepts, matching terms to definitions and terms to graphical examples.
Application	NA	NA	NA
Problem Solving	NA	NA	NA

Table 7.1

Example Activity

Conceptual: Students must identify each part of human anatomy within a series of images.

Application: Students must take figure-drawing exercises.

Problem Solving: Students must take figure-drawing exercises.

Photography Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of photography concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of photography concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of photography concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to create images demonstrating all photographic techniques.	Follow step-by-step instructions in order to create images demonstrating most photographic techniques.	Follow step-by-step instructions in order to create images demonstrating few photographic techniques.
Problem Solving	Accurately create an example of all photographic techniques.	Accurately create an example of most photographic techniques.	Accurately create an example of few photographic techniques.

Table 8.1

Example Activity

Conceptual: Students must identify photographic concepts within a series of images.

Application: Students must construct a camera from outlined steps.

Problem Solving: Students must recreate a photograph with each type of photographic concept illustrated.

Cinematography Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of cinematographic concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of cinematographic concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of cinematographic concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to create videos demonstrating all cinematographic techniques.	Follow step-by-step instructions in order to create videos demonstrating most cinematographic techniques.	Follow step-by-step instructions in order to create videos demonstrating few cinematographic techniques.
Problem Solving	Accurately create an example of all cinematographic techniques.	Accurately create an example of most cinematographic techniques.	Accurately create an example of few cinematographic techniques.

Table 9.1

Example Activity

Conceptual: Students must identify cinematic concepts within a series of images.

Application: Students must recreate iconic still shots from film making history by following outlines steps.

Problem Solving: Students must create a stop motion short film using found objects that illustrates all of the cinematic concepts.

3.3 Physics, Physiology, and Psychology

The content to cover within the category of physics includes: light emission, light interaction with media, light phenomena, and physically based animation.

Light Emission Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of light concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of light concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of light concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step experiments in order to recreate all light concepts.	Follow step-by-step experiments in order to recreate most light concepts.	Follow step-by-step experiments in order to recreate few light concepts.
Problem Solving	Accurately recreate an example of all light concepts.	Accurately recreate an example of most light concepts.	Accurately recreate an example of few light concepts.

Table 10.1

Example Activity

Conceptual: Students must identify light emission concepts within a series of images.

Application: Students must create an example of each light emission concept using provided objects, lights, and outlined steps.

Problem Solving: Students must record with photos and write a explanation of why an example of light emission concepts exists.

Light Interaction with Media Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of light interaction with participating media concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of light interaction with participating media concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of light interaction with participating media concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step experiments in order to recreate all light interaction with participating media concepts.	Follow step-by-step experiments in order to recreate most light interaction with participating media concepts.	Follow step-by-step experiments in order to recreate little light interaction with participating media concepts.
Problem Solving	Accurately recreate an example of all light interaction with participating media concepts.	Accurately recreate an example of most light interaction with participating media concepts.	Accurately recreate an example of few light interactions with participating media concepts.

Table 11.1

Example Activity

Conceptual: Students must identify light interaction concepts within a series of images.

Application: Students must create an example of each light interaction concept using provided objects, lights, and outlined steps.

Problem Solving: Students must record with photos and write a explanation of why an example of light interaction concepts exists.

Light Phenomena Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of light phenomena concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of light phenomena concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of light phenomena concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step experiments in order to recreate all light phenomena media concepts.	Follow step-by-step experiments in order to recreate most light phenomena media concepts.	Follow step-by-step experiments in order to recreate few light phenomena media concepts.
Problem Solving	Accurately recreate an example of all light phenomena concepts.	Accurately recreate an example of most light phenomena concepts.	Accurately recreate an example of few light phenomena concepts.

Table 12.1

Example Activity

Conceptual: Students must identify light phenomena concepts within a series of images.

Application: Students must create an example of each light phenomenon concept using provided objects, lights, and outlined steps.

Problem Solving: Students must record with photos and write a explanation of why an example of light phenomena concepts exists.

Physically Based Animation Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of physically based animation concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of physically based animation concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of physically based animation concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step experiments in order to recreate all physically based animation concepts.	Follow step-by-step experiments in order to recreate most physically based animation concepts.	Follow step-by-step experiments in order to recreate few physically based animation concepts.
Problem Solving	Accurately recreate an example of all physically based animation concepts.	Accurately recreate an example of most physically based animation concepts.	Accurately recreate an example of few physically based animation concepts.

Table 13.1

Example Activity

Conceptual: Students must identify each physically based animation concept within a series of images or videos.

Application: Students must create and record an example of each physically based animation concept using provided objects, slow motion cameras, and outlined steps.

Problem Solving: Students must record with video and write a explanation of why an example of each physically based animation concepts exists.

The content to cover within the category of physiology and psychology includes: the visual system, color psychology, and the functions of light.

Visual System Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the human visual system concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the human visual system concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the human visual system concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step experiments in order to demonstrate all human visual system concepts.	Follow step-by-step experiments in order to demonstrate most human visual system concepts.	Follow step-by-step experiments in order to demonstrate few human visual system concepts.
Problem Solving	Accurately recreate an example of all human visual system concepts.	Accurately recreate an example of most human visual system concepts.	Accurately recreate an example of few human visual system concepts.

Table 14.1

Example Activity

Conceptual: Students must identify components of the visual system within a series of images.

Application: Students must create a pinhole camera that simulates the components of the visual system using provided objects.

Problem Solving: Students must use two of the above pinhole cameras in order to capture and recreate different types of stereoscopic images.

Color Psychology Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of color psychology concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of color psychology concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of color psychology concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step experiments in order to demonstrate all color psychology concepts.	Follow step-by-step experiments in order to demonstrate most color psychology concepts.	Follow step-by-step experiments in order to demonstrate few color psychology concepts.
Problem Solving	Accurately recreate an example of all color psychology concepts.	Accurately recreate an example of most color psychology concepts.	Accurately recreate an example of most color psychology concepts.

Table 15.1

Example Activity

Conceptual: Students must identify examples of color psychology concepts within a series of images.

Application: Students must create optical illusions from each color psychology concept using provided objects, lights, and outlined steps.

Problem Solving: Students must create an illusion using color psychology concepts within a public space and record the reactions of individuals who experience it.

Functions of Light Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the function of light concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the function of light concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the function of light concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the functions of light concepts.	Follow step-by-step instructions in order to demonstrate most of the functions of light concepts.	Follow step-by-step instructions in order to demonstrate few of the functions of light concepts.
Problem Solving	Accurately recreate an example of all of the functions of light concepts.	Accurately recreate an example of most of the functions of light concepts.	Accurately recreate an example of few of the functions of light concepts.

Table 16.1

Example Activity

Conceptual: Students must identify the functions of light concepts within a series of images.

Application: Students must create an example of each of the functions of light concept using provided objects, lights, and outlined steps.

Problem Solving: Students must record with photos and write a explanation of why an example of a function of light concepts exists.

3.4 Computer Graphics

The content to cover within the category of computer graphics includes: mathematical models, color systems, raster graphics, vector graphics, compositing, 2D transformations, 2D animation, 3D structures, 3D transformations, 3D modeling, 3D surfacing, 3D rigging, 3D animation, and 3D rendering.

Mathematical Models Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the mathematical model concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the mathematical model concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the mathematical model concepts, matching terms to definitions and terms to graphical examples.
Application	NA	NA	NA
Problem Solving	NA	NA	NA

Table 17.1

Example Activity

Conceptual: Students must identify mathematical model concepts within a series of images.

Application: Students must graph examples of the mathematical model concept using outlined steps.

Problem Solving: Students must map an existing space and catalog objects within that space using mathematical concepts.

Color Systems Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the color system concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the color system concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the color system concepts, matching terms to definitions and terms to graphical examples.
Application	NA	NA	NA
Problem Solving	NA	NA	NA

Table 18.1

Example Activity

Conceptual: Students must identify color system concepts within a series of images.

Application: Students must create an image by using the color system concepts by following outlined steps.

Problem Solving: Students must recreate a existing artwork within a low resolution grid using a limited pallet in order to simulate a low resolution copy of the artwork (see figure 1.1 and 1.2).

Raster Graphics Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the raster graphics concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the raster graphics concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the raster graphics concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the raster graphics concepts.	Follow step-by-step instructions in order to demonstrate most of the raster graphics concepts.	Follow step-by-step instructions in order to demonstrate few of the raster graphics concepts.
Problem Solving	Accurately recreate an example of all of the raster graphics concepts.	Accurately recreate an example of most of the raster graphics concepts.	Accurately recreate an example of few of the raster graphics concepts.

Table 19.1

Example Activity

Conceptual: Students must identify raster graphics concepts within a series of images.

Application: Students must create an image using raster graphics by following outlined steps.

Problem Solving: Students must recreate an existing artwork by creating an image collage by using a provided set of raster images.

Vector Graphics Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the vector graphics concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the vector graphics concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the vector graphics concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the vector graphics concepts.	Follow step-by-step instructions in order to demonstrate most of the vector graphics concepts.	Follow step-by-step instructions in order to demonstrate few of the vector graphics concepts.
Problem Solving	Accurately recreate an example of all of the vector graphics concepts.	Accurately recreate an example of most of the vector graphics concepts.	Accurately recreate an example of few of the vector graphics concepts.

Table 20.1

Example Activity

Conceptual: Students must identify vector graphics concepts within a series of images.

Application: Students must create an image using vector graphics by following outlined steps.

Problem Solving: Students must recreate an existing artwork using vector graphics.

Compositing Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the compositing concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the compositing concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the compositing concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the compositing concepts.	Follow step-by-step instructions in order to demonstrate most of the compositing concepts.	Follow step-by-step instructions in order to demonstrate few of the compositing concepts.
Problem Solving	Accurately recreate an example of all of the compositing concepts.	Accurately recreate an example of most of the compositing concepts.	Accurately recreate an example of few of the compositing concepts.

Table 21.1

Example Activity

Conceptual: Students must identify compositing concepts within a series of images.

Application: Students must create an image from a series of provided images using compositing concepts by following outlined steps.

Problem Solving: Students must create a surreal image by compositing found images together (see figure 2.1, 2.2, and 2.3).

2D Transformations Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the 2D transformation concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the 2D transformation concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the 2D transformation concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the 2D transformation concepts.	Follow step-by-step instructions in order to demonstrate most of the 2D transformation concepts.	Follow step-by-step instructions in order to demonstrate few of the 2D transformation concepts.
Problem Solving	Accurately recreate an example of all of the 2D transformation concepts.	Accurately recreate an example of most of the 2D transformation concepts.	Accurately recreate an example of few of the 2D transformation concepts.

Table 22.1

Example Activity

Conceptual: Students must identify 2D transformation concepts within a series of images.

Application: Students must create an example of each 2D transformation by following outlined steps.

Problem Solving: Students must recreate a existing artwork by manipulating geometric primitives and 2D transformations.

2D Animation Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the 2D animation concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the 2D animation concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the 2D animation concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the 2D animation concepts.	Follow step-by-step instructions in order to demonstrate most of the 2D animation concepts.	Follow step-by-step instructions in order to demonstrate few of the 2D animation concepts.
Problem Solving	Accurately recreate an example of all of the 2D animation concepts.	Accurately recreate an example of most of the 2D animation concepts.	Accurately recreate an example of few of the 2D animation concepts.

Table 23.1

Example Activity

Conceptual: Students must identify 2D animation concepts within a series of images.

Application: Students must create ball bounce animation by following outlined steps.

Problem Solving: Students must recreate a iconic scene from film history by using 2D animation concepts, found objects, and stop motion filming.

3D Structures Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the 3D structure concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the 3D structure concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the 3D structure concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to create all of the 3D structure concepts.	Follow step-by-step instructions in order to create most of the 3D structure concepts.	Follow step-by-step instructions in order to create few of the 3D structure concepts.
Problem Solving	Accurately recreate an example of all of the 3D structure concepts.	Accurately recreate an example of most of the 3D structure concepts.	Accurately recreate an example of few of the 3D structure concepts.

Table 24.1

Example Activity

Conceptual: Students must identify 3D structural concepts within a series of sculptures.

Application: Students must create 3D primitives with sticks by following outlined steps.

Problem Solving: Students must recreate an existing sculpture with triangles made of sticks.

3D Transformations Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the 3D transformation concepts, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the 3D transformation concepts, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the 3D transformation concepts, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the 3D transformation concepts.	Follow step-by-step instructions in order to demonstrate most of the 3D transformation concepts.	Follow step-by-step instructions in order to demonstrate few of the 3D transformation concepts.
Problem Solving	Accurately recreate an example of all of the 3D transformation concepts.	Accurately recreate an example of most of the 3D transformation concepts.	Accurately recreate an example of few of the 3D transformation concepts.

Table 25.1

Example Activity

Conceptual: Students must identify 3D transformation concepts within a series of images.

Application: Students must create a sculpture using 3D primitives and 3D transformations by following outlined steps.

Problem Solving: Students must recreate an existing artwork using 3D primitives and 3D transformations.

3D Modeling Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the 3D modeling concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the 3D modeling concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the 3D modeling concepts and techniques, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the 3D modeling concepts and techniques.	Follow step-by-step instructions in order to demonstrate most of the 3D modeling concepts and techniques.	Follow step-by-step instructions in order to demonstrate few of the 3D modeling concepts and techniques.
Problem Solving	Accurately execute an example of all of the 3D modeling concepts and techniques.	Accurately execute an example of most of the 3D modeling concepts and techniques.	Accurately execute an example of few of the 3D modeling concepts and techniques.

Table 26.1

Example Activity

Conceptual: Students must identify 3D modeling concepts within a series of images.

Application: Students must create a sculpture using 3D modeling techniques by following outlined steps.

Problem Solving: Students must recreate a found object with only 3D primitives, then box modeling techniques, and finally by edge modeling techniques (see figure 3.1).

3D Surfacing Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the 3D surfacing concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the 3D surfacing concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the 3D surfacing concepts and techniques, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the 3D surfacing concepts and techniques.	Follow step-by-step instructions in order to demonstrate most of the 3D surfacing concepts and techniques.	Follow step-by-step instructions in order to demonstrate few of the 3D surfacing concepts and techniques.
Problem Solving	Accurately execute an example of all of the 3D surfacing concepts and techniques.	Accurately execute an example of most of the 3D surfacing concepts and techniques.	Accurately execute an example of few of the 3D surfacing concepts and techniques.

