Design Drawing – An Integrated Visualization System

Thesis

Presented in Partial Fulfillment of the Requirements for the Degree Master of Fine Arts in the Graduate School of The Ohio State University

By

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2012

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Abstract

Over the past two decades, computers and advancements in software have revolutionized the Industrial Design process. Designers are able to accelerate the development schedules for products by utilizing the same software for design and visualization as engineers use for implementation. Two-dimensional rendering software has become so advanced and intuitive that photorealistic images of a design are generated to help the client believe the product has already been manufactured. The design industry is facing a growing problem, however, as students, required to learn more skills than ever before, are not gaining the drawing skills preferred by or needed for professional practice. Curricula once structured for sketching, rendering and technical drawing have been superseded by Computer Aided Design and graphic courses. Exacerbating the issue are challenges in standardizing Industrial Design curriculum across the spectrum of design schools; as a result students are graduating with a wide range of less-than-ideal skill sets. (Amit, 2010) This thesis will examine the phenomenon of drawing in the design process and propose a new concept for drawing pedagogy that may augment or replace existing curricula to accelerate acquisition of design drawing skills and more fully prepare the student for the design profession.
Acknowledgements

I wish to acknowledge and give great thanks to Dr. Noel Mayo and Professors Maria Palazzi and Scott Shim for their help and support throughout the process of realizing this thesis. They have been a great design team, offering insight and wisdom at critical times. I hope to work with them again in the future.
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# Table of Contents

Abstract............................................................................................................................ii

Acknowledgements...........................................................................................................iii

Vita.......................................................................................................................................iv

List of Figures.......................................................................................................................xi

Chapter 1: **Introduction**.................................................................................................1

1.1 The **problem**..............................................................................................................1

1.2 Overview of History - **Design process**.................................................................1

1.2.1 **Role of designers** in product development.......................................................1

1.2.2 **Role of visualization** in design.................................................................4

1.3 Practice vs. Education...............................................................................................11

1.3.1 **Schism** between Education and Practice......................................................11

1.3.2 Lack of **usable skills** in graduating students.................................................13

1.4 Trends........................................................................................................................15

1.4.1 Technology and **changing nature** of design visualization............................15

1.4.2 Technology and **education**.............................................................................16

1.4.3 State of Design Discipline....................................................................................17

1.4.3.1 **Digital vs. Hand Skills**; Education vs. Practice......................................17
1.4.3.2 **Reduced drawing skills** negatively affect the students’ ability to solve problems and think in three dimensions. ........................................17

1.5 Problem Statement – **Research Question**.............................................19

1.6 What this thesis is **trying to accomplish**.............................................19

1.6.1 Examine **value of drawing** in the design process.........................19

1.6.2 Examine **four major design skills** and their individual contribution to the process.........................20

1.6.2.1 **Model building**.................................................................21

1.6.2.2 **Photography**.................................................................22

1.6.2.3 **Computer visualization**....................................................23

1.6.2.4 **Design Drawing**.............................................................24

1.6.3 Develop an **integrated, sequenced system of visualization** utilizing four major design skills.........................25

1.6.4 An **accelerated pedagogy** for design.........................................29

1.6.5 **Prototype and test** the system in an existing design drawing syllabus.........................................................31

1.6.6 **Analyze, evaluate, and assess** data generated by study............31

1.6.7 **Conclusions**...........................................................................32

1.6.8 **Significance** for both education and practice............................32
Chapter 2: **Background – The Role of Drawing in the Creative Process** ............33

2.1 Drawing in the **Design Process** .................................................................34

2.2 Drawing as a Tool for **Creativity** ...............................................................35

2.3 Drawing for **Idea Generation** .................................................................38

2.4 Drawing for **Problem Solving** ..............................................................39

Chapter 3: **System Design**

3.1 Design of the Integrated Visualization System (IVS) .........................42

3.1.1 **Four design skills** configured to inform and build

on each other sequentially .................................................................42

3.1.2 A visual guide to the **procedural steps** in the IVS .................44

3.1.3 **Other** Sequential Assignments for the IVS ..........................58

3.1.4 Empowering students to **self-initiate** learning ......................60

3.1.5 Accelerated pedagogy – Active **student participation in**

**constructing** individual learning system ..................................61

3.1.6 **Guidelines** for Teaching and Integration of IVS

into a Design Syllabus .................................................................62

3.2 Hypothesis .........................................................................................63
3.3 Research Design

3.3.1 Research Goals

3.3.2 The background and relevance of the sample

3.3.2.1 Control Group

3.3.2.2 Test Group

3.3.3 The qualitative nature of the testing and analysis

Chapter 4: Data/Analysis/Outcome

4.1 Presentation of subject data

4.1.1 Data interpretation – Internal Validity

4.1.2 Testing Data – before, after IVS

4.1.3 Project Data - Control and Test

4.2 Analysis

4.2.1 Evaluation, Assessment of Testing Data from the 2012 Test Group

4.2.2 Evaluation, Assessment of Project Data from Control, Test Groups

4.3 Significance

4.3.1 Design education

4.3.2 Design educators
4.3.3 Practice…………………………………………………………...102
4.3.4 Business………………………………………………………….103
4.4 Limitations…………………………………………………………104
4.5 Next steps…………………………………………………………106

Bibliography………………………………………………………………107
List of Figures

Figure 1.1 - Concept drawing sample .................................................................2

Figure 1.2 - Isometric view of machined casting ...............................................5

Figure 1.3 - Control drawings for a sporting good product ...............................6

Figure 1.4 - Explanation of perspective versus parallel projection ....................7

Figure 1.5 - Examples of divergent and distorted perspective .........................8

Figure 1.6 - Example of incorrect and correct ellipse configurations ...............9

Figure 1.7 - Example of proper perspective .....................................................9

Figure 3.1 – Step 1: Build models from simple materials .............................47

Figure 3.2 - Setup angles for photography .....................................................49

Figure 3.3 - Step 2: Photograph the models ..................................................50

Figure 3.4 - Step 3: Computer model in Trimble SketchUp .........................54

Figure 3.5 - Step 4: Trace/draw the models ..................................................57

Figure 3.6 - Timeline of IVS and D501 Syllabus ..........................................67

Figure 4.1 - Rubric for Perspective Assessment of In-Class Testing of Test Group 77

Figure 4.2 - Testing – sub. 1-4 ........................................................................78
Figure 4.3 – Testing – sub. 5-8 .................................................................79
Figure 4.4 – Testing – sub. 9-12.................................................................80
Figure 4.5 – Testing – sub. 13-16.................................................................81
Figure 4.6 – Design-Drawing Skill Acquisition – Rubric for Assessment.........................83
Figure 4.7 – Design-Drawing Skill Acquisition/Control Group – sub. 1-3..........................84
Figure 4.8 – Design-Drawing Skill Acquisition/Control Group – sub. 4-6..........................85
Figure 4.9 – Design-Drawing Skill Acquisition/Test Group – sub. 1-3..............................86
Figure 4.10 – Design-Drawing Skill Acquisition/Test Group – sub. 4-6..............................87
Figure 4.11 – Design-Drawing Skill Acquisition/Test Group – sub. 7-9..............................88
Figure 4.12– Design-Drawing Skill Acquisition/Test Group – sub. 10-12............................89
Figure 4.13 – Design-Drawing Skill Acquisition/Test Group – sub. 13-15............................90
Figure 4.14 – Design-Drawing Skill Acquisition/Test Group – sub. 16...............................91
Figure 4.15 – Assessment of Testing Data - Test Group...............................................93
Chapter 1: Introduction

1.1. The problem

Aggregate drawing skills in graduates of Industrial Design programs have been problematic for professional practice for some time (Gray, 1979; Garner, 1990; Oliver, 2007; Amit, 2010) with no documented improvement. Indications are that drawing skills in recent graduates continue to deteriorate. There are a number of factors that may be causal to this phenomenon as well as repercussions to the industry. This thesis will delve into some of these issues in this introductory chapter in order to provide a background to the concept for new drawing pedagogy discussed later as the primary focus.

1.2. Overview of the History - Design process

1.2.1. Role of designers in product development

Industrial Design is a professionally creative discipline effecting the function, value and aesthetics of mass-produced artifacts. The field requires a diverse set of skills normally learned in a four- or five-year development cycle for undergraduate college or university students. A designer must utilize craft ranging from scientific research methodologies to fine art, intellectual capacities from high-level cognition to emotional connections. Industrial Design affects virtually every product or cultural artifact we
use, interface with, or are influenced by. The skill sets required in successful design integrate specific talents from many disciplines in a unique configuration that can be difficult to describe or justify.

Designers often speak of their ‘process’ or the ‘design process’ in endeavoring to describe the methodology of their approach to researching and solving problems and issues in design. A general set of design process guidelines can include the following:

1 - Research
   - Expert vs. Participatory
   - Design-led vs. Research-led

2 - Problem definition

3 - Corporate identity, branding, product line analysis

4 - Market(s) analysis

5 - System and sub-system analysis

6 - Human Factors analysis

7 - Ideation and conceptual processes – The area of focus for this thesis

8 - Synthesis

9 - Prototyping

10 - Research testing of concepts

11 - Engineering system analysis

12 - Implementation, manufacturing

13 - Production, post-production issues
The diversity of the disciplines, procedures, and tasks within the Design Process are indicative of the broad range of skills a designer must have and utilize. Some of these are part of a design school’s curriculum and others develop from other education or on-the-job training (e.g., business practices and interaction.) This paper, however, will be examining stages and phases of the design process represented in the core skill sets imparted to students in a proto-typical Design School curriculum.

Within the Design Process, communication, visual, oral, and written, plays a critical role in the advancement of any new idea. Industrial designers are trained in all these disciplines, most especially, visual communication. Visualization, translating an unseen idea to a graphic reality, is a key skill designers use to help the client and product development group understand and achieve consensus in order to advance the potential of a new concept. Two- and three-dimensional computer-generated visualization modes are used on a regular, interchangeable basis depending on the deliverables requirements of a project. Although drawing has been a traditional staple of the design process, digital computer modeling has supplanted a number of original skill sets - drafting, drawing, modeling, rendering in some cases – with a versatile visualization and engineering system. Both are acknowledged and utilized as essential parts of the design process.
**Design Drawing** generally refers to any drawings or renderings drawn by hand on paper or an electronic tablet. Design drawings may range from precise Engineering Graphic specifications (see Fig. 1.2, Fig.1.3) to loose ‘doodles’ on a napkin to a careful perspective line sketch to photographic renderings. Although these type of drawings occur in Stage 7 of the Design Process listed on page 2, free-hand design drawings are generated throughout the design process as part of design thinking and communication – the design language.