Table 27.1

Example Activity

Conceptual: Students must identify 3D surfacing concepts within a series of images.

Application: Students must map an image to a 3D object using 3D modeling techniques and by following outlined steps.

Problem Solving: Students must transfer a 2D image to a 3D object by cutting out triangular pieces of paper and constructing from which to construct the 3D object and then translate that into 3D software (see figure 4.1).

3D Rigging Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the 3D rigging concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the 3D rigging concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the 3D rigging concepts and techniques, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the 3D rigging concepts and techniques.	Follow step-by-step instructions in order to demonstrate most of the 3D rigging concepts and techniques.	Follow step-by-step instructions in order to demonstrate few of the 3D rigging concepts and techniques.
Problem Solving	Accurately execute an example of all of the 3D rigging concepts and techniques.	Accurately execute an example of most of the 3D rigging concepts and techniques.	Accurately execute an example of few of the 3D rigging concepts and techniques.

Table 28.1

Example Activity

Conceptual: Students must identify 3D rigging concepts within a series of images.

Application: Students must create a rig using 3D rigging techniques by following outlined steps.

Problem Solving: Students must create a 3D armature for use in stop motion filming.

3D Animation Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the 3D animation concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the 3D animation concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the 3D animation concepts and techniques, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the 3D animation concepts and techniques.	Follow step-by-step instructions in order to demonstrate most of the 3D animation concepts and techniques.	Follow step-by-step instructions in order to demonstrate few of the 3D animation concepts and techniques.
Problem Solving	Accurately execute an example of all of the 3D animation concepts and techniques.	Accurately execute an example of most of the 3D animation concepts and techniques.	Accurately execute an example of few of the 3D animation concepts and techniques.

Table 29.1

Example Activity

Conceptual: Students must identify 3D animation concepts within a series of videos.

Application: Students must create a 3D animation using 3D animation techniques by following outlined steps.

Problem Solving: Students must create a stop motion film, which demonstrates the principles of 3D animation.

Simulation Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the simulation concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the simulation concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the simulation concepts and techniques, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the simulation concepts and techniques.	Follow step-by-step instructions in order to demonstrate most of the simulation concepts and techniques.	Follow step-by-step instructions in order to demonstrate few of the simulation concepts and techniques.
Problem Solving	Accurately execute an example of all of the simulation concepts and techniques.	Accurately execute an example of most of the simulation concepts and techniques.	Accurately execute an example of few of the simulation concepts and techniques.

Table 30.1

Example Activity

Conceptual: Students must identify simulation concepts within a series of images.

Application: Students must create each type of simulation using 3D software and techniques by following outlined steps.

Problem Solving: Students must create simulations in order to match a provided series of videos (see figure 17.1).

3D Rendering Rubric

	Proficient	Adequate	Inadequate
Concepts	Identify 100% of the 3D rendering concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify more than 70% of the 3D rendering concepts and techniques, matching terms to definitions and terms to graphical examples.	Identify less than 70% of the 3D rendering concepts and techniques, matching terms to definitions and terms to graphical examples.
Application	Follow step-by-step instructions in order to demonstrate all of the 3D rendering concepts and techniques.	Follow step-by-step instructions in order to demonstrate most of the 3D rendering concepts and techniques.	Follow step-by-step instructions in order to demonstrate few of the 3D rendering concepts and techniques.
Problem Solving	Accurately execute an example of all of the 3D rendering concepts and techniques.	Accurately execute an example of most of the 3D rendering concepts and techniques.	Accurately execute an example of few of the 3D rendering concepts and techniques.

Table 31.1

Example Activity

Conceptual: Students must identify 3D rendering concepts within a series of images.

Application: Students must create a rendering system by following outlined steps.

Problem Solving: Students must recreate images from provided photographs and 3D assets using 3D rendering concepts.

3.5 Purposed Teaching Methodology Conclusion

By implementing a curriculum experience that balances the cognitive load of schema and gives opportunity for hands-on problem solving execution, individuals are better prepared for the real world environment of the ever-changing field of computer graphics. The individual will be a self-learner who works well in a team environment where they will have to interface with others from across the spectrum of computer graphics specialties. The product of this holistic computer graphics educational pipeline will be an individual that has mastered the concepts, which drive the computer graphics industry and the functional ability to execute on these concepts.

CHAPTER FOUR

PROJECT IMPLEMENTATION CASE STUDY

Western Piedmont Community College has implemented a flow similar to the one described in the previous chapter in their Simulation and Game Development program. While the goal of this program is more acutely focused on the subfield of Simulation and Game Development, the overall concept of a holistic balance in a computer graphics related field is being applied. A holistic balance is achieved between the subjects of game art, game interactive design, and game specific programming. Within each course, the principles of active learning are applied through group and individual projects that engage the learner and encourage the individual to take ownership of their education through self-learning.

Below is the layout for the Western Piedmont Community College Simulation and Game Development Associates program excluding general education courses:

- Fall 1
    - Introduction to Simulation and Game Development
        - Description: This class provides a survey of all components of simulation and game development including: computer graphics core concepts, development tools, the simulation and game development industry, and a history of computer graphics and game development.

- 3D Modeling 1
  - Description: In this class students learn the basics of 3D software model creation including: software navigation, core polygonal graphics concepts, 3D primitives, the creation of different 3D surface types, and the core modeling tools (see figure 3.1).
- Drawing 1
  - Description: In this class students learn artistic concepts and application including: perspective drawing, traditional rendering skills, and the principles of 2D design.
- Computer Art 1
  - Description: In this class students learn 2D digital art concepts including: raster graphics, vector graphics, and color theory.

- Spring 1
  - 3D Modeling 2
    - Description: In this class students learn 3D concepts and software application techniques including: box modeling, UV creation, UV layout, texturing, and hard surface modeling (see figure 4.1).
  - Simulation and Game Programming 1
    - Description: In this class the student is introduced to programming concepts including: development tools, data types, variables, operators, conditional checks, functions, structures, and classes (see figure 9.1).

- Simulation and Game Design 1
    - Description: In this class the student is introduced to concepts used in game design including: design documentation, probability, statistics, game theory, narrative, and psychology (see figure 13.1).
- Simulation and Game 3D Animation
    - Description: In this class the student is introduced to the concepts of 3D animation including: timelines, keyframes, FK / IK animation, 12 principles of animation, and software tools for animation

- Summer
    - 3D Modeling 3
        - Description: In this class the student is introduced to the concepts of 3D modeling including: edge loop modeling, digital sculpting, human anatomy, and high resolution to low resolution mesh data transfer (see figure 6.1, 7.1, and 8.1).
    - 3D Rigging
        - Description: In this class the student is introduced to the concepts of 3D rigging including: joints, joint mesh relationship, attaching joints to mesh, FK / IK rig creation, set driven keys, constraints, controller objects, and human skeletal / muscle anatomy.
- Fall 2
    - Simulation and Game Programming 2

        - Description: In this class the student is introduced to game programming concepts including: polymorphism, input polling, the game loop, graphical user interface creation, real time audio, collision detection, rigid body physics, and game state control (see figure 10.1).
    - Simulation and Game Design 2
        - Description: In this class students are encouraged to create real time interactive applications using the concepts outlined in Simulation and Game Design 1 and Simulation and Game Programming 1 and 2 (see figure 13.1 and 14.1).
    - Graphic Design Tools
        - Description: In this class students are introduced to the concepts of texture painting including: advanced UV creation and manipulation techniques, hand painting, image sampling, image capture, image manipulation, image generation, and procedural image creation (see figure 5.1).
- Spring 2
    - Simulation and Game Mobile Programming
        - Description: In this class students are introduced to advanced game programming concepts including: alternative input systems, artificial intelligence, and interactive real time application networking (see figure 9.1, 10.1, 11.1, and 12.1).

- Simulation and Game Project
    - Description: In this class students are encouraged to pick a role within the industry to research and apply concepts from. Once a role is chosen, the student must define a milestone to be completed every third week. Each milestone must have an industry quality reference for the student to strive to match (see figure 17.1).

Figure 1.1: *Whistler's Mother* [WHIS91].

Figure 1.2: A digitally reduced Western Piedmont Community College student recreation of *Whistler's Mother* [WHIS91].

Figure 2.1: Step 1 of a Western Piedmont Community College student Photoshop composite.

Figure 2.2: Step 2 of a Western Piedmont Community College student Photoshop composite.

Figure 2.3: Step 3 of a Western Piedmont Community College student Photoshop composite.

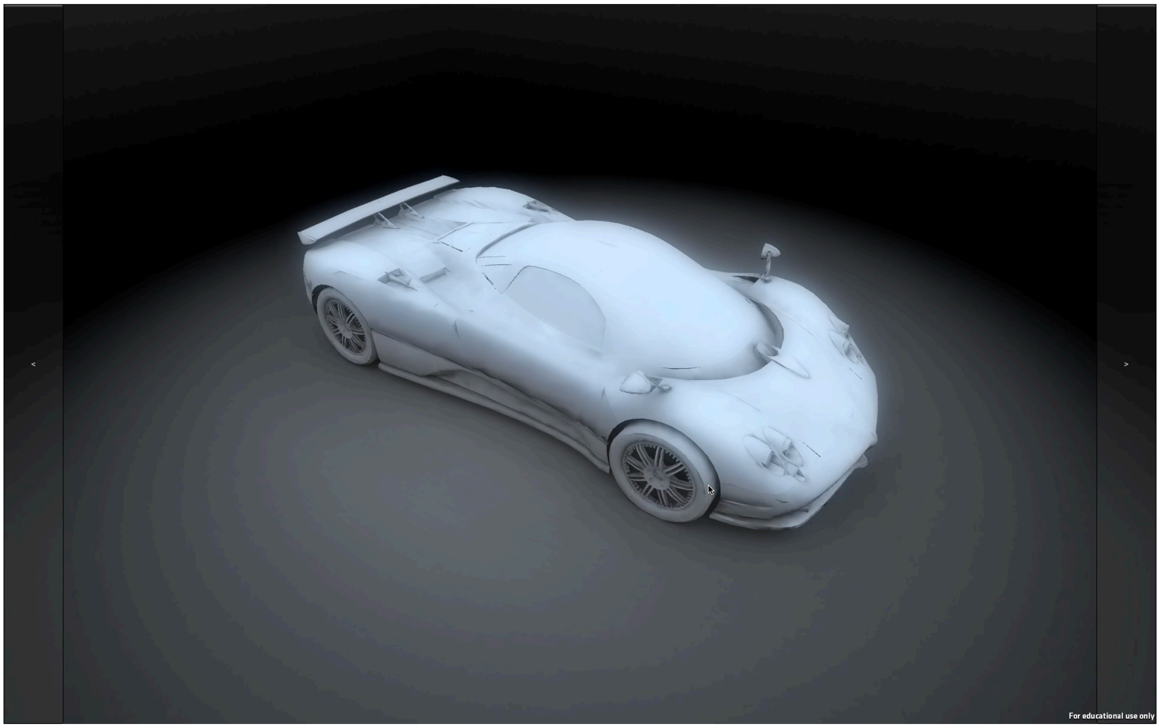

Figure 3.1: Western Piedmont Community College student 3D Modeling 1 project.

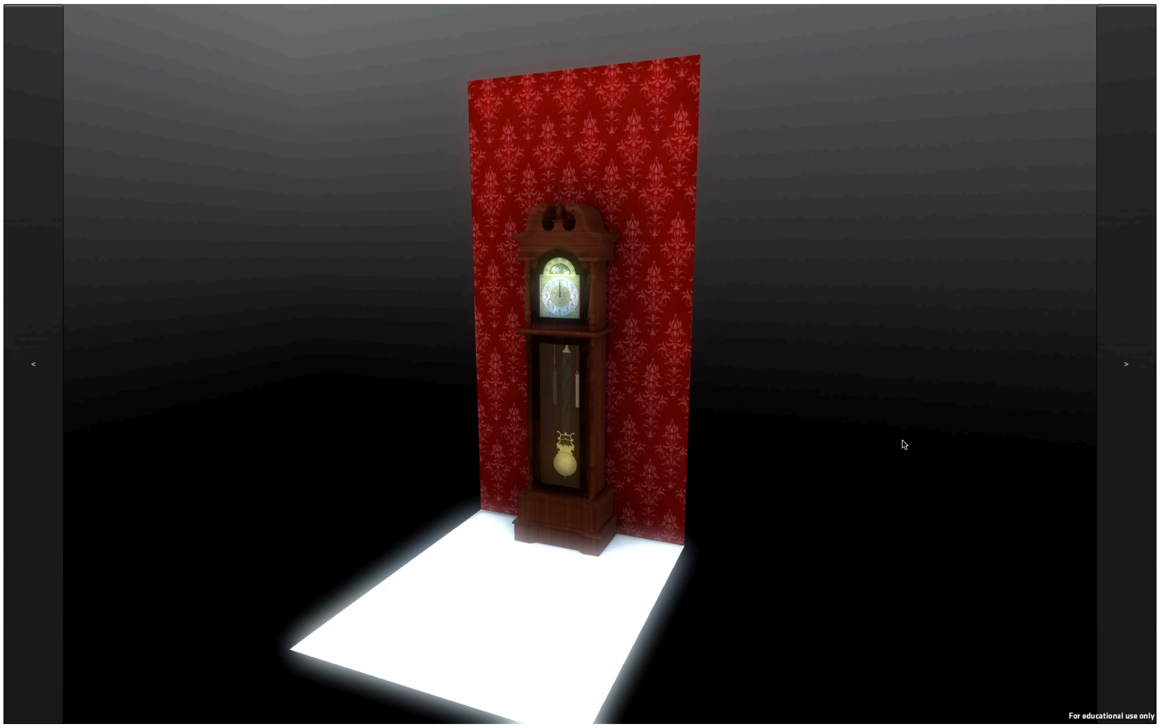

Figure 4.1: Western Piedmont Community College student 3D Modeling 2 project.

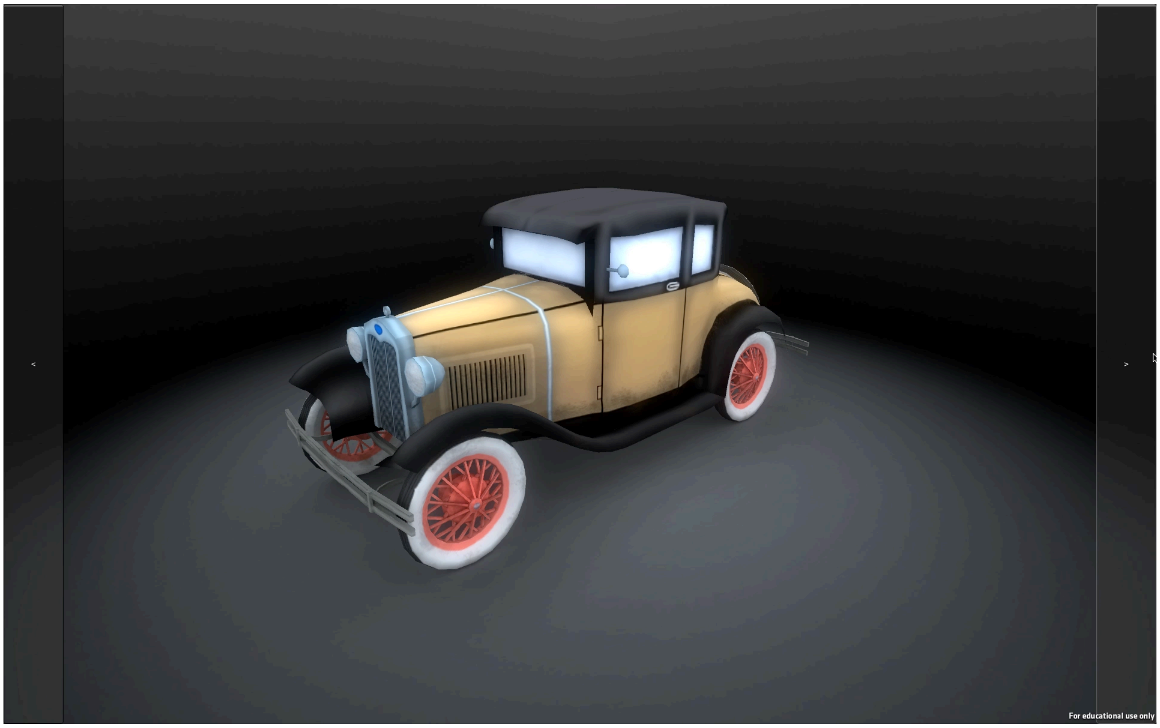

Figure 5.1: Western Piedmont Community College student Graphic Design Tools project.

Figure 6.1: Western Piedmont Community College student character Modeling 3 project.

Figure 7.1: Western Piedmont Community College student Modeling 3 project.

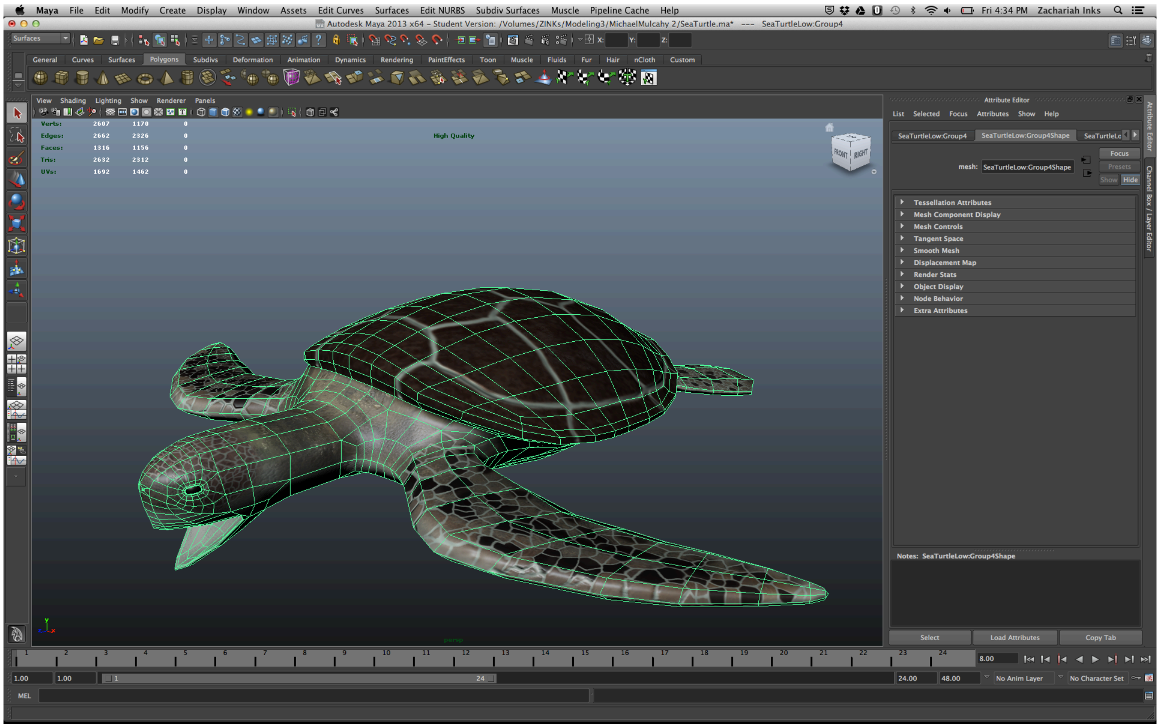

Figure 8.1: Western Piedmont Community College student Modeling 3 project.

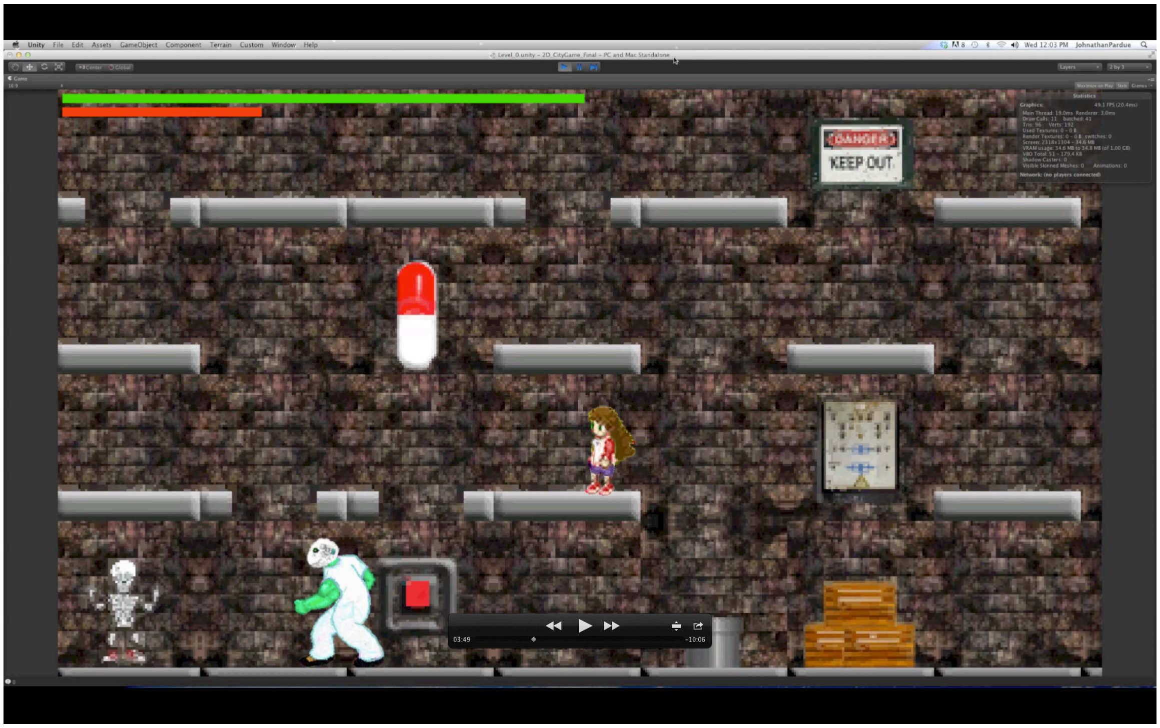

Figure 9.1: Western Piedmont Community College student Mobile Programming project.

Figure 10.1: Western Piedmont Community College student Mobile Programming project.

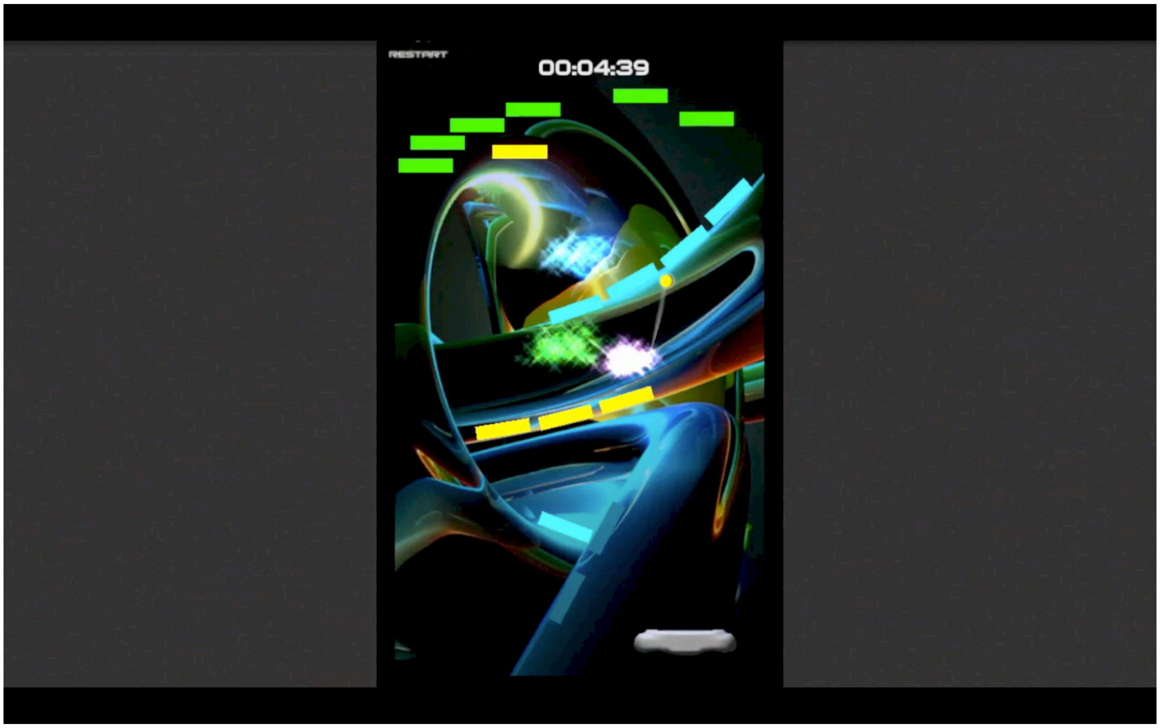

Figure 11.1: Western Piedmont Community College student Mobile Programming project.

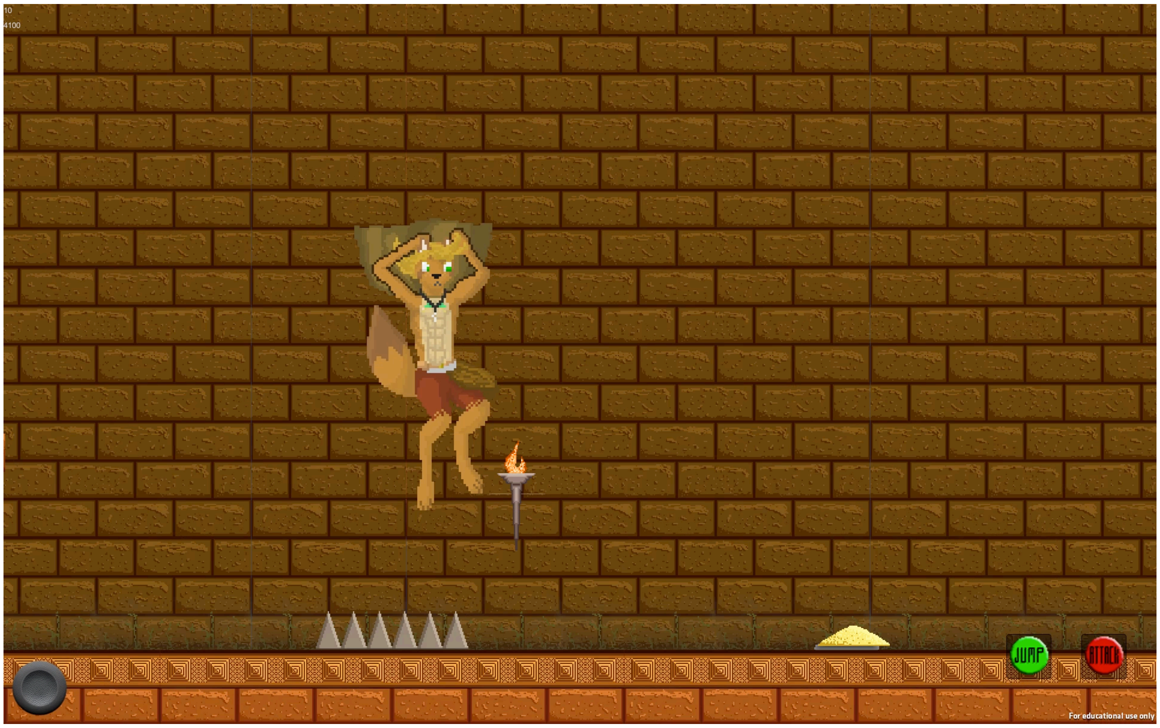

Figure 12.1: Western Piedmont Community College student Mobile Programming project.