1.2.2. **Role of visualization in design**

**Visualization** in design encompasses a number of different media – drawings, models, and computer-generated images – each providing important communication of design intent to the client and product development group. Depending on the graphic literacy of the client, much information about function, value, and aesthetics may be presented with simple line drawings. Rendered images, with color and shading completed by hand or on the computer, offer the next level of information to the client. Simple mock-ups or finished “appearance” models (looks and feels like the real product) are the next stage of development helping either the client or layperson (e.g., research subject from general population in a controlled Focus Group of a specific demographic) to fully understand and relate to the design.
To illustrate some of the issues most commonly found in flawed design drawings the following figures will show examples of different kinds of drawings used in the industry.

Industrial designers are responsible communicating ideas and information to several different disciplines in the design development group including other designers, engineers, marketing as well as the client.

Traditionally Industrial Design students learn Engineering Graphics, a separate formal visual language used universally in Engineering for preparing a concept for function and manufacturing. The latter may be defined as “technical drawing that is concerned with the graphical representation of designs and specifications for physical objects and data relationships as used in engineering and science.” (Giesecke et al, 2000, 9) In designing products, artifacts, and structures for safe use within different cultures, engineers shoulder the responsibility for implementing a design that functions safely and does not fail under normal use.

Figure 1.2 - Isometric view of machined casting (Giesecke et al, 2000, p264)
Figures 1.2 and 1.3 show an isometric and control drawing respectively. They present information to an engineer from a designer with minimal confusion. Both drawings can be executed accurately, by hand or computer, with established conventions for drawings that do not allow guesswork. All lines may be measured to scale. Whereas abstract freehand sketches may be ideal for creatively exploring initial ideas, engineering drawings, drafted with increasing accuracy at each successive step of the design process, must eliminate abstraction.
The difference, shown in Figure 1.4, is that a perspective view represents a projected image from one point, the viewer’s eye compared to an engineering drawing where all points are projected in parallel with no one viewpoint. Herein lies one of the biggest challenges designers face when attempting to accurately visualize a design: you may only approximate proportions and dimensions when drawing in perspective. Furthermore, changing the focal length, the distance from the station point to the picture plane, changes the apparent point of view from far away to close up. The closer the view or shorter focal length the more risk of distortion in the perspective. Composing the perspective focal length of a drawing without distortion is a skill attained only through endless practice. The following Figures illustrate some of the issues that may occur in perspective drawing:
- **Divergent**: parallel lines converge visually as they recede distantly towards a vanishing point.

- **Distortion**: parallel lines converging too quickly show distortion.

- **Ellipse**: one of the most complex phenomena in design drawing, a circle in perspective. Viewed obliquely, the longer dimension of the shape is perpendicular to the Minor Axis which converges to the vanishing point.

![Divergent Perspective](image1.png) ![Too Convergent Perspective](image2.png)

**Figure 1.5 - Examples of divergent and distorted perspective**
Figure 1.6 - Example of incorrect and correct ellipse configurations

Figure 1.7 - Example of proper perspective
Many of the engineering-type drawings shown previously have become part of the software packages offered to students and professionals. The systems are so inclusive that ‘drafting’ is no longer done – it is a byproduct of the CAD solid modeling process. One only needs to give a few mouse-interface clicks to the computer to generate a fully-dimensioned isometric or control drawing.

As digital mediums become ubiquitously available to students and professionals, the tools that designers use in their process have expanded in number. What was once done with sketches, 2d drafting, mockups and prototypes, may now be done almost entirely with 2d/3d computer modeling and rendering programs. Adobe graphic programs such as InDesign, Illustrator, and Photoshop, three-dimensional design/engineering software (Solidworks, ProEngineer/Creo, Catia, Unigraphics, Rhino, etc.), and rendering software (Maya, 3D Studio Max, Keyshot, or Bunkspeed) all represent software a designer may well have to use fluently. Depending on the school and professional studio, a student may need to know just a few or many depending on how the former work – the software represents some of the languages a designer must be fluent in to practice successfully.

A downside of ever-more-intuitive availability of digital visualization is that students spend less time drawing and learning to draw in order to address the complete design process. Lack of time spent drawing in design school translates into reduced design-drawing skill sets.
1.3 Practice vs. Education

1.3.1 Schism between Education and Practice

Schisms exist within the profession between designers and educators over a variety of issues pertaining to and preparation for the practice of design. (Amit, 2010) The nature of these issues relates to aspects of the profession that both define and detract from its identity within business, society and culture:

- Industrial Designers provide so many services to the product development process that their identified purpose within the business community may be diluted. As Buchanan intoned, the ability to apply the Design Process to ever-expanding technical and scientific issues makes designers appear capable in many areas but not necessarily masters of any one discipline. (Buchanan, 1992) Education, in an effort to keep pace with industry demands, includes a variety of digital design courses that have supplanted some of the traditional courses such as Engineering Graphics, photography, drawing, and design visualization (product rendering by hand). Traditional drawing skills, however, are still required but receive less attention than before. The result is that the uses of each medium, drawing and computer, are viewed as separate and divisive and not supportive of each other.

- Education and the profession have been at odds for decades over priorities in preparing future designers. (Brett, 1986; Coutts&Dougall, 2005) This
- may be a result of the relatively short development cycles of the typical design school curriculum or the conflicting natures of education and practice in general (e.g., engineering, nursing, humanities, law, business.) (Edmond, 2000; Harmer, 2001; Jacobs, 2008) Issues in nursing education/practice parallel those in design: expanding knowledge bases, fluency in technology, and clinical practice-based education are now all expected before a graduate is ready for hire. (Budgen & Gamroth, 2008)

- Lack of usable skills found in graduating students. (Amit, 2010; Oliver, 2007) Each school may teach a unique version of the Design Process based on its department standards and strengths of the instructors. The range of student skill sets upon graduation may be so over-extended and inconsistent that a design manager may need to interpolate potential versus verified skill in a portfolio.

These challenges between education and practice speak to an expanding dilution of deep skill sets in design graduate portfolios. **Is it possible they are being asked to become practicing experts in too many areas in the same way that the design industry is expected to expertly offer more diverse capabilities?** It may be myopic to simply think students aren’t as good as they used to be or that the current generation doesn’t work hard enough.
1.3.2 Lack of usable skills in graduating students

During the 14 years I spent at a Columbus, Ohio–based consultancy as a junior, senior, and director-level designer, I observed the shift in processes for design and business, the shift in skills required to succeed in the profession, and the quality of students graduating from design schools around the country. Students and schools may be faced with the challenge of learning good design skills, design process, and the digital software expertise that design firms expect. The correct proportion of visual literacy, drawing, and computer skills is difficult to quantify and appears to be interpreted differently by schools, design instructors, design students, and design firms seeking to hire entry-level designers into the profession. It is clear, however, from my point of view that basic design drawing skills have declined in favor of digital visualization. Whether this shift in educational focus is perceived by the average student is unknown.

A senior designer in the industry complains regularly about the lack of drawing skills in graduating students, “They simply cannot express themselves,” he has declared. The challenge he faces is hiring a student as a junior designer hoping, but not expecting, that the young designer will develop his/her drawing skills on the job. It can prove to be an expensive investment if the skills do not advance to an acceptable level.

Visualization skills are one perennially contentious issue found in the graduation of students from education to the profession. Drawing and computer modeling/rendering
skills are both needed in the design process but drawing skills appear to be the most lacking in the typical student. (Gray, 1979; Garner, 1990; Oliver, 2007) It’s been said that drawing is THE ‘language’ of design (Tipping, 1985; Garner, 1988) but, in reality, there are many languages of design communication, as well as dialects, if one considers the numerous software systems used in the process.

Considering how integrated digital modeling and visualization have become in the design process, one may wonder how drawing is still used at different stages throughout a program. (Schenk, 2005) Considerable research has shown how central the act of drawing can be to any process of creativity, design, engineering, collaboration, social interaction and even development of human cognition. The value of drawing in Industrial Design will be discussed at length in Chapter 2. The design industry expects education to keep pace with the needs of practice but often does not appear to understand the phenomenon of learning in the 4-year design student development cycle. Gadi Amit’s diatribe (“American Design Schools are a Mess, and Produce Weak Graduates”, 2010) against the US educational system makes valid points about lack of consistency in design process and drawing/thinking abilities in design graduates but does not acknowledge challenges in evolving curriculum demands.

An end goal of the thesis will be to examine a system of integration of processes in design education that uses each to inform and build upon the other symbiotically instead of divisively.
1.4 Trends

1.4.1 Technology and changing nature of design visualization

Both business and design have driven the need for and uses of technology in the design process. Traditional design control drawings specifying dimensions, shape, form, materials, manufacturing and other details would be completed by hand on paper 20 years ago. These would be transferred to an engineer who would translate the specifications to engineering part drawings or Computer Aided Manufacturing files for mold-making (AKA ‘tool’ in industry parlance). The risk at this juncture was that the engineering responsibilities for manufacturing and function could override design aesthetics, function, or other value as originally conceived by the designer. Designers effectively lost control of the final design and might often receive finished parts from manufacturing that were significantly different from the original intent.

With the introduction of Computer Aided Design (CAD) software (e.g., ProEngineer, Unigraphics, Solidworks) the designer could develop the design in a medium native to engineering. Design and engineering now spoke a similar language of product development where each group could work on the same electronic file. Development times shortened and Design had more control over the final product.

As CAD became more intuitive, software manufacturers added rendering and animation capabilities to both the native (original) software or other software that could integrate easily to the former. Computer Aided Manufacturing (CAM) software could
accept CAD files from the design or engineering team and quickly translate designs to finished models with high levels of accuracy with Computer Numeric Controlled (CNC) milling machines, Stereo Lithography (SLA), or 3D Printing. A design concept could now be rendered, animated, and constructed to look like the actual product in days or weeks compared to months.

Business has embraced these advances to shorten product line lead times and reduce development costs. As a result of these advances in design tool technology, the client and average consumer has learned to expect computer renderings that look more convincing than the real product and prices for design and services that are lower than the past. Design drawings alone no longer have the cache to excite business or the layperson.