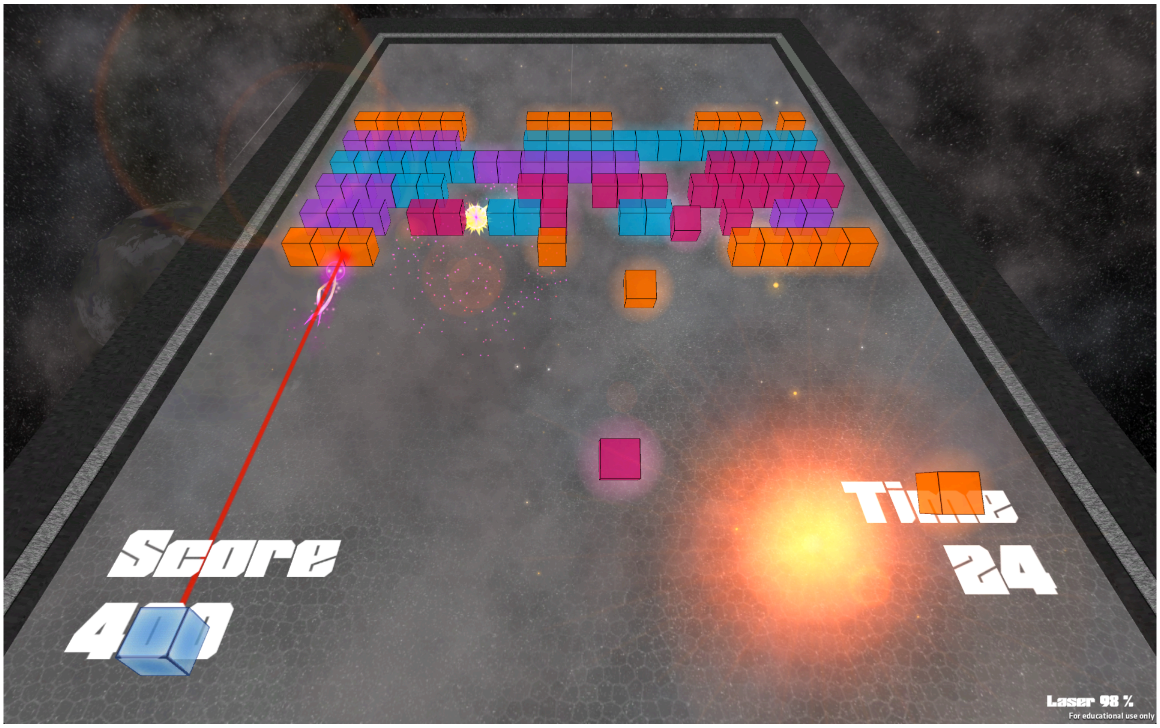

Figure 13.1: Western Piedmont Community College student SGD Design 2 project.

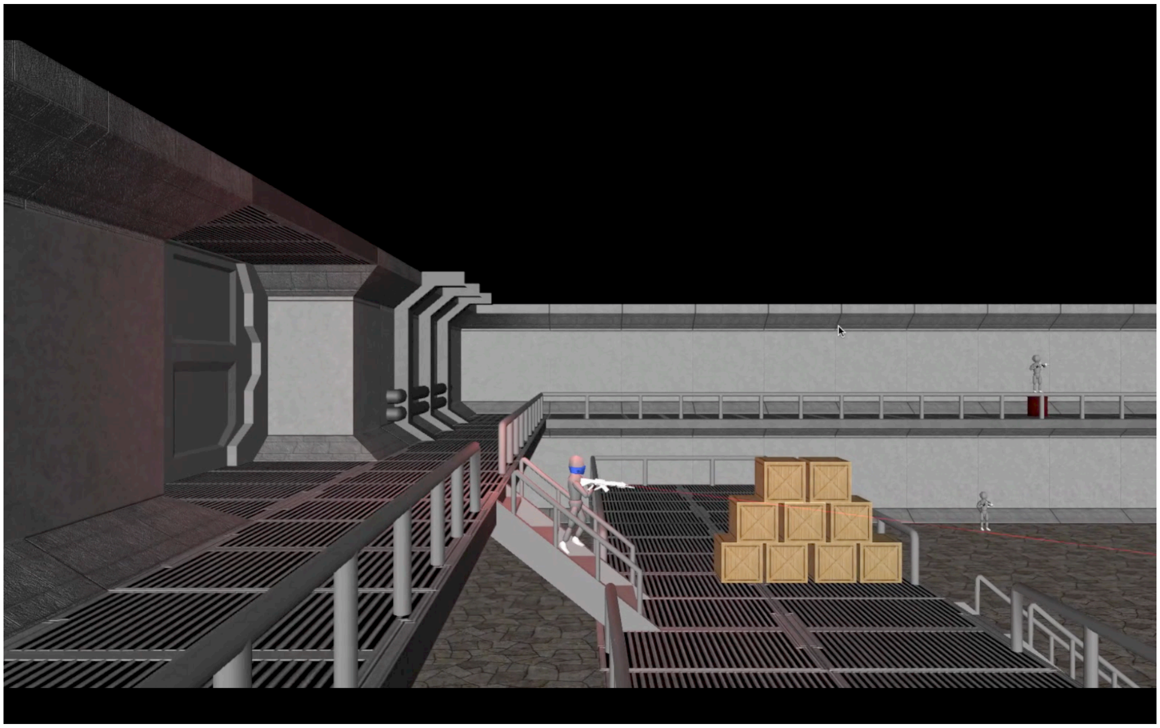

Figure 14.1: Western Piedmont Community College student SGD Design 2 project.

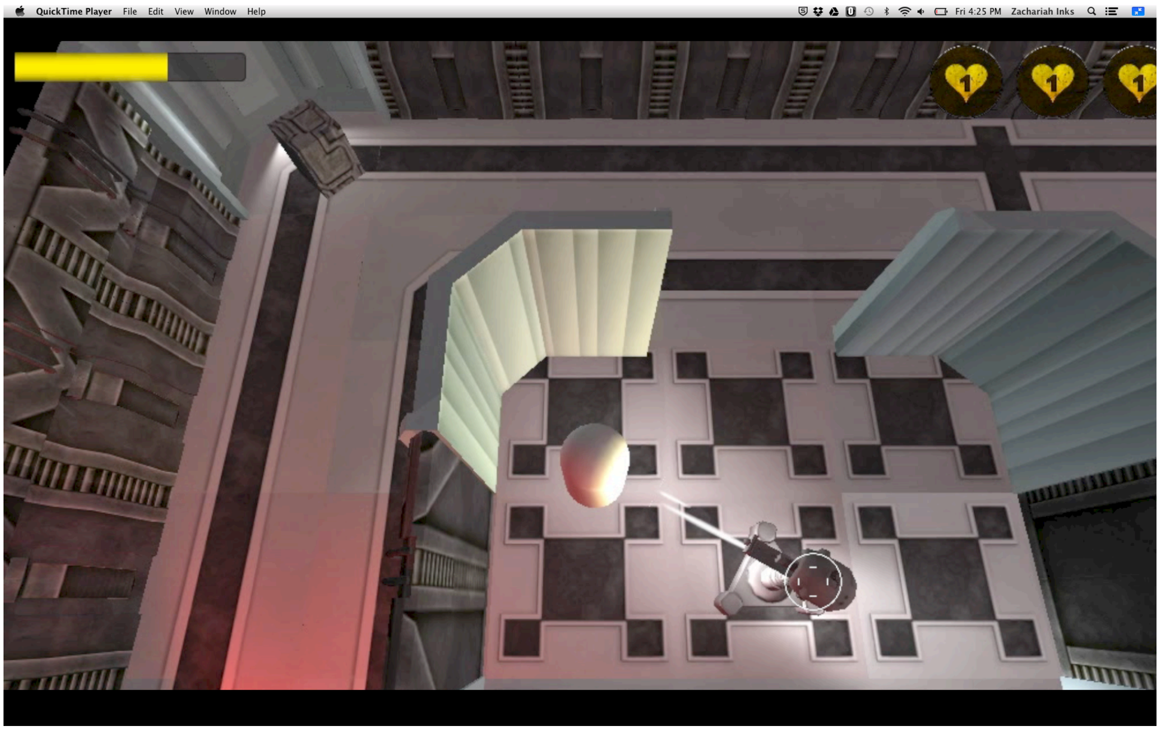

Figure 15.1: Western Piedmont Community College student Level Design project.

Figure 16.1: Western Piedmont Community College student Level Design project.

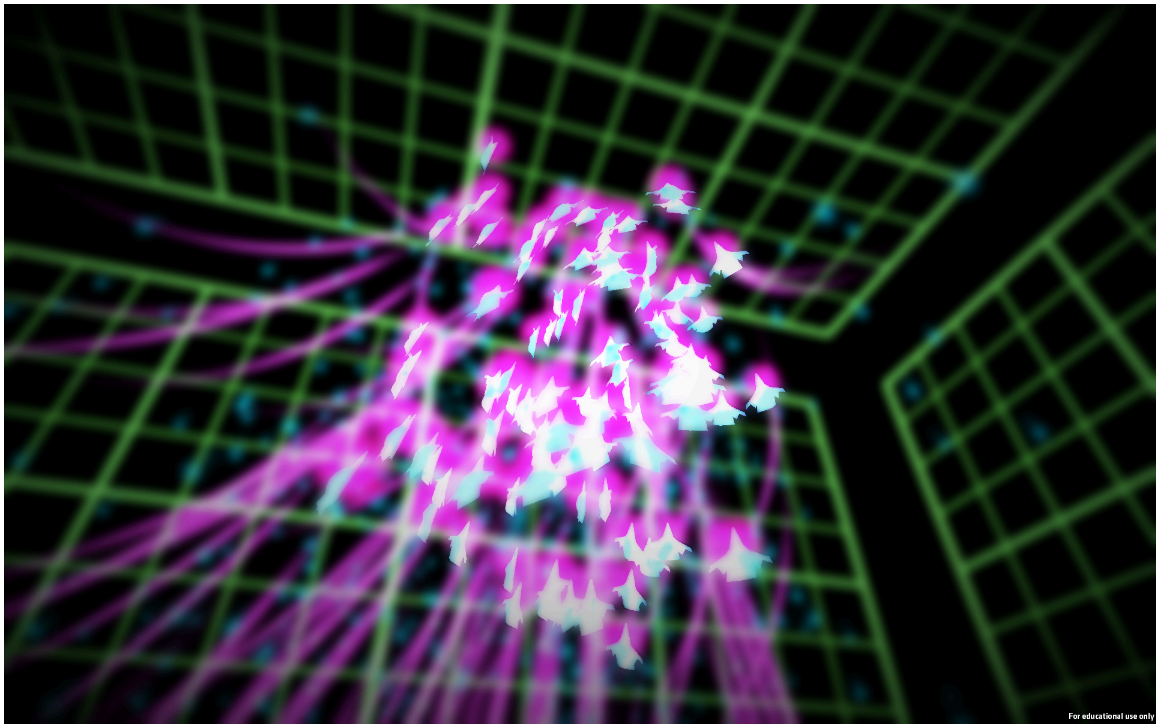

Figure 17.1: Western Piedmont Community College student Capstone project.

CHAPTER FIVE

CONCLUSION

By creating a holistic computer graphics educational pipeline, the student will benefit from a more comprehensive computer graphics education, retain the subject matter better, and be able to problem solve more effectively. The concept of a holistic education, in this case, focuses on building off of the fundamental areas of study from which many of the concepts in computer graphics are informed. Again, these fundamentals can be categorized as: art, physics, psychology, and computer science. Additionally, by using a methodology where concepts are firmly established through hands-on active learning strategies, reinforced by guided application, and also employed through problem solving activities, optimal cognitive load and flow can be achieved. Furthermore, by designing a program at the curriculum and class level that focuses on building on known concepts and connecting concepts throughout, optimal cognitive load and flow can be achieved from beginning to end. Achieving student success is universally the goal of instructors and institutions, but with this methodology, they can truly address the depth and breadth that is encompassed with the field of computer graphics.

APPENDICIES

The appendix to this paper includes a detailed outline of the content taught within the holistic computer graphics educational pipeline. All of the content corresponds to the topic areas outlined previously. Each section is labeled to match the above sections.

APPENDIX A: 2D Design [WONG72]:

1) Balance: The distribution of visual information.

2) Emphasis: The way in which visual elements control attention.

3) Line: The connection between two points.

4) Form: A visual elements internal composition.

5) Scale: The relationship between two or more objects being compared in terms of apparent size.

6) Proportion: The relationship between components of a single object or composition.

7) Contrast: The juxtaposition of opposing visual elements.

8) Gradation: A linear transformation of a visual element from one state to another.

9) Texture: The surface quality of a visual element.

10) Motion: The perceived or actual motion of element(s) within a composition or the motion of the composition as a whole.

11) Repetition: The reuse of similar elements, which creates a pattern.

12) Axis: The visible or invisible line, which bisects a composition.

13) Gestalt: The way in which all the visual elements of a composition relate as a whole.

13a) Closure: Visual elements that are incomplete or a space is not completely enclosed.

13b) Continuance: Visual elements that move the eye through one object and continue to another object.

13c) Similarity: Visual elements, which are similar, tend to be grouped together.

13d) Proximity: Visual elements near each other tend to be grouped together.

13e) Alignment: Visual elements that align by their edges or centers.

13f) Pragnanz: Visual elements tend to be organized or reduced to the simplest form possible.

13g) Continuity: Line tends to follow the smoothest path.

13h) Figure: Visual elements of form, shape and silhouette.

13i) Ground: Visual area around figure.

APPENDIX B: Color Theory [EDWA04]:

1) Color Models: Mathematical models used to represent color.

1a) Additive: Color models, which represent color when mixing light.

1b) Subtractive: Color models, which represent color when mixing pigment.

2) Color Wheel: Circular illustration of hues.

2a) Primary Colors: Colors that can be mixed to make a range of colors.

2b) Secondary Colors: Color made by mixing two primary colors.

2c) Tertiary Colors: Color created through combining a primary color with a secondary color, or two secondary colors.

3) Color Temperature: Measurement of color expressed in Kelvin.

4) Color Harmony / Scheme: Strategies for combining colors.

4a) Monochromatic: Shades of the same hue.

4b) Complementary: Two colors opposite on the color wheel.

4c) Analogous: Groups of colors adjacent to each other on the color wheel.

4d) Triadic: Three colors that are evenly spaced around the color wheel.

4e) Split-Complementary: Three colors where two of the colors are adjacent to a color and the third color is that color's complement.

4f) Double-Complementary (Tetradic): Four colors which are two complementary pairs.

4g) Square: Four colors spaced evenly around the color wheel.

5) Hue: The color.

6) Saturation: Intensity of color purity.

7) Value: Brightness of a color.

8) Tint: Mixture of a hue with white.

9) Shade: Mixture of a hue with black.

10) Tone: Mixture of a hue with gray.

11) Color Context: Behavior of color in relation to another color or shape.

APPENDIX C: 2D Perspective [LOOM51]:

1) Picture Plane: Flat surface located between the station point and the viewer.

2) Convergence: Parallel lines converge to a point as they move into the distance.

3) Vanishing Point: The point of convergence.

4) View / Station Point: Viewer location.

5) Horizon Line: A line that subdivides the composition from left to right.

6) Level of Form Detail: Shape information that can be viewed at a distance.

7) Level of Texture Detail: Surface information that can be viewed at a distance.

8) Light and Shadow: How the angle and direction of light and shadow affect the perception of perspective.

9) Atmospheric Absorption: Light absorption passing through an atmosphere over a distance.

10) Atmospheric Distortion: Light distortion passing through an atmosphere over a distance.

APPENDIX D: 3D Design [WONG76]:

1) Line (Form): Created from a continuous line in three-dimensional space.

2) Plane (Form): Created from a continuous plane in three-dimensional space.

3) Volume (Form): Created from the negative (empty) internal space of an enclosed three-dimensional space.

4) Mass (Form): Created from the positive (solid) internal space of an enclosed three-dimensional space.

5) Space: A continuous area.

5a) Positive: A space that is filled (solid).

5b) Negative: A space that is empty.

6) Texture / Material: Surface quality of a form.

7) Light: Qualities of light and shadow and how they interact with the three dimensional form.

8) Color: Surface hue.

9) Time: How the form is affected by the passing of time.

10) Gestalt: How the visual information is understood as a whole.

10a) Containment: Edge or boundary of a composition.

10b) Proximity: Spatial closeness.

11) Continuity: Consistency of relation between elements within a compositional three-dimensional form.

12) Closure: Mental connection of visual elements into a complete three-dimensional form.

13) Repetition: Reuse of the same visual element with relative frequency and proximity within a three dimensional form.

14) Variation: Use of unique visual elements within a three dimensional form.

15) Rhythm: Balance of repeating patterns and variations within a three dimensional form.

16) Balance: Distribution of visual elements within a three dimensional form.

17) Scale: Size of visual elements within a three-dimensional form relative to a unit of measure (usually relative to human size).

18) Proportion: Size of visual elements within a three-dimensional form relative to each other.

19) Emphasis: Visual dominance of an element within a three dimensional form.

20) Economy: Balanced use of visual elements within a three dimensional form.

21) Unity / Variety: Balance between uniformity and chaos of visual elements in a three dimensional form.

22) Visual Hierarchy: The relative relationship of visual importance between visual elements in a three dimensional form.

23) Form Type: Classification of different types of forms.

23a) Organic: A form which shapes are indicative of nature.

23b) Geometric: A form which shapes are artificial.

23c) Static: A form which shapes indicate an inert object.

23d) Dynamic: A form which shapes indicate an object in motion.

23e) Kinetic: A form, which shapes are in motion.

23f) Representational: A form, which is intended to represent an existing object.

23g) Abstract: A form, which is intended not to represent any existing, object, but may have meaning.

23h) Non-Objective: A form, which is intended not to represent any existing object, but does not have meaning.

24) Dimensionality Types: Classification of different types of three-dimensional forms by way that they occupy three-dimensional space.

24a) Relief: A three-dimensional form where a two dimensional image has the foreground raised above the background.

24b) Three-Quarter: A three-dimensional form where two or three of the sides of the form are unfinished or attached to another structure.

24c) Free Standing: A three-dimensional form where one or less of the sides of the form are attached to another structure.

24d) Environmental: A three dimensional form that is part of or attached to an existing environment.

APPENDIX E: Geometry [LOOM47]:

1) 2D Primitives: Basic geometric two-dimensional shaped derived from an algorithm.

1a) Point: Dimensionless object having only location.

1b) Line: Geometric Object with an infinite length, but no width or height.

1c) Line Segment / Ray: Object with a finite length, but no width or height.

1d) Plane: Two-dimensional surface.

1e) Circle: Set of all points in a plane that are a given distance from a center point.

1f) Ellipse: Set of all points in a plane that are an oscillating distance from a center point.

1g) Triangle / Polygon: Object formed from at least 3 points which all lie on the same plane and connected by edges that form a close shape with no concave sections.

1h) Spline Curve: Smooth curved line formed by a series of points.

2) Line: Types: Geometric types of interrelated lines.

2a) Intersecting: Two or more lines which cross.

2b) Perpendicular: Two or more lines which are at right angles to each other on a two dimensional plane.

2c) Parallel: Two or more lines in a plane, which never intersect.

3) Polygon: Components.

3a) Point: Point, which defines a corner of a polygonal shape.

3b) Line: Line, which connects two points on a polygonal shape.

3c) Centroid: Average center point of all of the points that make up a polygonal shape.

3d) Angle: Angle between two lines attached by a point on the polygon.

4) Angle: Ratio of length of a circular arc to its radius.

4a) Acute: An angle that is less than 90 degrees.

4b) Obtuse: An angle that is greater than 90 degrees.

4c) Interior: An angle inside a shape.

4d) Exterior: An angle outside a shape.

5) Polygon: Types.

5a) Triangle: A three sided polygon.

5b) Quadrilateral (Tetragon): A four sided polygon.

5c) Pentagon: A five sided polygon.

5d) Hexagon: A six sided polygon.

5e) Heptagon: A seven sided polygon.

5f) Octagon: An eight sided polygon.

5g) N-Gon: Any polygon with more than three sides.

6) Polygon: Rules [CHOP11].

6a) Points on a Single Plane: All points of a polygon must sit on a single plane.

6b) Closed Shape: The polygon must be a closed shape.

6c) Convex: All interior angles of the polygon must be equal to or greater than 180 degrees.

7) 3D Primitives: Basic geometric three-dimensional shaped derived from an algorithm.

7a) Sphere: A perfectly round three-dimensional solid object.

7b) Cube: A three dimensional solid object made from six square faces.

7c) Toroid: A doughnut shaped solid object.

7d) Cylinder: A shape formed by extruding a circle in a direction perpendicular to itself.

7e) Pyramid: A solid object formed by connecting a polygonal base to a point.

8) Platonic Solids: A solid polygonal object where each face is made of the same sided polygon.

8a) Tetrahedral: Four triangular faces.

8b) Cube: Six square faces.

8c) Octahedron: Eight triangular faces.

8d) Dodecahedron: Twelve pentagonal faces.

8e) Icosahedron: Twenty triangular faces.

9) Symmetry: Types.

9a) Reflection: Object is identical, but inverted and mirrored across an axis or plane.

9b) Rotation: Object is identical when rotated a given degree any number of times.

9c) Translational: Object is identical when translated, but not rotated or scaled.

9d) Glide Reflection: Combination of a reflection and a translation.

9e) Roto-Reflection: Object is rotated about an axis and then reflected in a plane perpendicular to the axis.

9f) Helical: Object with rotational symmetry and then translated along the axis of rotation.

10) Fractal: A self-similar pattern.

APPENDIX F: Traditional Image Rendering [LOOM61]:

1) Point.

1a) Pointillism: Images formed from many small dots of pure color.

2) Line: Quality.

2a) Value: Lightness or darkness of a line.

2b) Width: Width of a line.

2c) Direction: Direction that a line is moving in.

2d) Curvature: Curvature of a line.

3) Line: Type

3a) Contour: Line formed from points that are on the surface or edge of an object.

3b) Continuous: Image formed by a single unbroken line.

3c) Gesture: Line that represents the action of something.

4) Shading: Creates the illusion of depth or shadow by applying media in dense, dark applications for darker areas and visa versa in lighter areas.

4a) Parallel / Cross Hatching: Shading is accomplished by applying directional strokes that are either parallel or crossed.

5) Texture.

5a) Physical: A surface, which has a pattern, formed by smaller variations in depth.

5b) Visual: A surface, which has a pattern, formed by color variations.

6) Reductive Rendering: A technique of creating images by taking away media rather than adding it.

APPENDIX G: Human Form [SCHI]:

1) Proportions: Relative size of one body part to another.

2) Anatomy.

2a) Skeletal: Structural support for a human body.

2b) Muscle: Locomotive function.

2c) Vascular: System for transporting blood around the body.

2d) Fat Tissue: Layers of fat below the skin.

2e) Dermal: Layers of skin.

3) Biomechanics: Structure and function of anatomy.

4) Kinesiology: Study of human movement.

APPENDIX H: Photography:

1) Technical Concepts.

1a) Focus: Distance from camera where subject matter is clearly represented.

1b) Exposure: Amount of light that is exposed to the camera film or sensor.

1c) Aperture: Opening through which light enters the camera.

1d) Shutter Speed: Speed at which the camera shutter opens and closes.

1e) ISO Speed: Measure of a media's sensitivity to light.

1f) White Balance: A manipulation of color temperature (blue vs. red light) so that white items appear white in the end image.

1g) Metering: Setting for camera exposure.

1h) Autofocus: A sensor that controls camera focus mechanically.

1i) Depth of Field: Area from distance of camera that a camera can focus.

1j) Lens Flare: Unwanted light scattering created by internal reflection and scattering inside the lens system.

1k) Chromatic Aberration: Failure of a lens to focus all colors on the same convergence point.

1l) High Dynamic Range: Method of capturing a dynamic range of values between the darkest and lightest values of an image.

1m) Non-Visible Spectrum: Capturing ranges of the electromagnetic spectrum beyond the visible light.

1n) Stereoscopic Photography: Method of capturing two images that align to mimic human vision.

1o) Light Field Photography: Method of using an array of micro lenses to capture 4D light field.

2) Photographic Composition.

2a) Center of Interest (Rule of Thirds): Compositional rule of thumb where a image is divided by two evenly spaced horizontal and vertical lines and where the highest points of interest are the intersections of those lines.

2b) Subject Placement (Head Room / Lead Room): Compositional rule of thumb where the subject is given adequate space between it and the edges of the composition.

2c) Simplicity: See 2D Design Principles.

2d) Viewpoint: See 2D Design Principles.

2e) Camera Angle: See 2D Design Principles.

2f) Balance: See 2D Design Principles.

2g) Lines and Shapes: See 2D Design Principles.

2h) Pattern: See 2D Design Principles.

2i) Volume: See 2D Design Principles.

2j) Lighting: See 2D Design Principles.

2k) Texture: See 2D Design Principles.

2l) Tone: See 2D Design Principles.

2m) Contrast: See 2D Design Principles.

2n) Framing (Cropping): See 2D Design Principles.

2o) Foreground: See 2D Design Principles.

2p) Background: See 2D Design Principles.

2q) Perspective: See 2D Design Principles.

3) Lighting System.

3a) Three Point System: Lighting system consisting of a key light, rim light and backlight.

4) Light Quality.

4a) Natural Light: Category of light which consists of only light coming from the sun directly or reflected off of other objects.

4b) Artificial Light: Category of light, which is emitted from any light, which requires a power source.

4c) Flash: Artificial light that is emitted in a short, intense burst.

4d) Soft / Hard: Quality of light where the light is more reflected around the subject or is more singularly directional.

4e) Diffuser: An object that creates softer lighting by making the light rays passing through it less directional.

4f) Reflector: An object that is used to reflect light onto a subject.

APPENDIX I: Cinematography [MERC10]:

1) Pre Production.

1a) Storyboard: Sequential images used to illustrate key moments in a film, animation or interactive experience.

1b) Animatic: Animated storyboards.

1c) Previsualization: Blocked in animation.

2) Shot Type.

2a) Wide / Long Shot: Shot that shows the entire subject matter.

2b) Establishing Shot: Establishes the context of a scene.

2c) Medium Shot: Shot half way between a long shot and a close-up.

2d) Close-Up: Shot that tightly frames the subject.

2e) Extreme Close-Up: Shot where subject may fill the entire frame.

2f) Insert Shot: Shot of the same subject as the primary shot but from a different angle.

2g) Reaction Shot: Shot that cuts to the reaction of a character.

3) Camera Angle.

3a) Eye Level: Camera angle that is level with the human eye height.

3b) Low Angle: Camera angle looking up on the subject.

3c) High Angle: Camera angle looking down on a subject.

3d) Dutch Tilt: Camera angle that is tilted so that vertical and horizontal lines of the subject are not diagonal.

3e) Point-of-View: Camera angle that emulates looking through the eyes of a character.

4) Camera Moves.

4a) Pan: Horizontal rotation of a stationary camera.

4b) Tilt: Vertical rotation of a stationary camera.

4c) Dolly / Track: Horizontal linear camera translation.

4d) Pedestal: Vertical linear camera translation

4e) Zoom: Magnification of the subject matter through the lens of a camera.

4f) Dolly Counter Zoom: Zoom magnification while dollying in opposite direction.

4g) 180 Rule: Invisible plane formed by two subjects and should not be crossed.

5) Editing Transitions.

5a) Cut: Transition abruptly between one shot to another.

5b) Fade In / Fade Out: Transition that blends one shot out to a blank shot then blending another shot in.

5c) Dissolve: Transition that blends one shot out while blending one shot in.

5d) Wipe: Transition where a line is moved across the screen where one side of the line is the old shot and the other side of the line is the new shot.

5e) Iris: Transition where a circular point either expands or contracts to transition to a blank shot.

APPENDIX J: Light Emission [ROSS99]:

1) Electromagnetic Spectrum: Frequency range of all possible electromagnetic radiation.

2) Emission.

2a) Incandescence: Emission of light as a result of temperature.

2b) Luminescence: Emission of light not as a result of temperature.

2c) Luminous Intensity: Measurement of wavelength power emitted by a light source.

2d) Brightness: Visual perception of luminous intensity.

3) Color: Portion of the electromagnetic spectrum that is visible to humans.