1.4.2 Technology and education

Design Education also understands the value of advanced technology: for any institution to maintain current relevance and enrollment it must offer technology used in the industry to the students also used by future employers.

Conversely, traditional visualization curriculum (drawing/drafting/model building) is given less emphasis due to the high demand for digital media. Complete engineering graphics and drafting courses have been reduced or eliminated since the CAD programs can provide complete design draftings automatically. The final design occurs
much faster without the use of traditional skill sets.

1.4.3 State of Design Discipline

1.4.3.1 Digital vs. Hand Skills; Education vs. Practice

With the current state of technology in both education and practice it is not surprising that much of what students and practitioners provide as deliverables is electronic in origin. Presentations on paper may be graphic reproductions of drawings completed on tablets, graphic layouts assembled in Illustrator or Photoshop, and images of designs developed in CAD and presented in short animations. Models can be accurately machine so that the only finishing needed is sanding a paint with some assembly for articulating parts. Overall, however, the hand skills once learned to build a model from scratch or draw designs only on paper are beginning to fade. The understanding of craftsmanship is fading because digital software offers easy access to Undo/Delete functions in the development process so final output is artificially high. Reviewing a student portfolio of both digital output and un-doctored drawings on paper can reveal dramatic differences in craftsmanship between the two.

1.4.3.2 Reduced drawing skills negatively affect the students’ ability to solve problems and think in three dimensions.

Research has indicated that not only are design students’ drawing skills given less time to develop in school but that their abilities to think and visualize three-dimensionally
and to learn 3D software are being impaired. Alias et al (2002) found in a study of both architectural and engineering students a definitive correlation between drawing and spatial visualization abilities. Ulman et al (1990) found direct correlation between mechanical engineers using drawing in their thought process and higher levels of problems solving, more complete communication with other engineers, and faster design resolution. McLaren (2007) found in her interviews with engineering students and professors positive correlation between mechanical drafting (compared to using CAD alone) and problem solving, visualization, accuracy, and aesthetic design ability.

It seems clear that one of the challenges in education is and will be to satisfy the demands of the industry to use the most sophisticated technology available while taking full advantage of the practical, cognitive, aesthetic, and solution-oriented potential of drawing as a core feature of the design process. Professional designers continue to call for graduating students with a more complete set of skills. Education develops curriculum and technology integration as possible with limited budgets and development cycles. To date, however, no research indicates drawing and digital pedagogy working together to enhance the learning process of the other. They are still seen as separate design skills.
1.5 Problem Statement – Research Question

As the skills needed for Industrial Design become more diverse, how may steps in the design process be sequenced and integrated into drawing pedagogy for more engaged learning and a more thorough understanding of visualization skills in Design education.

1.6 What this thesis is trying to accomplish

1.6.1 Examine value of drawing in the design process

Chapter 2 will focus on the value of Drawing in the design processes used in a number of creative fields in addition to Industrial Design. Extensive research has shown a high value of drawing in art, architecture, engineering, and visual communication. Practitioners extol its value and seek out the best capabilities in the next generation of creative talent. An ongoing challenge all design fields face is how professional-level drawing skills can be promoted, generated, and continued in Education while being overshadowed by the powerful use and need of computer technology in virtually every aspect of the design process. A curious phenomenon has existed in design since the advent of digital media: the speed, versatility, and dazzling visual results of computer technology have an intoxicating effect on even the most experienced design professionals. They must be able to objectively evaluate the quality of a design without being swayed by the visual power of digital media. Conversely, simple drawings (‘napkin sketches’) or crude mockups may offer high levels of thought process and
solutions in decidedly ‘unsexy’ presentation. Appreciating the value of drawing is not a simple process: it requires innate and learned design skill, as well as intellect, to preview the full potential of one of the simplest but most enduring modes of narrative in society and culture.

1.6.2 Examine four major design skills and their individual contribution to the process

The Design Process encompasses a considered approach to examining issues facing the end user of a system or product and developing creative solutions using a systematic methodology used and adapted by most designers. Ostensibly, the system incorporates a series of tasks using specific skills or capabilities to research, examine, dissect, analyze, conceptualize, and synthesize innovative ideas and products. Four skills in particular are discussed here not just for their contribution to the process but also for their potential to be used in a specific, ordered configuration to devise a novel approach to drawing pedagogy.

Initially, these skills (Model building, Photography, Computer Modeling, and Trace drawing) will be discussed for their individual contributions. Later, in Chapter 3, they will be discussed in aggregate significance in context of the Research Design. Each of these four procedures represents essential elements to the Research Design component of this thesis. They perform important roles in generating and gathering information
used in the learning process of the Integrated Visualization System discussed in
Chapter 3 and 4.

1.6.2.1 Model building –
Industrial Design is primarily an endeavor in developing three-dimensional artifacts for
culture and society. The discipline also encompasses efforts to improve or develop
interface, interaction, and even theoretical systems. Each of the results benefits from a
tangible, touchable example of the initial or final design.
Physical models serve different purposes:

- Any level of design definition from an initial sketch mock up (made from soft,
easy-to-work-by-hand materials) to a finished presentation model (constructed
from manufacturing materials and finished to look real) all help to illustrate a
physical manifestation of an idea/concept for the benefit of the client,
development group or end user/demographic group. In each of these
permutations the design allows the observer/user to explore the appropriateness
of the interface, form, ergonomics, and intended interaction (Burr&Andreasen,
1989)

- Models also serve as a ‘meta-language’ to improve communication between
design team members. Often members of a design team represent very different
backgrounds (e.g., engineering, marketing, sales, and design) with different
perceptions of what design means and what to expect from the deliverables.
- Each representative may have varying levels of graphic literacy so that drawings or 2D visualizations of the concept(s) may not be fully understandable. A full-sized model of the actual design helps each party to understand the idea and communicate his or her interpretation with less ambiguity. (Burr & Andreasen, 1989)

- Design problems or other issues may not be fully understood until a model is constructed providing both answers and new questions. Sometimes, regardless of the quality and level of detail a drawing or other visual provides to the design team, subtle but significant concerns such as form, size, fit, ergonomics, and interface cannot be reconciled until a solid model is presented. (Brandt, 2007)

In order to teach students how to visualize reality, they need a sample or benchmark of that reality in three dimensions to gather data about shape, form, light, and perspective. Models help the designer to continue the visualization and design processes with this objective data while providing validation or proof-of-concept to the client or user group.

### 1.6.2.2 Photography –

In Industrial Design photography has been taught primarily as a means for documentation of research, ideas, concepts, and models. In spite of its own unique graphic design and art background and potential, photography is a tool for gathering accurate and complete visual data for the observer. Learning to see with visual accuracy, however, is a challenge due to the physiological nature of the human optical
system. (Collier & Collier, 1986) Even as designers know they are skilled at observing and remembering details to make informed design decisions, it is important to understand how human optical system processes information before storing it as visual images. The eye functions differently than a camera. (Bruce et al, 2003) Understanding this difference is why photography is essential as one of the four steps in the Integrated Visualization System.

That part of our ‘central vision’ measures only 0.5 to 2.0 degrees of arc diameter, about 25mm at arm’s length from the eye. (Duchowski, 2007, 33) Outside of that central view, the retina provides mostly peripheral processing. The central vision is most capable at discerning detail and contrast (we read with our foveal vision). The peripheral vision is capable at discerning movement, shadow and color. (Bruce et al, 2003) A culturally recognized result of this visual system is the ongoing debate over the facial/mouth expression of Leonardo Da Vinci’s *Mona Lisa*. If we view the details of the mouth with our central vision we do not see a smile. The rendered shading around the mouth, however, when viewed peripherally looks convincingly like a subtle smile. This distinction will become important later in understanding the information generated in the steps of the Integrated Visualization System.

1.6.2.3 Computer visualization –

The advent of CAD software allowed the design to develop the surfaces and parts of a design very accurately and minimize or eliminate any interpretation by the engineer
once those files were given to the latter for engineering. A significant bonus is that the same file may now be used at the same time for any high-resolution computer rendering, illuminated and placed in a use context to look real and already manufactured. Computer Aided Design supports design evaluation (Tovey, 1989) and aesthetic development with the ability to make small iterative changes quickly. The power to visualize perspective environments and make small changes to a composition are traits that ostensibly help designers refine design for production but also provide a visual composition potential for generating custom perspective grids for drawing.

While CAD is not ideal for generating initial concepts quickly, the complex and measured system it provides for developing design also provides a power to generate backgrounds for drawing that require many hours to do so by hand without the ability to change focal length and composition quickly. The unique capabilities of the computer will be utilized in the context of the research portion of this thesis to provide a learning tool for individual designers and the perspective drawing and visualization portion of their design education.

1.6.2.4 Design Drawing

One of the skills Industrial Designers offer in practice and develop in training is Visual Literacy: the ability to see image-based information, to process it cognitively to comprehension, and the skill to communicate it to others through drawing and modeling. (Anderson, 2002; Ulman et al, 1990; Newcomer et al, 1999) Visual literacy
is an essential attribute of the ability to draw. Drawing and visual arts historically represent disciplines significant in training visual literacy through the act of *doing*. (Flood et al, 2004) Drawing and visual literacy ideally maintain a symbiotic relationship: Draw to learn visual literacy and improve visual literacy to improve drawing skills – both require active participation. Active participation in creating is a first step in the ability to perceive, understand, process, and synthesize images. The current generation of student’s orientation towards computers and software and less experience with drawing and three dimensional form construction results in more difficulty perceiving and understanding form. (McGown et al, 1998)

Unfortunately, visual perception and communication are not simple skills to acquire. Successful visual concepts are built upon the experience of the designer. Understanding is based on knowledge and experience acquired through life. (Arnheim, 1954) Learning about rules and context, rote memorization, is not the most successful way of building the ability to apply knowledge since that knowledge may be abstract in nature. Doing, in context, makes the concepts and rules meaningful to that person. (Schank et al, 1996)

Eric Anderson’s research in drawing studies using perspective grids was more effective than traditional arts approaches for teaching drawing to engineers and non-design professionals. Data showed positive results in increases in confidence, cognitive understanding of form and visual literacy. (Anderson, 1997)
1.6.3 Develop an integrated, sequenced system of visualization utilizing the four major design skills symbiotically

As discussed earlier, Industrial Design students face and increasing number of specialized skill requirements for viability as professionals. No longer do drawing and model building represent the base skills of a design process. Computers and software with the latter’s multiple languages and dialects have, for better and worse, been integrated into the design process and curriculum. The results have been mixed: while understanding of digital media in education has grown drawing skills in graduating students have not improved in the aggregate. There may be two or more reasons for this phenomenon:

1. There are too many skills to learn in the four-year development cycle so that the overall and individual skill sets become diluted and less effective.