APPENDIX K: Light Interaction with Media [ROSS99]:

1) Reflection: A change in direction of a wave front caused when that wave front bounces off of one media and then another, where the wave front is unchanged on the second bounce other than direction.

2) Absorption: A media takes up Electromagnetic radiation.

3) Scattering: The change in trajectory of electromagnetic radiation when it encounters a media.

4) Refraction: The change in trajectory of electromagnetic radiation when it encounters the surface of a media.

5) Caustics: Reflected or refracted light rays by a curved surface.

APPENDIX L: Light Phenomena [ROSS99]:

1) Wave Phenomena.

1a) Diffraction: Apparent bending of waves around obstacles.

1b) Interference: When two waves overlap to form a resulting wave of greater or lower amplitude.

1b) Polarization: Oscillation of a wave in more than one orientation.

2) Photoelectric Effect: Matter emitting electrons when they absorb light.

APPENDIX M: Physically Based Animation [ERLE05]:

1) Forces.

1a) Mass: Objects resistance to acceleration.

1b) Linear / Angular Force: Force that pushes, pulls or rotates an object.

1c) Linear / Angular Velocity: Velocity of motion or rotation of an object.

1d) Linear / Angular Acceleration: Acceleration of motion or rotation of an object.

1e) Conservation of Energy: Energy remains constant within a closed system.

1f) Moment of Inertia: Resistance to a change in angular velocity about an axis of rotation.

1g) Elasticity of Collision: Total kinetic energy maintained after a collision.

1h) Maximum Velocity: Object velocity that is not exceeded once a force such as gravity is met with an equal resisting force such as air drag.

APPENDIX N: Visual System [REMI11]:

1) Eye.

1a) Cornea: Transparent cover over the iris, pupil, and anterior chamber.

1b) Iris: Circular structure that controls the diameter of the pupil.

1c) Pupil: Hole in the center of the iris.

1d) Lens: Transparent, biconvex structure that refracts light and focuses it on the retina.

1e) Retina: Light-sensitive tissue on the inner lining of the eye.

1f) Vitreous Humor: Clear gel in the space between the lens and the retina.

1g) Optic Disk: Connection between the inner eye and the optic nerve.

1h) Optic Nerve: Nerve that connects and transmits visual information to the brain.

1i) Visual Cortex: Part of the brain responsible for processing visual information.

1j) Peripheral Vision: Vision outside of the center of gaze.

2) Image Inversion: The reversal of an image in both the horizontal and vertical.

3) Color Vision.

3a) Photoreceptor: Neuron capable of photo transduction.

3a) Photo transduction: The conversion of light to electrical signals.

3b) Rods: Photoreceptor that responds to low light but not color.

3c) Cones: Photoreceptor that responds to color light.

4) Pupillary Light Reflex: Reflex that controls the diameter of the pupil.

5) Stereoscopic Vision.

5a) Inter-pupillary Distance: Distance between the center of the pupil and the center point between the eyes.

5b) Field of View: Extent of the observable environment seen at a given moment.

5c) Stereopsis: Impression of depth perceived with binocular vision.

5d) Binocular Disparity (Parallax): Difference in image location of an object between the left and right eyes.

5e) Depth Perception: Ability to perceive the world in three dimensions using depth cues.

5f) Binocular Fusion / Summation: Combination of each eye's images into one perceived image.

5g) Ocular Dominance: Preference towards visual input from one eye.

5h) Shadow Stereopsis: Depth cue created from each eye seeing different shadows.

6) Multi-stable Perception: Visual patterns that create ambiguous visual cues.

6a) Necker Cube: Ambiguous line drawing.

6b) Structure from Motion: Construction of three dimensional depth cues from a sequence of motion.

6c) Monocular Rivalry: Phenomena that occur when two superimposed images shift visual dominance.

6d) Binocular Rivalry: Phenomena that occur when a different image is presented to each eye where they shift in visual dominance.

6e) Contour Rivalry: Image that can be viewed as a different image when flipped or rotated.

7) Lateral Masking: Problem of visual system to discern repetitious similar objects within close proximity.

8) Beta Movement Effect: Phenomena where when a series of static images are shown in rapid section the image appears to be in motion.

9) Subjective Constancy.

9a) Size: Objects of the same size appear to the contrary due to depth cues.

9b) Shape: Objects that are transformed appear to be the same shape even after transformation.

9c) Color: Color of an object stays similar under varying conditions.

9d) Luminance: Object lightness stays similar under varying conditions.

9e) Distance: Object apparent distance is not proportionate to physical distance.

9f) Location: Object apparent relationship to viewer especially when moving and viewing a stationary object.

10) Color Vision.

10a) Wavelength Detection: Ability of human vision to detect different wavelengths of light.

10b) Scotopic Vision: Human vision in low light.

10c) Purkinje Effect: Human vision discerns less color in low light.

12) Color Blindness: Inability to see color.

13) Color Fatigue: Overstimulation of retina that causes visual ghosting.

14) Color Interaction (Simultaneous Contrast): Color proximity changes the perception of color.

15) Color Perception Mathematics: Mathematical representation of the range of color within the human perception.

APPENDIX O: Color Psychology:

1) Light and Color Perception Effects.

1a) Perceived Color: Range of color that can be perceived.

1b) Perceived Position: Perceived location of an object.

1c) Perceived Form: Perceived revelation of form.

1d) Perceived Motion: Perceived explicit or implicit motion.

2) Meaning: Learned vs. Biological: Associated meaning that is prescribed by society and circumstance or innate to one's biological makeup.

3) Meaning: Functional vs. Sensory-Social: Associated meaning that is attached to something that is based on the function of that thing or the social association.

4) Meaning: Color Pairs

4a) Foreground: Meaning derived from color pairs that exist on the same plane.

4b) Figure vs. Ground: Meaning derived from color pairs that are perceived to be one close and the other far away from the viewer.

5) Influence of Context: Perception of color due to the association to some subject either directly or indirectly.

6) Color preference.

6a) Gender: Bias of color due to gender.

6b) Age: Bias of color due to age.

6c) Culture: Bias of color due to culture.

APPENDIX P: Functions of Light:

1) Selective Visibility: Hiding or revealing subject matter using light and shadow.

2) Revelation of Form: Hiding or revealing to the shape of a subject using light and shadow.

3) Focus: Directing of attention using light color and intensity.

4) Mood: Creation of a particular mood in the viewer through using light color and intensity.

5) Location: Perception of a location or time through the use of light color and intensity.

6) Projection: Creation of form by the juxtaposition of light and shadow.

7) Plot: Use of light color and intensity as narrative device.

8) Composition: Use of light and shadow to frame a composition.

APPENDIX Q: Mathematical Models [SHIR02]:

1) Coordinate System.

1a) Cartesian.

2) Axis: Center line between the positive and negative space on a plane.

3) Origin: Coordinate with a value of 0 in the X, Y and Z-axes.

4) Point: Zero-dimensional geometric primitive.

5) Line: One-dimensional geometric primitive of finite or infinite length.

6) Vector: Geometric primitive with a direction and magnitude only.

7) Half-Space: An infinite plane that divides three-dimensional space.

8) Quadrant: Two-dimensional space that has been divided once on the horizontal and again on the vertical.

9) Octant: Three-dimensional space that has been divided by three perpendicular infinite planes.

10) Right Handed vs. Left Handed: Coordinates defined by the direction positive value of the axis perpendicular to the forward and up axes in relation to each other.

APPENDIX R: Color Systems [SHIR02]:

1) Bit / Color Depth: Number of bits used to represent the color value of a pixel.

2) Bitmap: Array of bits that represent an image where a single bit represents either a black or white pixel.

3) Gray scale: Array of pixels where the value of each pixel can represent black, white or some grey value.

4) Indexed Color: A limited pallet of unique colors that are referenced to propagate an array of pixels in order to create an image.

5) RGB / CMYK Color: A model where a single pixel represents color with three or more channels each represented by a number.

6) Gamut: Subset of colors that can be represented by a particular medium.

APPENDIX S: Raster Graphics [SHIR02]:

1) Pixel: An individual picture element.

1) Pixel Aspect Ratio: The ratio of the width versus height of a pixel.

2) Resolution Matrix Structure: Matrix of pixels.

3) Resolution: Number of pixel columns and rows in an image.

3a) Pixel Density: ppi / dpi: Number of pixels that fit within a unit of space.

4) Opacity / Transparency: Mixing of one pixel color to another.

5) Histogram: Graph that represents the distribution of color information in an image.

6) Aliasing: Jagged pixel representation of smooth curves in an image.

7) Noise.

7a) Perlin: Function that creates cloud like noise.

7b) Dither: Intentional use of noise to randomize an image.

8) Filtering.

8a) High / Low Pass: Reduces the amplitude of low or high values.

8b) Gaussian Blur: Applying a Gaussian filter to an image.

8c) Unsharp Masking: Filter that combines a blurred image with a mask created from the original image in order to create a sharper image.

9) Pixel Selection.

9a) Region: The selection of pixels within a defined shape.

9b) Value: The selection of pixels based on the value of the pixel.

10) Common Operations.

10a) Replace: Replacing a pixel value with another value.

10b) Fill: Setting the value for a group of pixels to the same value.

10c) Erase: Setting the value for a single pixel or group of pixels to white, black or fully transparent.

10d) Cut / Copy / Paste: Copying a group of pixels from a region and replacing another group of pixels within a region with the copied pixels.

10e) Find Edge / Stroke: Finding a set of adjacent pixels with a level of contrast and then filling in the pixels on that border.

10f) Invert: Changing a group of pixels values to be the opposite value.

10g) Adjust HSV: Altering the hue, saturation and or value of a pixel.

11) Rasterization: Process of taking an image and turning it into an array of pixels.

APPENDIX T: Vector Graphics [SHIR02]:

1) Point: Zero-dimensional geometric primitive.

2) Line and Curve (Path / Stroke): A non-straight line, which can exist in two or three dimensions.

2a) Curve Point (Knot): Point, which the curve passes through.

2b) Control Vertex: Point, which influences the curvature of a curve, but does not necessarily sit on the curve itself.

2c) Tangent: Point on a curve where a line can "just touch" the curve.

2d) Hull: A collection of control vertex that influences a curve.

2e) Start / End Point: Point on a curve designated as the beginning or end of the curve.

2f) Thickness: Rendered thickness of a curve in pixels.

2g) Color: RGB value of a rendered curve.

2h) Antialiasing: Method for smoothing the rendered curvature of a curve.

3) Polygon and Shape.

3a) Point: Zero-dimensional geometric primitive represented by an X and Y position and or a pixel.

3b) Edge: A line that connects two points.

3c) Fill (Color / Gradient) Rasterization: Filling in the pixels of a closed shape formed by a series of edges that are connected at their verts.

3e) Primitives: Geometric shapes formed by algorithms and controlled by parameters.

3f) Antialiasing: Method for smoothing the jagged or "stair stepped" effect from rendering diagonal lines into pixels.

APPENDIX U: Compositing [SHIR02]:

1) Layer: A single pixel image that can be placed above or below another pixel image.

2) Blending: Method for combining two overlapping pixels.

2a) Alpha Blending: Combination of a foreground and background pixel value based off of the value in the alpha channel.

2b) Add: Combination of a foreground and background pixel value by adding the two values together.

2c) Subtract: Combination of a foreground and background pixel value by subtracting one value from the other.

2d) Multiply: Combination of a foreground and background pixel value by multiplying the two values together.

2e) Divide: Combination of a foreground and background pixel value by dividing one value by the other.

3) Masking: Isolating a group of pixels based off of a pixel channel value of a second image.

3a) Rotoscope: Technique of isolating a group of pixels within an image sequence using a third image sequence.

3) Keying: Isolating a group of pixels based off of their pixel channel value, specifically the RGB and or HSV values.

3a) Chroma Key: Isolating a group of pixels by the RGB value in order to set them as transparent.

4) Tracking: Extracting motion from an image sequence.

4a) 2D: Tracking that disregards three dimensional space, camera motion or distortion.

4b) 3D: Tracking that interprets three dimensional space, camera motion and distortion.

5) Match Lighting: Method of matching the lighting direction, color and quality between two or more images.

APPENDIX V: 2D Transformations [SHIR02]:

1) Translation: Movement of points or pixels from one coordinate to another.

2) Rotation: Rotation of a group of points or pixels around a pivot point.

3) Scale: Scale of a group of points or pixels from a pivot point.

4) Mirror: A negative scale of a group of points or pixels about an axis.

5) Skew: Transformation to the points of pixels of a group where the distribution of the transformation is unequal or opposite across the group.

6) Warp: Non-uniform transformation of point or pixel subgroups within a group.

7) Offset / Wrap: Translation of points or pixels where their positions are confined within a bounds and if they exceed that bounds then they wrap back around.

8) Affine Transformations.

8a) Translation: See above.

8b) Reflection: Negative scale about an axis.

8c) Rotation: See above.

8d) Shear Mapping: Similar to a skew.

8e) Similarity Transformation: One shape that can be transformed to match another shape.

8f) Spiral Similarities: Combination transformation of homothetic and rotation with the same pivot point.

9) Closed Shape Operations.

9a) Union: Combination of two shapes that overlap so that the overlapping section now becomes shared between the two objects.

9b) Difference: Combination of two shapes so that the overlapping volume remains and the non-overlapping volume is deleted.

9c) Intersection: Combination of two shapes so that the overlapping volume is deleted and the non-overlapping volume remains.

10) Animation: Change over time at a specified rate.

10a) Timeline: Representation of time at a specified rate.

10b) Key frame: A single unit of time used to hold the state of something at that point in time.

APPENDIX W: 2D Animation [PARE02]:

1) Animation Function.

1a) Change Over Time: What is animation.

2) 12 Principles of Animation [WILL01].

2a) Squash and Stretch: The squash and stretch of an object due to forces and its mass.

2b) Anticipation: Loading action and hold before the main action.

2c) Staging: Composition of the scene.

2d) Straight Ahead / Pose-to-Pose: Animating one frame at a time or just the key poses and then filling in the in-betweens.

2e) Follow Through / Overlapping Action: Action due to the momentum of a previous action.

2f) Slow In / Slow Out: Acceleration and deceleration of an object.