1. Cognitive overload may be occurring preventing students/designers from maintaining focus on any one task or endeavor.

In laypersons’ terms, cognitive overload can occur when Multitasking – attempting to do more than one task at the same time. Multitasking, while making one feel productive, is cognitively inefficient. Reduction of efficiency by up to 40% can occur when mental blocks are created in the task-switching process. (Rubenstein et al, 2001)

There are two ways in which cognitive overload may be mitigated or solved:

1. Devise tasks so that actions serve in an epistemic fashion – relating to self-validation. An example would be changing the orientation of an image to aid in
understanding such as: turn a random page of text right side up to enable reading the text.

2 – Devise tasks to serve each other in complementary function. An example would be when young children count faces in a crowd, they point with their finger and count out loud. Used together, these actions reduce the error rate that might occur if counting without using the finger or talking out loud. Both of these actions may aid in reducing the cognitive efforts resulting from attempting to complete a task quickly and with minimal error rate. (Kirsh, 2000)

The Integrated Visualization System has been designed to take advantage of the individual strengths of each process skill while using all in a sequenced and integrated configuration to reduce cognitive overload and concentrate the acquisition of design drawing skills.

Step 1 – Build physical models of the forms one is designing concepts for. These may be simple geometric solids or dimensioned mockups of a particular product. Using simple modeling materials such as paper or soft foam offers low-cost but fast modeling media. Modeling by hand versus machine teaches good craftsmanship, an essential feature of good design. Monochromatic finishes focuses attention on form and light without the distraction of color.

Step 2 – Photograph the model(s) in a monochromatic background with a single light source. Gathering images of perspective, light, shading, and cast shadows provides the designer with objective reference data for drawing visualization or computer rendering.
Step 3 – Model in CAD the basic shape and dimensions. Repeat the same screen view orientation of the form as in the photographs. Print out these views on paper. Although any 3D modeling software may be used for this step, Trimble SketchUp is a free download and very intuitive to learn. An essential feature of SketchUp is that strong cast shadows may be generated providing outlines for Step 4. Hidden lines in the forms may also be generated removing any guesswork about how to ‘draw through’ the perspective drawing.

Step 4 – Using the printed views of the forms generate in Step 3 as underlays, trace the same exact lines in the underlays on fresh paper and indicate perspective, shading and cast shadows. The perspective views generated in the computer can be adjusted to reduce distortion, probably the single most important factor in correct perspective drawing.

These four steps represent four of the most important skills in the basic design process. They should be done in this order, sequentially. Following the end of Step 4, the designer can make changes to the models and repeat the process. Each step provides information for the next step to continue, informed, reducing the guesswork that is part of the creative visualization process.

A critical feature of this system is that students, designers may use the system to help teach themselves about correct observation and correct design drawing. Traditionally, designers might rely on a ‘fresh set of eyes’ of another designer to tell them if their
drawing was in correct perspective. The Integrated Visualization System takes advantage of the power of the computer to calculate the correct perspective automatically. Brooks&Brooks (1993) reveal findings on knowledge retention rates that traditional methods of classroom teaching offer only 5% retention (lecture) to 75% retention (doing/practicing). If one teaches the subject, however, knowledge retention soars to 90%. Providing students with a system where they can teach themselves by creating their own reciprocating knowledge base may make a significant difference in the design drawing skill acquisition rate.

Natascha Radclyffe-Thomas (2008) argues that Information and Computer Technology (ICT) has been introduced so quickly into the art and design school curriculum that both students and teachers have yet not realized or understood how best to integrate digital media and technology into traditional curricula. In fact, she argues that it is less necessary that instructors learn the technology at the same level of their tech-savvy students and more important that the former design ways to integrate the new media into traditional pedagogy. The Integrated Visualization System is a concept for doing just that: bringing the ever-improving potential of computer technology into traditional drawing pedagogy.

1.6.4 An Accelerated Pedagogy for teaching design

An end goal of the system is to provide a modular syllabus that may be integrated into
other design schools, disciplines or professions to enhance and accelerate the learning process. A sound pedagogy for learning design skills should deliver a nominal rate of learning for an average student. Research indicates that many schools are not successfully delivering the learned level of design abilities needed for effective professional practice. It would be naïve and short-sighted to simply blame the instructors or students for not working diligently towards this goal. John Watson (1913), a noted psychologist, characterized learning as a ‘change in behavior’. Watson claimed learning any skill is possible with the right behavioral modifications. (Watson, 1930, 82) Design, however, is not a linear process but instead requires exploration both cognitively and in basic design skills to effectively learn both. By a definition of behavioral modification or conditioned response as Watson demonstrated in his research, however, asking the students to explore may result in inconsistent learning rates due to variations in the cognitive or manual practices they use in the process of exploration.

If a pedagogical system can be devised to make the exploration faster, more efficient and more effective, it may represent an **accelerated pedagogy**. The behavioral modifications needed to learn the discipline are configured to reduce time wasted and motions reinforcing non-productive behaviors. Theoretically, if a student is provided with a learning system for design that teaches skills in a linear methodology without negatively effecting non-linear creative exploration and problem solving, then the student’s learning rate may be accelerated within a set time period. Further, if such a
system provides a way for and requires the student to assess their work on a regular procedural basis, the instructor’s effectiveness is increased proportionately by providing the student with a method for teaching themselves when the former is not present. This procedural methodology represents the logic behind the **Integrated Visualization System**.

### 1.6.5 Prototype and test the system in an existing design drawing curriculum

An optimal method for testing this prototype is to gain access to a design drawing course with more than two years of curriculum exposure in order to sample prior years’ work as control data for comparing to test data. Professor Scott Shim, at The Ohio State University, proposed integrating the IVS prototype into the syllabus of the 2012 Design 501 – Design Drawing course he teaches to the Sophomore Industrial Design class. The four steps outlined in Section 1.12.3 were integrated into the first half of the school session in order to use course projects generated in the second half as test data to compare to the same projects from the 2011 Design 501 class work.

### 1.6.6 Analyze, evaluate, and assess data generated by study

Data was generated and gathered from both the 2011 and 2012 Design 501 design drawing class work. Corollary data will be examined and analyzed in Chapter 4 of this thesis.
1.6.7 Conclusions

Analysis of the data will show a positive corollary to the Hypothesis and Prediction.

1.6.8 Significance - Education and Practice

The Significance of the findings from the data analysis will offer a wide-ranging potential for Education, Educators, Students, the Design Profession, and related disciplines and businesses that seek innovative methods for improving visual literacy and visual communication in addition to the primary audiences for drawing skills.
Chapter 2: Background – The Role of Drawing in the Creative Process

Drawing is a phenomenon found in many aspects of our lives and culture. The average person may sketch doodles in a notebook during a class or meeting without imparting much thought to the symbols. Artists rely on drawing and painting to express their intent and ideas. Children use drawing as a communication and socialization tool interchangeably with words, singing, physical movement and whatever interactive materials they have access to. (Coates & Coates, 2006) Paintings in the caves in Lascaux, France date from nearly 18,000 years ago depicting both people and animals. At first thought simply to be artistic documentation of events at the time, archaeologists later discovered ritualistic links to hunting and fertility. (Capelo, 2010) As a narrative function drawing represents one of the most ancient of human artifacts. (Lloyd, 2000) Children use drawing to not just as a communication tool but also as a methodology for understanding their environment. (Matthews, 1984) Given this range of social and historic needs and uses for drawing it is little wonder that this act is central to our cognitive and creative processes.
2.1 Drawing in the Design Process

A unique skill designers develop over time and through practice is the ability to explore ideas, concepts, forms, and systems in a novel way. (Garner, 1990) Although it might be considered easy to the layperson to come up with a good idea, generating a new idea, not thought of before, is in fact very difficult. We generally express the same things again and again whether in speech, thought, writing, or drawing – as creatures of habit, it’s easy and comfortable for us. Drawing with fluency allows the designer the ability to generate thoughts and record them without needing to think about the actual drawing process. Once an idea is set on paper it can be explored in different configurations with different details. If the drawing arrives differently that the original thought it can be fortuitous for the designer’s reflection to have discovered something unintended. The lack of definitive precision in an exploratory sketch is a key factor to a serendipitous idea – something that no one has seen before.

Designers are faced with the task generating new ideas with possibly only one offering an appropriate solution for the problem as presented. The many constraints of a design brief usually cull out most of the concepts generated in a creative session. Like any language vocabulary, the ideas, or words, we access in the thought process of exploring potential ideas come from both long- and short-term memory. We may have had a prior experience that realized solutions similar to the current project’s needs, which may be downloaded to paper for later critical analysis and reflection by us or others in the design process. Drawing acts as a recording tool that allows us to move
onto other considerations and frees the short-term memory from overload by trying to remember too many ideas at once. Goldschmidt surmises that in observations of architects and engineers drawing represents the most efficient and functional way of accessing the long-term memory of the designer. (Goldschmidt, 1992; Purcell & Gero, 1998) In effect fluent drawing skills allow the designer to generate many ideas without losing track of individual ones which could occur if a focused cognitive effort was needed just to think about how to draw the image the designer has in his/her mind.

We often think of drawing associated with visualizing specific objects or scenarios. In fact, this is true for much of Industrial Design. There are often, however, many instances where what we design is more abstract. Instructions, flow charts, traffic patterns all represent systems that must be explored, often in teams or groups of people. Software design, protocol and systems analysis also represent abstract concepts where the solution is not a visible product to be touched or seen. (Eckart et al, 2004) The ability to visualize through drawing represents an advantage not just to document a concept for a wiring diagram but to conceive of the abstraction to start. A good designer can see both the image of a pattern in his/her mind as well as the movement, shifting, rotating or reconfiguration of that pattern before it is translated to paper.