2g) Arcs: Natural action tends to follow an arched trajectory.

2h) Secondary Action: Supporting action to the main action.

2i) Timing: Order, frequency and duration of actions.

2j) Exaggeration: Expression of an action beyond a perfect imitation of real life.

2k) Solid Drawing: Quality drawing skills and techniques.

2l) Appeal: Charisma of the character doing the action.

APPENDIX X: 3D Structures [SHIR02]:

1) Point / Vertex: Point in three-dimensional space.

2) Vector / Line / Edge: Line connecting two vertexes.

3) Face: Closed shape formed by three or more edges.

4) Normal: Normalized vector that indicates the direction of face, vertex or edge shading.

5) Polygon.

5a) Triangle: Three sided polygon.

5b) Quad: Four sided polygon.

5c) N-Gon: Polygon of three or more sides.

6) Mesh: A collection of polygons with shared vertex and edges.

6a) Vertex Array: An array of vertex.

6b) Face Index Array: An array of vertex that combines to form a face.

6c) Winding Order: Order of the vertex in the face index array, either clockwise or counter clockwise that determines the direction of the face normal.

6d) Face Normal: Normal that indicates the front of a polygon face.

6e) Vertex Normal: Normal at a vertex that affects the polygon shading as it interpolates to that vertex.

6f) Edge Normal: Normal at an edge that affects the polygon shading as it interpolates to that edge.

7) 3D Primitives.

7a) Sphere: Spherical mesh.

7b) Cube: Six sided mesh formed by six quads.

7c) Cylinder: A "circle" mesh that is extruded down a perpendicular direction.

7d) Cone: A "circle" mesh that is extruded to a point.

7e) Plane: A mesh formed from a single quad.

7f) Torus: A doughnut shaped mesh.

7g) Prism: A triangle polygon that is extruded down a perpendicular direction.

7h) Pyramid: A non-circular cone with three or four converging sides.

7i) Platonic Solid: Mesh formed from congruent, regular polygons with the same number of faces meeting at each vertex.

APPENDIX Y: 3D Transformations [SHIR02]:

1) Translation: See 2D Transformations.

2) Rotation: See 2D Transformations.

2a) Euler: Rotation about one of three axes.

2b) Quaternion: Rotation represented by a number system that extends complex numbers.

2c) Gimbal Lock: When two axes are in a parallel configuration.

3) Scale: See 2D Transformations.

4) Matrix: Rectangular array of numbers organized into rows and columns that can represent transformations.

5) Mirror: A negative scale about an axis.

6) Skew: See 2D Transformations.

7) General Warp: Non-uniform deformation of a mesh.

7) Lattice: A warped grid that then deforms a mesh.

8) Projection: Projecting one object (2D or 3D) onto another object so that it conforms to the shape of the other object.

APPENDIX Z: 3D Modeling [VAUG12]:

1) Types of Surfaces.

1a) Polygonal Surfaces: Mesh surface formed from a collection of polygons.

1b) Subdivision Surfaces: Smooth mesh created through the subdivision of a coarser piecewise linear polygon mesh.

1c) Implicit Surfaces: Surfaces that are formed procedurally in order to simulate blobby substances.

2) Polygon: Mesh Components.

2a) Vertex: Single point.

2b) Edge: Line between two vertexes.

2c) Face: Closed flat shape formed by edges.

2d) Face Normal: Normalized vector that is parallel to the plane of the polygon face.

2e) Vertex Normal: Normalized vector that determines shading between two faces.

2f) Winding Order: Order in which vertex are stored to form a face and determine the direction of the face normal.

2g) Smooth Shading: Lighting calculation that interpolates the shading across polygon edges.

2h) Polygon Rules: Must be a flat, closed, convex shape.

2i) Pivot: Point in 3D space about which rotations and scales are formed.

3) Polygon: Mesh Creation: Creation of polygons by creating the sub components.

4) Extrusion.

4a) Vertex: Creation of polygons from extruding a vertex.

4b) Edge: Creation of a polygon from the extrusion of an edge.

4c) Face: Creation of polygons from extruding a face.

5) Polygon: Adding.

5a) Vertex: Adding a single vertex to a mesh.

5b) Edge: Adding an edge to a mesh.

5c) Face: Adding a face to a mesh.

6) Polygon: Deleting.

6a) Vertex: Deleting a vertex from a mesh.

6b) Edge: Deleting an edge from a mesh.

6c) Face: Deleting a face from a mesh.

7) Polygon: Combining.

7a) Vertex: Combining multiple vertexes into one.

7b) Edge: Combining a single edge or multiple edges into one edge or vertex.

7c) Face: Combining a single face or multiple faces into one face or vertex.

8) Polygon: Append: Filling the space between two polygon edges with a polygon face.

9) Polygon: Bevel: Creating one or more faces from a polygon edge.

10) Polygon: Multiple Meshes.

10a) Combine: Combining multiple meshes into a single mesh where the meshes are not sharing vertex.

10b) Separate: Separating multiple meshes from a single mesh where the individual meshes are not sharing vertex.

10c) Extract: Separating a subset of faces from another mesh.

11) Triangulate: Subdividing a polygon face with more than three edges into triangles by creating new edges that connect existing vertex.

12) Subdivide / Smooth: Splitting the edges of a polygon face by creating new verts and then connecting those verts with edges.

13) Constructive Solid Geometry.

13a) Union: See 2D Transformations.

13b) Difference: See 2D Transformations.

13c) Intersection: See 2D Transformations.

14) Curves: Components.

14a) Curve Point (Knot): See Vector Graphics.

14b) Control Vertex: See Vector Graphics.

14c) Tangent: See Vector Graphics.

14d) Hull: See Vector Graphics.

14e) Start / End Point: See Vector Graphics.

15) Curves: Creation: Creation of a curve by placing curve points in three-dimensional space.

16) Curves: Adding.

16a) Add Curve Point: Adding an additional curve point to the end of a curve.

16b) Insert Curve Point: Adding an additional curve point along a curve.

17) Curves: Deleting.

17a) Delete Curve Point: Deleting a curve point from a curve.

18) Curves: Combine / Separate: Breaking one curve into two curves at some point along the curve.

19) Curves: Open / Close: Connecting or disconnecting the start and end curve points.

20) Curves: Reorder.

20a) Reverse: Reversing the order of curve points from start to end to end to start.

20b) Move Seam: Move the start and end points on a closed curve.

20c) Edit Parameterization: Change the spacing between curve points along a curve by adding or reducing curve points.

21) NURBs: Surface Components.

21a) Control Point: Similar to a curve point, but associated with the intersection point of two curves on a NURBs surface.

21b) Control Vertex: Similar to a control vertex on a curve, but controls the intersection point of two curves on a NURBs surface.

21c) Isoparm: A curve used to form a NURBs surface.

21d) Hull: Similar to a curve hull, but controls a NURBs patch.

21e) Patch: A NURBs surface.

22) NURBs: Surface Creation.

22a) Revolve: Creating a surface from the rotational extrusion of a curve about an axis.

22b) Loft: Creating a surface from the interpolation between two curves.

22c) Planar: Creates a NURBs surface from a flat, closed curve.

22d) Birail: Creates a NURBs surface from a curve swept across two or more rail curves.

22e) Boundary: Creates a NURBs surface from four curves that define the surface's boundary.

23) NURBs: Adding / Deleting.

23a) Isoparm: Add an isoparm to a NURBs surface or delete an existing one.

24) NURBs: Combine / Separate: Combines or separates two NURBs surfaces at a boundary edge or at an isoparm.

25) NURBs: Open / Close Surface: Connects or disconnects a boundary edge on a NURBs surface to another boundary edge on that same surface.

26) NURBs: Reorder Surface.

26a) Reverse: Reverses the start and end order or control points on a NURBs surface.

26b) Move Seam: Moves the seam on a closed NURBs surface to another isoparm.

26c) Edit Parameterization: Changes the density of a NURBs surface isoparms.

27) NURBs: Stitch: Connects the control points on a boundary edge of two NURBs surfaces so that they stay together.

28) NURBs: Trim: Projects a closed curve on a NURBs surface to create a hole in the surface.

29) Subdivision Surface Components.

29a) Vertex: Vertex on control mesh.

29b) Edge: Edge on control mesh.

29c) Face: Face on control mesh.

29e) Control Cage: Low polygon version of control mesh.

30) Subdivision Surface Creation: Creation of subdivision surface from control mesh.

31) Subdivision Surface Adding / Deleting: Adding or deleting control mesh components.

32) Subdivision Surface Combine / Separate: Combining or separating multiple subdivision surfaces.

33) Subdivision Levels.

33a) Resolution Independent: Subdivision surfaces can dynamically create more polygons to better approximate surface smoothness based off of view distance.

34) Topology: Distribution and organization of polygons within a mesh.

34a) Quads: a mesh with all quad faces creates Good topology.

34b) Edge Loops: Smooth flow and transitions between connected edges.

34c) Inline Edges: Sharp yet smooth transitions created by placing multiple edges close together.

34d) Poles: When 3 or more edges converge on the same vertex.

34e) Even Sided N-Gon to Quads: Can be subdivided into quads.

34f) Uneven Sided N-Gon to Quads: Cannot be subdivided into quads.

34g) Circulated Edge Flow: An edge flow that loops back onto itself.

35) Metaballs: A type of implicit surface.

36) Point Cloud: A group of points in three-dimensional space that define a volume.

37) Voxel: A volumetric picture element on a three dimensional grid.

38) Modeling Techniques.

38a) Primitive Modeling: Creating form using only polygon mesh primitives.

38b) Box Modeling: Creating forms starting with a polygon primitive and then extruding and manipulating components.

38c) Edge Loop Modeling: Creating form by extruding faces from edges.

38d) Finite / Dynamic Sculpting: Creating form using a starting mesh and pulling or pushing the surface with brushes.

38e) Image Based Modeling: Extracting form from two or more images of an object.

38f) 3D Scanning: Extracting form-using lasers to scan the surface of an object.

APPENDIX AA: 3D Surfacing [LANI08]:

1) Surface Shading.

1a) Diffuse Shading (Lambertian): Brightness of surface is not affected by viewer angle.

1b) Specular Shading (Blinn / Phong): Specular reflection is added to the surface shading and is affected by the viewer angle.

2) UV.

2a) Component: UV point, edge and shell.

2b) Creation: UV projection assigns UV coordinates to each vertex and associates edges and shells.

2c) Transforming: UV translation and rotation.

2d) Combining: Merging multiple UVs into one.

2e) Separating: Splitting a single UV into multiple.

2f) Wrapping: Behavior of UVs beyond the 0 to 1 range in UVW space.

2g) Animation: Transforming UVs over time.

3) Texture.

3a) Pixel to Texel: Pixels are converted to texels when an image is used as a texture.

4) Material Texture Control.

4a) Diffuse: Controls the unshaded or lambertian shaded color of a surface on a per texel basis.

4b) Transparency: Controls the opacity of a surface on a per texel basis.

4c) Specular: Controls the color and intensity of the specular reflection on a per texel basis.

4d) Reflection: Controls the color and intensity of the surface reflection on a per texel basis.

4e) Bump: Affects the lighting calculation by taking the surface normal and perturbing its height it on a per texel basis.

4f) Normal: Affects the lighting calculation by taking the surface normal and perturbing its angle it on a per texel basis.

4g) Height Displacement: Creates geometry from a surface and raises it perpendicularly off of the original surface by an amount on a per texel basis.

4h) Vector Displacement: Creates geometry from a surface and raises it off of the original surface at an angle by an amount on a per texel basis.

4i) Emission: Allows a surface material to cast light and it controls the color and intensity on a per texel basis.

5) Projection Painting.

5a) Vertex Color: Projects color information on a surface that is then stored in the vertex.

5b) Face Color: Projects color information on a surface that is then stored in the polygon face.

5c) Stencil: Projects color information on a surface that is then stored in a texel at a point on a polygon.

6) Procedural Texture: A texture generated by an algorithm.

7) Texture Technique: Hand Painting.

7a) Per-Pixel Painting: Creating an image by manually adding color on a per pixel level.

7b) Custom Brush: Creating an image-using user created "brushes".

7c) Blending: Mixing adjacent pixel values.

7d) Layering: Blending multiple images together by laying them on top of each other.

7e) Masks: Isolating pixel groups.

7f) Gradient: Interpolation from one pixel value to another across the image.

7g) Blur / Sharpen: Blurring or sharpening an image by evaluating neighboring pixels.

7h) Noise: Random variation of color or brightness across a group of pixels.

7i) Painting Highlights / Shadows: Manually creating a brighter or darker set of pixels in order to fake a shadow.

7j) Using Grid / Ruler / Guides: Allows for the "snapping" behavior of pixels to a predefined grid, ruler unit or linear guide.

7k) Texture Atlas: Technique of placing as many UV shells from as many meshes as possible on one texture.

8) Texture Technique: Image Sampling.

8a) Tileable Image Offset: Offsetting an image by some number of pixels an allowing it to wrap around to the other side of the image in order to attempt to make the texture tileable.

8b) Tileable Cloning: Sampling pixels from one part of an image in order to blend them into the image on top of tiled seams.

8c) Color Correction (HSV / Contrast): Manipulation of the overall color or brightness of an image in order to achieve a particular look.

8d) Histogram Interpretation (HSV / RGB): Interpreting an image using its histogram data.

8e) Histogram Normalization (HSV / RGB): Normalizing an image color and brightness based off of its histogram data.

8f) Correcting for Light Direction: Reducing highlights and shadows in the sample image.

8g) Correcting for Distortion: Warping an image to correct for perspective distortion.

8h) Selecting Texture Photo Samples: Process of eliminating images with the least desirable color, lighting and distortion.

8i) Photographing Texture Samples: Process of capturing images in a way that provides for the least likely undesirable color, lighting and distortion.

9) Texture Technique: Mesh Transfer.

9a) Bump Map: Evaluating a highly detailed mesh and a similar lower detailed mesh and generating a texture based off of the surface relative height differences.

9b) Specular: Evaluating the specular information from one mesh when compared with another in order to copy that information to a texture.

9c) Normal Map: Evaluating a highly detailed mesh and a similar lower detailed mesh and generating a texture based off of the surface normal direction differences.