2.2 Drawing as a tool for creativity
The power and nuances of drawings in the design process are often lost even on those who generate them or the person who facilitates a design presentation or development
group. Initially, one may interpret one drawing as the equivalent of one idea. In reality, however, the collaborative process that sometimes occur in a program encourages one or more other members of the group to interpret one idea in very different ways. This may not be advantageous if the interpretation is the opposite of the designer’s intent. (This phenomenon may occur when the drawing is not fluent enough to be understandable.) If, however, a level of ambiguity is expertly included in a drawing, the ‘guessing’ that occurs for the client or design group may actually generate more and better ideas by inspiring new interpretations. (Do & Gross, 1996) One drawing may inspire an entire design team to see more than was ever intended by the original designer.

Multiple interpretations also catalyze further collaboration between team members. A designer’s most important skill at times may be the ability to facilitate collaboration between different disciplines through drawing ability. A fluent drawing skill in a meeting will gather most people’s attention. One of the many advantages drawing has over computers is this provisional quality – some element that is never quite finished and allows people to generate their own interpretation. (Eckart et al, 2004)

“A sketch is a reflection of the guiding mental image; but it is not, and cannot be, identical with it, and this difference is precisely what makes it a precious instrument for the designer.” (Arnheim, 1993, p.17) Arnheim argues that examining the tasks required in the problem solving aspect of design initiates a mental model of the goal image or
solution. The drawing that results from this effort reflects an optical memory that may relate to a solution but is not the same. The optical memory reflects things that we know; the mental model, seeking an original solution to an abstract question, will, by its nature be ill defined. The dramatic tension inherent in the relationship between the abstract question and well-defined visual memory/drawing is the key ingredient to a continuous flow of creative, original ideas. Furthermore, the designer can never fully understand his/her design process because the activity of the mind can never be fully observed while in process. The drawings, however, represent moment-in-time partial documentation of how the mind is working. The more fluency in the drawings the better reflection of the optical solutions the mind is creating. Once the initial sketch is on paper, the lack of perfect definition motivates the mind to continue the mental-model search for design refinement.

Drawing is not the same thing as the product or idea it is attempting to solve or discover. One of its most critical attributes is the offering as a means to exploration and manipulation (Garner, 1990) A Drawing provides a function and central purpose within a creative endeavor while leaving a legacy of its own inherent aesthetic following the process. Sometimes the most memorable artifact from a design process is not the final product in manufacturing and distribution but a drawing left over contributing a more interesting vision or potential than the solution itself.

"I prefer the sketch quality, the tentativeness, the messiness, the appearance of in-progress rather than the assumption of total resolution and finality.."
(Frank Gehry. Pollack, 2006)
Sidney Pollack’s film about Frank Gehry, “Sketches of Frank Gehry”, composed an in-depth exploration of the architect’s design process. While he has assistants to provide CAD support and implementation, Gehry’s two primary objectives from the brief are to 1) generate a solution and 2) imbue the solution with the loose, “sketch-quality” aesthetic of his working drawings. He attempts to integrate the organic ‘lack of definition’ (Arnheim, 1993) nature of his drawings into the hard definition innate to most architecture.

2.3 Drawing for Idea Generation

One of the duties of a designer and expectations from the client is to generate ideas, lots of them. Even though only one idea goes to production, the act of generating many ideas is needed to finalize one concept that is original. Changing the appearance or function of a design means that the interaction of that change with the rest of the system sub-systems must also change. Each of these changes requires a creative solution. Arriving at that creative solution is not a linear process – if it was, all problems would be simple to resolve like an arithmetic equation. Drawing proves to be a particularly useful method for developing ideas. Discussion in 2.1 revealed that the process of drawing to solve problems, by its nature, is repetitive. (Garner, 1990) The regular differences between the mental and optical models Arnheim (1993) introduced almost guarantees that the sketch will never be the same solution as the mental model resulting in a “carrot before the horse” syndrome of the designer never quite reaching
the end goal. The product of this process is many drawings and many ideas. Remko van der Lugt (2005) studied the effectiveness of concept generation the three different groups of experienced product designers:

1 – Designers drawing individually
2 – Designers drawing collaboratively
3 – Designers writing/talking/drawing collaboratively

His results showed that the first two groups were effective in idea generation. The second group, with designers working together, was particularly effective because each designer, following the first individual design effort alone, was able to stimulate a higher rate of ideas by using other designers drawings as inspiration for new concepts. The third group, utilizing brainstorming techniques of discussions, diagrams and post-it notes generated fewer than half the number of ideas than the second group. While group meetings for development teams are a necessary part of the design process for consensual understanding, the method for idea generation needs careful facilitation for maximum productivity. Conclusively, however, it appears that allowing drawings to ‘do the talking’ is most advantageous for creating many concepts.

2.4 Drawing for Problem Solving

One of the most critical elements of a design process is solving problems. An initial thought of this conundrum may be related to functional issues or articulating parts – an engineering specialty. Problems, however, can be related to all aspects of human
creative endeavor. Artists must first solve the problem of how to best express themselves whether the solution is a specific medium or setting or if what they are trying to express must be reconfigured for better understanding. Automotive designers are faced with aesthetic problems every day and must create an appearance solution that no one has seen before. Industrial designers must address ergonomic, color, functional, material and manufacturing issues regularly. The strength and depth of the design process allows the designer to contract with a product manufacturer on a topic the former has no prior knowledge of and still generated excellent solutions.

Goldschmidt (1992) studied architectural design processes and found a common denominator through all: ‘serial’ sketching. The definition is repetitive, iterative generation of original categories and refinements of ideas. Each successive sketch is a refinement of the idea before; each refinement offers a new visual to reflect on, obtain feedback from and make incremental changes towards one or several solutions. It represents a systematic process of progressing from an initial state of unknown to an eventual problem solution. The results are a paper record of human information processing. (Goldschmidt, 1992) Revolutionary changes are not as important as repeated drawings with small changes. Although sudden, serendipitous insight can and does occur, it cannot be depended on. Serial sketching offers a more methodical yet successful approach to problem solving.

Another feature of sketching ideal to problem solving relates to the interaction a designer has with his drawings. Following completion of a drawing, a designer may
review the drawing later and see aspects to the composition, marks, or configuration that were unintended when first done. The cognitive process that generates creativity is not the same as that facilitating analysis. (Suwa et al, 1999; Davies & Talbot, 1987) Even though a designer will review his/her drawing during the visualization process to determine if the effect of the details and whole is as desired, changing the thinking from creation to analysis slows or stops the idea generation rate. This is often why design development groups will present a series of concepts to a client, after which the latter will offer a very creative insight: the mindset of one needs the other for maximum creativity. Introduction of new design issues during the process may also help to ‘stir the pot’ and gain insight from new requirements influencing the potential of older ideas. (Suwa et al, 1999)
Chapter 3: System Design

3.1 Design of the Integrated Visualization System (IVS)

3.1.1 Four design skills configured to inform and build on each other sequentially

The research study is predicated on testing a prototype developed primarily for design-drawing curriculum in Industrial Design Education. Based on the preliminary research done for this thesis, a novel approach was designed to increase rates of design-drawing skill-acquisition during visualization courses for students in the Industrial Design major at The Ohio State University. Specifically, the proposed approach integrates areas of the major’s curriculum traditionally separated as different skill-sets. From research, Brooks and Brooks (1993) suggested that the most effective way to learn a subject is to teach it. In studies, 90% memory retention of a subject has been documented through teaching compared to 30% retention from observation of a demonstration and 75% retention by doing. Taken literally, this paradigm can inform the student that the most effective learning strategy may be through alternatively teaching themselves a skill and doing a task requiring the same skill, fundamentally increasing the rate and effectiveness of the teaching/learning process. This concept for accelerated pedagogy, from 1.6.4, requiring an active participation by the student in constructing their knowledge base and teaching themselves, integrates four skills from
the design process in a **functional sequence** to inform and improve design-drawing skills:

1. **Physical model-building** – creates a physical model to touch, compose and photograph for perspective and lighting documentation

2. **Photography** – documents perspective and lighting as reference for Steps 3, 4

3. **Computer Visualization** – uses the lighting and perspective information from Step 2 to guide the composition of the computer model and lighting.

4. **Perspective** drawing using gridded underlays to **trace** over. Uses information and underlays generated in Steps 2 and 3 to guide sketching and rendering.

If followed carefully, each step creates a database of tactile, visual, and cognitive information that provides a foundation for the following step to build on.

As documented in **Figures 3.1.2a – d** – Model/Photograph/Computer/Trace – The visual guide to the procedural steps in the IVS represent the **first assignment** given to the students. They are required to build, document, computer model, and draw the four geometric solids to begin the process of using the system for more complex design projects. Additional assignments are suggested in 3.1.3 Other Sequential Assignments, to take advantage of the knowledge potential from the physical models build before moving onto more complex surfaces. Traditional Industrial Design curriculum from 20 years ago demanded multiple projects with these simple forms for a strong foundation in design drawing.
3.1.2 A visual guide to the procedural steps in the IVS

Step 1 – Model - Build models from simple materials

Reasons, benefits for building the models:

The primary reason for building models of the objects to be drawn is to prepare physical surfaces for photographic documentation. A complete understanding of the appearance of a solid object in light, context and perspective can only occur in a real three-dimensional environment - reality. As it has been documented, drawings and images can be distorted or give incorrect information depending on how it is visualized. The models also provide the physical means to change a composition much faster than a drawing or computer rendering – a time-saver for design exploration. Often a designer will cycle from drawings to models and back to ideation because of the information models provide that are not cognitively available to draw. Drawing circles on a cube, for example, gives the designer a tool to turn in space to understand the mechanism for a circle becoming an ellipse when viewed obliquely.

Design students learn model building as a way to express their ideas to themselves as well as others. Models represent a common language (i.e., the real, three-dimensional object that is easier for someone to understand than a drawing) for everyone in a design development team and so minimizing confusion that might result with an image of an
idea. (Burr and Andreasen, 1989) Models also represent a final decision in appearance since 2d images may be manipulated to look better than reality. Regardless of the level of finish, models aid the designer in understanding form and dimensions in space and improved visual literacy through interaction (Flood et al, 2004). Constructing models also teach very important skills in the design process: measuring, cutting, forming, and finishing. The ability to do these process steps repeatedly in different media for different kinds of design help the student to develop his/her level of craftsmanship, a key trait of good designers.

In the design-of-a-product process, physical models are required to validate design decisions. If a concept is not functionally and ergonomically validated, moving to manufacturing and tooling commitment would be prohibitively expensive in this last step of implementation.

**Step 1 – Model**

**Directions** for model building:

**Sphere** –

1 - Purchase a white, smooth ball from a sporting goods store - about 2.5” - 3” in dia. Build the three other solids to this dimension.

**Cube** –

1 - Draft the six sides of a cube, unfolded, on a piece of white paper or Bristol board.

    Each edge of each square side must be outlined.

2 - Each square side will be connected by at least one edge to another side (see Fig.
3.1). The resulting drawing will look like a cross.

3  - Cut off the paper outside the boundaries of the cross.

4  – Fold all sides inward at each border. Each fold must be crisp and bent 90 degrees

5  – Use transparent tape to temporarily close edges together. White glue works best for finished assembly. All edges should be flush.

**Cylinder** –

1 – Draft and cut two circles the same diameter (D) as the sphere

2 – Calculate the length of the cylinder side by multiplying 3.14 (Pi) x D.

3 – Draft and cut the rectangle representing the length and height of the cylinder side.

4 – Curl the ends of the rectangle and join the ends with tape or white glue.

5 – Attach the circles at both ends of the open tube. Make sure all edges are flush.

**Cone** –

1 – Draft two circles: a) D and b) 2.24D

2 – Draft a line bisecting the large circle.

3 – From the center of the large circle, draft a line 22 degrees off the bisect line.

4 – Cut the large circle in half at the bisect line. Moving carefully around the perimeter of half circle, curl the paper (22 degree line facing out) on the axis of the diameter to form a cone shape.

5 – Wrap the edge of the cone around the other edge with the 22 deg. and up to this line. Tape the cone shape and join the small circle to the bottom, edges flush.
1 MODEL

Build 4 paper geometric solids:

- cube
- cylinder
- cone
- sphere

Figure 3.1 – Step 1: Build the models from simple materials.
Step 2 - Photograph – Visually document the models.

Reasons, benefits for photographing the models:

The primary reason for photography at this stage of the system is to document the appearance of the design. This includes how it looks in perspective, indexed units of measurement in space in perspective, and how light and shadow show the surfaces’ true definition. Using a camera to store this visual information is also important because photography does this more accurately than human observation can (Collier and Collier, 1986) and our optical system is not designed to objectively record all details that we see (Bruce et al, 2004). Creating a visual record allows the designer to revisit that specific information to understand it better with repeated viewings. Photography is also as important to initial design research and intermediate processes as it is to documentation of the final product.

Photography also represents a fast way of composing a two dimensional image. Instead of taking the time to layout a drawing, one can view a scene through a camera and compose the image quickly and easily so the image can be quickly transferred to a paper underlay for a drawing. Going through this process also helps the designer learn about how light works – highlights, shading, core, shadows, reflections, and indirect light – all essential features to effective visualization of a product or concept. Learning about the nuances of light and composition are training for observation – how to see
things that the average person may not – another defining skill of a good designer. The information documented in the photography step informs the designer for later computer rendering where many software packages may enhance the visual by real data input instead of relying on default lighting settings.

Step 2 - Photograph

Directions for photography:

- Arrange the models in a square pattern on a level white surface
- Space the models separately distanced equal to their dimensions
- Illuminate with a single light source placed in line with the corner axis
- Elevate light 55 degrees off horizontal
- Establish 8 axis positions for the camera directly off corner and center axes
- Elevate camera 40 degrees off horizontal and shoot one image of each axis
- Maintain a focal length (distance) of about 1 meter

Figure 3.2 – Setup angles for photography
Figure 3.3 – Step 2: Photograph the models in composition from indexed views with a single light source.
Step 3 - Computer – Generate computer models.

Reasons, benefits for computer modeling:

In the IVS, generating a view of the design in the computer is a critical step in developing a custom perspective grid over which the designer can draw the designs knowing that the computer instantly generates a proportional grid system with minimal distortion. It eliminates the need for archaic, distorted and laborious layout systems developed originally for architecture and replaces them with system and an ability to compose a background with incremental adjustment. Trimble (formerly Google) SketchUp permits fast modeling, lighting and shading for almost any form. If the freeware cannot model a specific surface, the 3D Warehouse available to the designer usually has a sample build by other designer for free import and use.

Industrial Design requires computer modeling as a basic skill for all students. Repeated use of this system teaches an initial understanding of protocol, how a surface or image is constructed through systematic input of dimensional information from models or prior specifications from a client. SketchUp is a simple introduction to this design process that becomes very strict and regimented the closer to manufacturing implementation the design process moves. There are many side benefits for the designer: he/she must learn a visual language of engineering while discovering a
system similar to photography where one must compose a complex setting within a view. Math and geometry skills are needed to work successfully in this medium. Finally, and so important to the process of design, one must learn how to design surfaces in the computer, following the manual process of physical model building, for communication to other designers, engineers, and final implementation.

3 - Computer

**Directions** for digital modeling:

- Download *Trimble* Sketchup 8 (freeware, not Pro version)
- Begin with these Settings, from Menu Bar, to understand how each can make the process of preparing a clear underlay more effective
  - Template – Engineering (for setting black lines on a white background)
  - View – Check: Axes, Guides, Shadows (provides axes for perspective reference and snap-to guides on lines for simple dimensioning. Shadows turns on this function that provides a true cast shadow depending on the date and time.)
  - View – Edge Style – Check: Edges, Back Edges, Profile (allows the designer to see and trace *through* the drawing – the surfaces and edges in the back as well as the sides and front.)
  - View – Face Style – Check: Shaded with Texture (gives each surface a shaded value)
- Camera – Check: Perspective (for 2pt and 3pt perspective – ideal for product design)
- Window – Check: Shadows (brings up the pop-up menu for adjustments)

- Use web tips for questions how to build solids in the space:
  - File – 3D Warehouse – Get Models (a resource for any free surfaced model of anything you might want to download)

- Shadow Settings pop-up Menu:
  - Time: 2pm; Date: mid-August (a good time of year for shadows that don’t get too long – better for product design visualization)
  - Light – 52; Dark – 56 (settings for highlights, shading and shadows – not too dark and not too light – balanced)
  - Check: ‘Use Sun for Shading’ (best for light from above)

- Using SketchUp, construct and compose the geometric solids in the same orientation and focal length as the views from Step 2. Fill half of the page.

- Export the views to be printed on 8.5” x 11” paper, landscape format. The 8 views suggested are indexed views – every 45 degrees around the entire composition. This allows for full view of light and shadow on the composition from any view any view position.
3 COMPUTER

Model solids in Google SketchUp in the same composition as photo axes.

Select menu settings for best resolution.

Include shading and cast shadows. Print each axis view.

Figure 3.4 – Step 3: Computer model the objects in Trimble SketchUp for perspective underlays.
Step 4 – Trace – Trace Trimble axes views.

Reasons, benefits for tracing:

Eric Anderson, in his thesis research (1997), observed what many designers already know intuitively: drawing over an underlay with existing perspective permits a fast and simple way of iterative design drawing and learning perspective. Using subject sample groups from outside the design industry, Anderson documented faster rates of drawing skill acquisition and reduced frustration in learning. Tracing and designing at the same time requires the ability to interpolate: what are indexed distances between two or more points in perspective. Tracing, however, minimizes the need to understand and draw an entire perspective grid before hand.

By tracing and drawing the perspective of a known object in a variety of positions and compositions, the designer will soon learn intuitively the correct perspective image for that object regardless of orientation. Learning to draw in correct perspective occurs sooner because the designer ONLY draws over correct perspective instead of reinforcing incorrect drawings. The process works similarly for light: highlights, shading, and cast shadows may all be learned by copying instead of using obsolete layout drawing systems. This system requires a lower level of geometric expertise and thus represents a better potential learning tool for the average design student. Increased
visual literacy has been documented through drawing and the traditional arts (Flood & Lapp, 1998; Anderson, 2002). By providing a system of learning through copying, the IVS promotes drawing in a simpler, easier, more comfortable manner for people outside the discipline of design as well as within.

Finally, drawing by tracing helps make sketching and design visualizing more intuitive and therefore more productive - the designer is required to design and visualize at the same time. If the cognitive process of thinking about how to draw a concept is reduced, the designer will have proportionately more time to devote to design and less to design drawing.

**Step 4 – Trace**

**Directions** for drawing:

- Compose each view so that the objects fill about one half of the page. Print out each axis view from Trimble SketchUp.

- Use trace or bond copy paper to draw on. Black pen only.

- Line-only for value in first set of drawings, cool-grey markers for later drawings.

- Use light values from Step 2 for reference.

- Repetition is the key factor here as training the eye-hand-memory coordination happens only through regular practice.
4 TRACE

Assignment 01
Model in Google SketchUp

Prepare axes views and print

Trace over each axis view and add value - line only

Use photo reference for value

Figure 3.5 – Step 4: Trace/draw the objects using the printouts from Step 3 as underlays.
3.1.3 **Other Sequential Assignments** for the Integrated Visualization System

Other design assignments are recommended for the IVS in the design student’s early education. Each has a specific reason and offers benefits unique to the IVS design. Of course, the instructor and student are encouraged to integrate this system into other design assignments in order to maximize the skills learned from any design project as well as developing a sound design process for the portfolio. The assignments suggested here recommend using the geometric solids constructed for the first assignment.

Learning to accurately visualize and draw forms as simple as these may seem overly simple but doing so accurately is very difficult. If done correctly, the results will provide a broad understanding of form, critical for good design skills.

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**Assignment 02 - Dynamic Composition Using Line**

**Reasons, Benefits** for Assignment 02:

Assignment 02 requires the designer to compose the same objects from A01 in a configuration where the shadows of one solid fall on another. Observation and understanding of how shadows are cast and how they may be used to highlight and accentuate design surfaces is the primary objective of this assignment. The
contrast in value between light and dark are the single most effective way to make a design look real. Learning this concept early in a design education will help a student produce the most effective visualizations on paper or in the computer. Using line only to render these values is an essential skill for the junior designer.