9d) Displacement Map: Evaluating a highly detailed mesh and a similar lower detailed mesh and generating a texture based off of the surface actual height differences.

9e) Vector Displacement Map: Evaluating a highly detailed mesh and a similar lower detailed mesh and generating a texture based off of the surface angle and height differences.

9f) Ambient Occlusion Map: Evaluating the ambient occlusion information from one mesh when compared with another in order to copy that information to a texture.

9g) Cavity Map: Similar to an ambient occlusion transfer except focusing on the small surface details.

9h) Light Map: Evaluating the lighting information on one mesh when compared with another in order to copy that information to a texture.

10) Texture Technique: Projection Painting: Using a "brush" behavior and projecting texture information onto a mesh at a point.

11) Texture Technique: Procedural Generation: Turning a procedural textures into a raster graphics image.

12) Texture Consistency: Comparing all textures used to make sure they are within a consistent range for color, brightness and saturation throughout a project.

APPENDIX BB: 3D Rigging [PARE02] [OSIPA03] [ALLE08]:

1) Anatomy / Physiology.

1a) Material mechanics: Function of biological materials.

1b) Bones: Structure and function of skeletal features.

1c) Joints: Structure and function of joints.

1d) Muscle: Structure and function of muscles.

1e) Connective tissue: Structure and function of connective tissue.

2) Articulated Rigging.

2a) Hierarchical Structure: Creation of a hierarchical structure where the parent's transforms affect the child's.

3) Morphing: Transitioning the vertex positions of one mesh to the positions of the vertices of another mesh.

4) Deformers: Deforming a mesh vertex positions based on an algorithm and a set of parameters.

5) Set Driven Keys: Creating a relationship between two objects where the attributes of the first affect the attributes of the second.

6) Expressions: Creating a relationship between an expression attribute and the attributes of an object where the expression can control the objects attributes.

7) Skeletal Rigging: Using a virtual skeleton to drive the deformation of a mesh.

7a) Rigid Bind: Associating a group of vertices so that they follow a virtual bone 100%.

7b) Smooth Bind: Associating a group of vertices so that they can follow a group of virtual bones where each bone controls a fraction of the vertex motion.

7c) Vertex Weights: The percentage of influence a bone has over a vertex.

8) Kinematics: Mechanics of motion that does not take into consideration the cause of the motion.

8a) Forward: Computing the motion of a hierarchy of objects where each object's transformation affects the objects below it.

8b) Inverse: Computing the motion of a hierarchy of objects by interpreting the desired position of the end effector and transforming all objects down the hierarchy accordingly.

9) Constraints: An object that controls another object's transformations with it's own transformations.

10) Control Objects: An object that serves no other purpose but to allow for animation control of another object either through constraints, expressions or set driven keys.

APPENDIX CC: 3D Animation [PARE02] [OSIPA03]:

1) Animation Function.

1a) Change Over Time: What is animation.

2) 12 Principles of Animation [WILL01].

2a) Squash and Stretch: The squash and stretch of an object due to forces and its mass.

2b) Anticipation: Loading action and hold before the main action.

2c) Staging: Composition of the scene.

2d) Straight Ahead / Pose-to-Pose: Animating one frame at a time or just the key poses and then filling in the in-betweens.

2e) Follow Through / Overlapping Action: Action due to the momentum of a previous action.

2f) Slow In / Slow Out: Acceleration and deceleration of an object.

2g) Arcs: Natural action tends to follow an arched trajectory.

2h) Secondary Action: Supporting action to the main action.

2i) Timing: Order, frequency and duration of actions.

2j) Exaggeration: Expression of an action beyond a perfect imitation of real life.

2k) Solid Drawing: Quality drawing skills and techniques.

2l) Appeal: Charisma of the character doing the action.

3) Animation Forces.

3a) Mass: Objects resistance to acceleration.

3b) Linear / Angular Force: Force that pushes, pulls or rotates an object.

3c) Linear / Angular Velocity: Velocity of motion or rotation of an object.

3d) Linear / Angular Acceleration: Acceleration of motion or rotation of an object.

3e) Conservation of Energy: Energy remains constant within a closed system.

3f) Moment of Inertia: Resistance to a change in angular velocity about an axis of rotation.

3g) Elasticity of Collision: Total kinetic energy maintained after a collision.

3h) Maximum Velocity: Object velocity that is not exceeded once a force such as gravity is met with an equal resisting force such as air drag.

4) Kinematics.

4a) Forward: Animating the transformation of each object in a hierarchy directly.

4b) Inverse: Animating a controller object that then drives a solver which calculates the transformations of all objects in a hierarchy that will result in the alignment of all object to meet the transformations of the controller object.

5) Biomechanics [ALEX92].

5a) Force: Force exhibited on or by biomaterials.

5b) Equilibrium / Stability: Conservation of energy in biomechanical systems.

5c) Maximum effort: Use of all joints in order to accomplish an action.

6) Computer Animation Components.

6a) Timeline: A representation of time broken down by some unit.

6b) Keyframe: The storage to state information at a particular point in time.

6c) Animation Curves: Interpolation between keyframes.

6d) Tangent: Controls the angle of entrance and exit an animation curve takes through a keyframe.

6e) Interpolation: The change from one value to another over time.

6f) Cycling: Repeating a set of animation keyframes infinitely.

6g) Motion Path: A curve in two or three-dimensional space that an object moves down at some rate defined by the beginning and end of the curve.

6h) Ghosting: A graphical representation of the state of an object in previous or future keyframes.

6i) Motion Capture: The capture of real life motion data to be used to drive animated objects.

6j) Non-Linear Animation: The manipulation of the timing of an animation.

APPENDIX DD: Simulation:

1) Forces.

1a) Mass: Objects resistance to acceleration.

1b) Linear / Angular Force: Force that pushes, pulls or rotates an object.

1c) Linear / Angular Velocity: Velocity of motion or rotation of an object.

1d) Linear / Angular Acceleration: Acceleration of motion or rotation of an object.

1e) Conservation of Energy: Energy remains constant within a closed system.

1f) Moment of Inertia: Resistance to a change in angular velocity about an axis of rotation.

1g) Elasticity of Collision: Total kinetic energy maintained after a collision.

1h) Maximum Velocity: Object velocity that is not exceeded once a force such as gravity is met with an equal resisting force such as air drag.

2) Particle System: Simulating chaotic systems such as smoke using a large number of sprites.

3) Flocking: Simulating the behavior of animals such as birds or fish that move in large groups that maintain cohesion and alignment but avoid collision.

4) Crowd Simulation: Similar to flocking simulations but with different agent goals that may be individual to that agent.

5) Rigid Body: Simulation of physics on a solid object where deformation is negated.

6) Fracturing: Simulation of the shattering of a solid object during collision.

6) Soft Body: Simulation of physics on a deformable object.

7) Cloth: Soft body simulation that attempts to simulate the behavior of cloth.

8) Hair / Fur: Simulation of strand objects.

9) Muscle System: Soft body that generates force to contract and deform and affect the deformation of other objects.

10) Procedural Animation: Driving animation through algorithms and parameters.

11) Procedural Growth / L-System: Generation of objects that model the morphology of organisms.

12) Fluid: Simulation of the physics of fluids such as water or smoke.

13) Volume: Simulation of objects that have internal volume or density such as fluid.

14) Simulation Baking / Caching: Storing the results of a simulation so that it can be replayed without being resimulated.

APPENDIX EE: 3D Rendering [LANI08] [FOLE96]:

1) Virtual Camera: Simulated camera.

1a) Orthographic Projection: Rendering 3D objects in 2D.

1b) Perspective Projection: Rendering 3D objects with perspective distortion.

1c) Camera Transformation: The translation, rotation, and zoom of the virtual camera.

2) Rasterization: Process of converting 3D surface data into 2D pixel data.

2a) Projection: Mapping of 3D points to a 2D plane.

2b) Clipping: Excluding objects from rendering based on their location relative to a plane.

2c) Back to Front (Depth Sorting): Sorting of objects based on depth.

2d) Front to Back (Transparency): Sorting objects based on depth and then rendering the objects with transparency in a front to back order.

2e) Hidden Line Removal: Not rendering edges on objects that are being occluded by faces.

3) Culling: Process of excluding objects, in whole or in part, from being rendered.

3a) Frustum Culling: Culling of objects outside of the camera's frustum.

3b) Backface Culling: Culling of faces that are facing away from the camera.

3c) Occlusion Culling: Culling of faces / objects that are behind (relative to camera) other faces / objects.

3d) Portal Culling: Special case occlusion culling that allows objects that are “outside” are culled when the portal is closed. An example would be to cull the outside world when a door is closed.

4) Spatial Data Structures: Data structures that are created and organized to subdivide 2D or 3D space into regions for the purpose of culling.

4a) Bounding Volume Hierarchy: Objects are enclosed in bounding volumes and then grouped and then the groups are enclosed in bounding volumes in order to create a hierarchy of grouped volumes.

4b) Binary Space Partitioning: Recursively subdividing space with planes in order to group objects within the subdivided spaces.

4c) Octree: Recursively subdividing space into eight octants.

5) Shading: Calculating the interaction of simulated lighting with a surface.

5a) Flat: No lighting calculated.

5b) Gouraud: Diffuse light and surface color calculated.

5c) Phong / Blinn: Diffuse and specular light and surface color calculated.

5d) Reflection: The reflection of lights is calculated.

5e) Refraction: The effect of light passing through an object is calculated.

5f) Procedural Shading: Using custom algorithms to control the rendering of a surface. The effect may or may not represent a photo real effect.

5) Texture Mapping: The mapping and translation of 2D pixels to 3D texels on a 3D surface.

5a) 1D / 2D / 3D Textures: A multidimensional array of pixels.

5b) Color: Diffuse: A pixel that controls the diffuse color of a texel.

5c) Color: Transparency: A pixel that controls the opacity of a texel.

5d) Color: Specular: A pixel that controls the specular color and power of a texel.

5e) Color: Emissive: A pixel that controls the emissive light color and intensity of a texel.

5f) Bump: A pixel that controls the angle of a normal (based on gray scale) at a texel.

5g) Normal: A pixel that controls the angle of a normal (based on RGB color) at a texel.

5h) Parallax: A pixel that controls the angle of a normal (based on RGB color for normal direction and gray scale for height displacement) at a texel.

5i) Relief: A similar technique to parallax, but that actually displaces texels off of the surface.

5j) Height Displacement: A pixel that controls the height displacement of a vertex.

5k) Vector Displacement: A pixel that controls the height displacement and angle of a vertex.

6) Texture Filtering: Form of anti-aliased smoothing of neighboring texels.

6a) Linear: Uses value of absolute neighbor texel.

6b) Bilinear: Uses the four nearest texel values.

6c) Trilinear: Similar to bilinear filtering, but it also references mipmap variations.

6d) Mipmap: Storing and using texture copies that are half sizes as an object moves further from the camera.

6e) Anisotropic: Most complex form of filtering.

7) Types of Lights [LANI08].

7a) Ambient: A light that sets the lowest RGB value any surface texel can be rendered at.

7b) Directional: A non-positional infinite light that is represented by a direction, color and intensity.

7c) Point: A light that radiates from a point in a sphere shape.

7d) Spot: A light that radiates from a point in a cone shape.

7e) Area: A light that radiates from a plane in a single direction.

8) Shadow.

8a) Self Shadow: Shading the faces on an object darker if they face away from the light.

8b) Cast Shadow: A shadow that falls from one object onto another or from one part of an object on another part of itself.

8c) Shadow Mapping: A shadow created by "rendering" the z-depth of objects from the position and direction of the light.

8d) Shadow Volume: A shadow created by a 3D volume that represents the area occluded by an object from the light.

9) Rendering Methods.

9a) Image Space Rendering: Rendering the 3D scene using the image space as a window through which the scene is captured.

9b) Scanline Rendering: Rendering an image one line of pixels at a time.

9c) Tiled Rendering: Rendering an image in groups of pixels.

10) Object Space Rendering.

10a) Ray Tracing: Rendering an image by casting rays from the camera point through the pixels on the image plane and recording the color and lighting information of objects that the ray intersects with.

10b) Path Tracing: Rendering by casting rays from light sources and calculating their bounces to the camera image plane.

10c) Beam Tracing: Similar to ray tracing, but it replaces rays with beams which have a thickness.

10d) Photon Mapping: Similar to path tracing, but it is biased.

10e) Photon Tracing: Similar to photon mapping, but the light rays continue to bounce until absorbed or recorded by the camera.

11) Global Illumination Effects.

11a) Ambient Occlusion: Calculates lighting based off of how likely an area is to receive light.

11b) Reflection: Rays that are bounced off of objects in a parallel fashion.

11c) Refraction: Rays that are bent as they pass through objects.

11d) Caustics: Bending of light by passing through a curved surface and illuminating another object where the light rays converge to form a more intense concentration of light.

11e) Subsurface Scattering: Light that enters an object's surface before being reflected or refracted.

11f) Volumetric Sampling: Technique, which renders the effects of lights passing through a non-solid volume.

12) Rendering Techniques.

12a) High Dynamic Range: Lighting calculation that is at a higher fidelity.

12b) Image-Based Lighting: Using an HDR image to cast light from its pixels onto a scene.

12c) Distributed Rendering: Breaking up the rendering of an image across multiple processors and or machines in a network.

13) Rendering Channels.

13a) Spectral: Rendering of the specular values to a separate image.

13b) Alpha: Rendering of the alpha values to a separate image.

13c) Depth: Rendering of the z-depth values to a separate image.

13d) Motion Blur: Rendering of the camera motion blurs values to a separate image.

13e) Reflection: Rendering of the reflection values to a separate image.

13f) Refraction: Rendering of the refraction values to a separate image.

13h) ID Passes: Rendering of the objects as different RGB values according to ID to a separate image.

14) Stereoscopic Rendering: Rendering of two cameras in order to capture two images that would represent what each eye in the human visual system would see.

14a) Anaglyphic: Each eye's view is presented in either red or blue.

14c) Polarized: Each eye's view is presented in either vertical or horizontal polarized nature.

14d) Shutter: Each eye's view is presented in rapid alternating fashion.

14e) Autostereograms: Eyes are control focus and angle in order to perceive a 3D image from a 2D source.

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