**Assignment 03 - Model, Observe and Draw Complex**

**Surfaces**

**Reasons, Benefits** for Assignment 03:

Assignment 03 requires the student to model the form of a simple product, a hair dryer in this case, out of soft foam (expanded polystyrene), finish the surface smoothly with sandpaper, and paint with white for monochromatic photography. The directive of the design is to create an inflective complex surface (changes curvature from convex to concave), document two models of the same design in Step 2 of the IVS in different positions, build the complex surface in SketchUp, and complete the drawing requirements for Step 4, again, using line only. Most surfaces a designer will be building are complex and require an intimate understanding of how the surface looks, feels, and may be visualized.
Assignment 04 - Dynamic Composition Using Grey Markers

Reasons, Benefits for Assignment 04:

Assignment 04 is a similar exercise to 02 but incorporates grey markers for rendering surfaces. A new geometric solids composition is required so that the students will learn how to judge and visually index space and depth in perspective. The single-dimension solids provide the means to learn how units of measurement are multiplied or divided visually in space. With practice, grey markers are a highly effective tool for manually rendering the subtleties of light. This skill is required for generating large quantities of design concepts quickly, a standard procedure in most design processes.

3.1.4 Empowering students to self-initiate learning

Drawing represents a knowledge- and practice-based discipline that requires a majority of the latter. In order to practice correctly, however, the student needs access to a methodology providing regular and reliable prompting and feedback through the learning process. Traditional drawing and visualizing systems rely on subjective judgment by an instructor or antiquated perspective layout systems that cannot account
for distortion. This results in the student being told his/her perspective drawing “looks wrong” and/or not understanding why the rendering appears distorted. The Integrated Visualization System provides the student with a systematic procedure for generating visual information of any design in three different media mechanisms prior to the drawing/tracing process. The sequential nature of generating correct information based on physical and photographic data reduces the need for interpretation by the student and provides a system for self-assessment when a drawing doesn’t look right.

3.1.5 Accelerated Pedagogy - Active student participation in constructing individual learning system

Using the Integrated Visualization System may initially appear complex and arcane due to the disciplined process of generating indexed information. This may be counter intuitive to skilled artists who rely on careful observation to make drawing and rendering decisions. The phenomenon of making a drawing and later (sometimes MUCH later) reviewing the image only to comprehend that the perspective, proportions, lighting or other elements were fundamentally flawed when first completed. This learned element of visual perception is traditionally one of the reasons for requiring professional instruction for quality education. If students follow a different course of generating precise reference information before drawing, they are, in effect, teaching themselves the correct way of doing something before actually doing it. The self-teaching and doing parts both result in very high knowledge retention rates: 75% - 90% (Brooks & Brooks, 1993). Instead of relying solely on the instructor
for a correct answer, the student now has a methodology for constructing his or her own detailed knowledge base resulting in an accelerated long-term skill development. Instructors may be able to focus less on providing answers and more helping the student take an active role in determining how quickly and thoroughly they absorb new information.

3.1.6 Guidelines for Teaching and Integration of IVS into a Design Syllabus

The Integrated Visualization System is a modular teaching unit that may be incorporated into any level of Industrial Design Studio or Visual Communication Course. The skill sets – Model building, Photography, Computer visualization/modeling, and Tracing/drawing/rendering – may be used for instructing basic design skills and process at any level from student to professional. The concepts of understanding perspective, light, form, and drawing are used at all levels of design. The system may be used to enhance basic perspective line drawing to advanced CAD product renderings. While some designers excel at some or all of the Four Procedural Steps, the system may still be used to generate data about perspective, light, form, or color to offer the expert new insights into methods for visualization. For example, the nuances of light may be found to act differently than default settings in a rendering software and offer information leading to novel ways of seeing and presenting designs. Cinematography, a design discipline unto itself, is not found in most Industrial Design curricula and yet has a profound effect on how we view media.
These are some suggested guidelines for effective implementation of the system in an academic or professional setting:

1 – The procedural steps may seem dry, boring, or repetitive but used together, sequentially, have proven very effective. Regardless, retaining student engagement is critical to its success. **Wait to incorporate the system until after the first course assignment has been completed.** This first assignment will serve as a benchmark for both instructor and student to refer to at the end of the course to understand the effectiveness of the IVS within existing syllabus or curriculum.

2 – Begin **using the system as outlined with newer** versus older **students.** The younger set will generally be more open to experimental pedagogy. The aggregate response to the system is important to maintain discipline. Otherwise, students will find excuses not to do it.

3 – The exercises at outlined with **basic geometric shapes are critical for learning proportion.** Many important design programs rely on the designer’s ability to make simple shapes beautiful.

4 – Cover **at least 3 assignments with the geometric solids** exploring different compositions and drawing media (pen to markers). Covering so many drawings with the same indexed shapes helps the designer understand proportion more effectively than designing complex forms.

5 – Begin the Tracing/drawings **using trace paper** for overlays. This effects better accuracy in the copying process and is more effective for visual literacy.
6 – Modeling can be done with white bond or Bristol Board paper. The **monochromatic appearance is important to understanding how light functions** when viewing the photographic data.

7 – **Set up a lighting studio or area with a single** (halogen) light source for easy access by students or professionals. Blocking off all other light is not critical but aids in understanding principles of cinematography.

8 – Implement the system for about a **month spent on geometric forms** before designing more interesting projects.

9 – Encourage/require students to **use the system for their studio projects**. The four procedural steps cover the important design skills and provides a system for them to learn and solve problems on their own.

10 – **Craftsmanship is essential** for maximal learning in each step and design in general.

### 3.2 IVS Hypothesis

Integrating the sequential system of modeling, photograph, computer modeling and tracing (IVS) into an established design-drawing syllabus will accelerate the student’s design-drawing skill acquisition rate faster than the same syllabus without inclusion of the IVS.
The Integrated Visualization System will provide students with a system for learning to draw for the purposes of Industrial Design in correct, indexed perspective intuitively without depending on traditional perspective layout systems, vanishing points, measuring points, or a horizon line. Two- and three-point perspective will be accommodated as well as comprehension of ellipses and minor axes.

Visualization, the ability to draw, compose an image, and design at the same time, will positively effected because of increased sketching ability without the need to think extensively about composition of the image’s perspective. The reduced cognitive load permits more thought processes available for the concept design itself. Additionally the IVS will provide accurate guidance for shading, cast shadows, highlights and reflections for both design drawing and computer rendering.

### 3.3 Research Design

#### 3.3.1 Research Goals

The study tracked the effects of introduction of the Integrated Visualization System (IVS) into Design 501, a second–year Industrial Design drawing course at The Ohio State University, Professor Scott Shim, instructor.

The scholarly aim of the research study was to detect any improved rate and degree of skill development of design drawing when compared to prior (2011) curriculum, using models, photography, computer visualization, and drawings tracing computer-generated images.
As in a standard design-drawing course, lectures were given to the participants/student subjects during each class to explain the tasks, educational objectives and goals of each assignment given. The lectures and assignments were sequential and cumulative in process and design. Students were required to complete each assignment in order to understand and comprehend the next lecture/assignment in sequence.

Participation in the corresponding study of data generated by the students, however, was voluntary. Student subjects consenting to participate permitted the work they generated in the assignments to be used as data in the analysis, evaluation and assessment stages of the research. for the publication of this subject data was allowed solely through the consent process. The revised curriculum was integrated into the existing 2011 syllabus and taught as the Design 501 standard administered during the academic quarter.

IVS Assignments 01 – 04 were integrated in the first part of the quarter with smaller drawing assignments traditional to the Design 501 syllabus. In-class testing was indexed regularly to track learning progression of student subjects through the course. The primary assignments for Design 501 were three two-week design projects. The first, a concept for a shampoo bottle, was started in Week 4 of the academic quarter. The work generated for these projects represent the primary data available for this research.
Figure 3.6 – Timeline of IVS and D501 Syllabus

Week  Design 501  Spring 2012

01

02  IVS Assignment 01 - Geometric shapes composed separately, equi-
    distant on the ground plane  
    - Line-only tracing for outline and shading values

03  IVS Assignment 02 - Geometric shapes dramatically composed together
    - Line-only tracing for outline and shading values

04  IVS Assignment 03 - Complex forms with inflective surfaces. Two of the
    same forms composed in different positions
    - Line-only tracing for outline and shading values

05  D501 Project 01 - Shampoo Bottle
    - Market Research, Ideation, Initial and Final
    sketches, Design Process - bound

06  IVS Assignment 04 - Geometric shapes dramatically composed together
    - Line-tracing for outline; grey markers for
    shading values

07

08  D501 Project 02 - Game Controller
    - Market Research, Ideation, Initial and Final
    sketches, Design Process - bound

09

10  D501 Project 03 - Power Tool
    - Market Research, Ideation, Initial and Final
    sketches, Design Process - bound
Figure 3.3.1a represents the syllabus timeline of the quarter showing approximate introduction of course assignments, projects, testing and the Integrated Visualization System.

3.3.2 The background and relevance of the sample subject groups

The subject participants for the research study were all students from the Ohio State University Design 501 course that specifically teaches Design Drawing. All subjects had existing skill sets developed through the Department of Design’s Foundation Studies that responded accordingly to the proposed research study tasks. The Sophomore Industrial Design (ID) students at The Ohio State University were chosen as a representative subject sample because of the stage of their education where design drawing is first introduced following observational art drawing in the Foundation program. The curriculum for ID students at this point in the major presents universal design skills all students must learn to progress. The students’ mindset may also be more flexible at this early stage in their design education, allowing introduction of new pedagogy especially when framed as an additional benefit to the students.

The classification of the nature of this research study is Quasi-Experimental. The selection of the sample groups occurred without randomization of participants based on specified criteria outlined above concerning assessment of curriculum.
3.3.2.1 Control Group

The Control Group for this research study was comprised of the 2011 Design 501 class at The Ohio State University. Out of 20 students in the class, 6 consented to participate in the study. These six subjects permitted access to the drawings they produced for the 2011 class for research purposes. No other interaction with or influence by this sample group occurred. With unknown implications, a limitation of the Control Group is that the 6 participants represent, essentially, the ‘best’ students in the class, according to the 2011 Design 501 instructor.

3.3.2.2 Test Group

The Test Group for this research study was comprised of the 2012 Design 501 class of students at The Ohio State University – the Sophomore Industrial Design class. Out of 22 students enrolled in the class, 16 consented to participate in the study.

3.3.3 The Qualitative nature of the testing and analysis

The primary variables of analysis for Project Drawings completed by both Control and Test groups will be:

1) **2-Point Perspective** – Do the drawings exhibit parallel lines that properly converge towards vanishing points without distortion.

2) **Ellipses and minor axes** – Do circular forms, when viewed obliquely, display the correct angle of ellipse and do the corresponding minor axes
converge correctly towards respective vanishing points.

3) **Indexing** – Do units of measurement appear proportional in perspective. This may be evident by viewing orthographic drawings included in the project and comparing those proportions to the ones shown in the perspective view.

Perspective, ellipses and indexing are primary factors in determining if a design drawing will be convincing to the client and other designers. If the perspective is incorrect, the drawing will appear distorted and not portray an accurate picture of the design intent. Any surface values or rendering will not mitigate problems with perspective.

Examples of drawing data from each sample subject’s work were extracted for both Initial (First) Project and Final Project drawings. Some projects are the same for both groups and others are not due to variations in the project topics from year-to-year. The variables of analysis were assessed chronologically through the course to observe how rates of learning progress for each group. Correct perspective grids were overlaid onto each drawing and compared to perspective conventions displayed by each drawing. Significant discrepancies were noted and tallied as error rates for individuals and the aggregate group. While no published perspective grids exist to overlay onto all drawing data, a perspective grid was generated by the Key Personnel of the study (Thornton Lothrop, a senior designer with 18 years experience) to facilitate the assessment. Analysis and assessment of the success of
each drawing were interpretive/qualitative since there is no accurate way to measure exactly the perspective systems used by the student subjects.

Secondary variables of analysis for both In-class Test and Project drawings produced by the Test Group only include:

4) **Shading including highlights, cores, and reflection** – Does the student subject display knowledge of primary light source, respective shade values on each surface, the core (darkest value), and light reflected indirectly from nearby surfaces and objects.

5) **Cast shadows** – Does the student subject understand the principles of shadow casting, variable light values reflected inside.

The last two variables, shading and shadow casting, are both included in the IVS assignments. Data for both variables is extensive from both the Step 2 – Photography and Step 3 – Computer and is implemented in Step 4 – Trace when the student subjects add said values. Respectively, the student subjects in the Test Group will be responsible for adding this information during assignments and in-class testing.

Light, shading, shadows and reflections represent design visualization details essential to complete understanding of the design intent. Inclusion of this information may be essential to understanding nuances of form in important design details. The ability to understand and implement this kind of information in either a drawn concept sketch or a
computer rendering is one of the traits that makes designers unique. The Integrated Visualization System offers a complete set of visual data for use in design drawing regardless of the level of detail used by the designer. Light, shading, shadows and reflections were covered in the 2012 Design 501 curriculum but not in the 2011 Design 501 curriculum, however, and so will not be included in the final assessments and conclusions in Chapter 4.
Chapter 4: Analysis/Outcome

4.1 Presentation of subject data

4.1.1 Data interpretation – Internal Validity

Due to the quasi-experimental (non-random sampling) nature of this study and the subjective nature of data interpretation, there were a number of ways in which the study may have been biased:

1. Participants knew beforehand that their rate of learning was being studied and therefore may have consciously or unconsciously biased the work/data they produced.

Research Justification: Students understood that employment opportunities in the design industry are extremely competitive and the brief nature of the three-year design education cycle. Resistance to cooperation with research, professors, instructors, curriculum, classmates, and other elements of an educational dynamic, even if not in the student’s best interest, does occur in a learning process requiring behavioral and cognitive changes. A certain percentage of the sample participation was expected to expend a less-than-earnest effort. The aggregate trend in design-drawing skills data analysis, however, should reveal noticeable shifts in rate of learning.
2. Because the curriculum changed from previous classes, students/participants may not have agreed with the course structure, in spite of evidence from a pilot study that shows definitive benefits for participants.

**Research Justification:** The course/study curriculum was similar enough in nature to the 2011 class syllabus that test quizzes should reveal changes over time.

3. The study was using only one group/one class of design students for both Control and Test groups. Because each class is slightly different, especially from one school to the next, objective, quantifiable data is more difficult to accumulate to convincingly prove the hypothesis.

**Research Justification:** The study does not predict statistical validation as much as qualitative trends that could justify a larger, longer study with students from different disciplines as well as Industrial Design.

4. The study size (6 in Control; 16 in Test) is not statistically large or comprehensive given that there are approximately 60 undergraduate Industrial Design programs in the United States, each with similar class sizes to those at The Ohio State University. **Research Justification:** Validation of the purpose of the study may occur even if just a minority of the study participants shows some increase in their rate of learning compared to the same in the Control
group. The literature reviews indicate practical applications and uses for the proposed pedagogy in other disciplines such as engineering and art.

4.1.2 Testing Data – before, after IVS

Following each assignment Test Group Participants/students were given an in-class drawing test to benchmark overall perspective comprehension and drawing skills during the course of study. Shown in Figures 4.2 – 4.5 are the initial and final test drawings completed by each subject. Examples of drawings from the Test Group will be assessed as group skill levels examining perspective, fluency of line-work, accuracy, and understanding of shading and shadow-casting conventions. The time constraints (1 minute observation, 5 minute drawing allotments) represent an assessment criteria not significant in the Project Data presented in 4.1.3. The intent behind the limits was to help the students understand the time constraints that will factor into all their student as well as later professional work. Setting these limits also helps to direct the students to avoid hesitation and simply draw intuitively, a product of their innate skills and training. While more time would permit better craftsmanship in most cases, working with markers demands speed for best results.

Figure 4.1.2a shows a sample rubric for assessment of the drawings done in In-Class testing in the 2012 d501 test group. Comparisons were made to the perspective
visualized in the Trimble SketchUp and projected onto the wall for the students to observe. Primary and secondary criterion were assessed and noted for each student subject. Figure 4.15, in the 4.2.1 Analysis section exhibits the assessment for the full Test Group.
RUBRIC FOR PERSPECTIVE ASSESSMENT

IN-CLASS TESTING - TEST GROUP
Test Image geometric composition shown to student subjects:

- The SketchUp image shows correct 2-point perspective. 3-point perspective is seen in the minor axes of the cone and cylinder ellipses.
- Red overlay lines generated to compare to images drawn in test by subject.

Subject #1
Test 01 (first) Drawing:

- Cube shows distorted perspective (heavy blue lines) compared to Test Image (red lines).
- Cylinder ellipses (blue lines) show distortion and tilted minor axes.
- Sphere is less than round compared to Test Image (red lines).
- Cast shadows are different lengths and angles. Heavy blue line standard.

Subject #1
Test 04 (final) Drawing:

- Objects are drawn smaller with more indexed space between than Test Image (red overlay).
- Cube (heavy blue lines) shows less distortion in perspective compared to Test 01 drawing.
- Cylinder ellipses (blue) show proper axis orientation and less distortion than Test 01.
- Sphere is less distorted than Test 01.
- Cast shadows are more equal to each other in length, angle, and orientation than Test 01.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Perspective</th>
<th>Ellipses</th>
<th>Indexing</th>
<th>Shading</th>
<th>Highlight</th>
<th>Core</th>
<th>Reflection</th>
<th>Cast Shadow</th>
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</tbody>
</table>

Figure 4.1 – Rubric for Perspective Assessment of In-Class Testing of Test Group. Top image explains evaluation process. Bottom image shows respective assessment.
Figure 4.2 – Testing – sub. 1-4: After each assignment, test subjects’ ability to visualize by drawing geometric objects in perspective and adding shading and cast shadows.

TEST - TEST GROUP

Observe image for one minute

Draw from memory

Cast shadow with light source overhead from the left

14/16 test subjects showed skill improvement in perspective convergence, ellipses, shading and cast shadows in the 4 weeks between benchmark and final testing. (#14, 15 excepted)
Figure 4.3 – Testing – sub. 5-8: After each assignment, test subjects’ ability to visualize by drawing geometric objects in perspective and adding shading and cast shadows.
Figure 4.4 – Testing – sub. 9-12: After each assignment, test subjects’ ability to visualize by drawing geometric objects in perspective and adding shading and cast shadows.
Figure 4.5 – Testing – sub. 13-16: After each assignment, test subjects’ ability to visualize by drawing geometric objects in perspective and adding shading and cast shadows.
4.1.3 Project Data - Control and Test

The following pages contain drawing project data from both Control and Test groups. These images represent projects completed in the latter part of the Design 501 class for both years, 2011 and 2012. These projects, compared, for example, to the IVS assignments, required background product, demographic, and market research to establish a set of design criteria to guide the student through a short design process examining function, value and aesthetics, traditional Industrial Design components. The students were required to address these issues with a variety of concepts while paying strict attention to the design-drawing requirements of each project. These requirements expanded from line drawings in initial projects to more finished presentation drawings in the final project rendered with color, light, shading and cast shadows.

Figures 4.7 – 4.8 represent one initial and one final project drawing from each Control Group subject exhibiting the best work.

Figures 4.9 - 4.14 represent one initial and one final project drawing from each Test Group subject exhibiting the best work.

Included in each subject’s drawings are red-line overlays indicating proper perspective lines and ellipses. Blue dots indicate discrepancies or distortions, both important criterion used by professional designers in evaluation of portfolio drawings.
RUBRIC FOR PROJECT PERSPECTIVE ASSESSMENT

- Project drawings consistently show two
  Orthographic views with the Perspective.
- Perspective views vary according to subject but
  are not consistent in elevation or focal length.
  Some perspective views appear close to parallel
  projection views
- Red overlay lines indicate correct perspective
  grid for view drawn by the designer
- Blue dots indicate discrepancies (errors)
- Error rates will determine final evaluation

Project 01 (Initial) Drawing -

- Base of mower is in proper perspective although
  the proportions are different than the
  Front/Side Views.
- Errors:
  1 - Corners of handle are different heights.
  2 - Front corner wheel is incorrect ellipse angle.
  3 - Handle and corners are disproportionate to
     Orthographic Views
- Design Drawing Skills assessed at Basic level

Project 03 (Final) Drawing -

- Base is in correct perspective and proportion
  compared to Orthographic Views
- Errors:
  1 - Driver head axis tilted up compared to
     horizontal Orthographic view
  2 - Handle grip is too thin compared to
     Orthographic views
- Design Drawing Skill Acquisition Rate
  Perspective, proportion, details, and color are
  improved and advanced to Intermediate level

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Figure 4.6 – Design-Drawing Skill Acquisition – Rubric for Assessment
CONTROL GROUP

Design Drawing skill change shown from First to Final Projects

Red lines indicate correct perspective grid, ellipses, center lines or profiles

Blue dot indicates perspective/ellipse/proportion discrepancy

SUBJECT # - INITIAL PROJECT

01

02

(No Data Available)

03

FINAL PROJECT

Figure 4.7 – Design-Drawing Skill Acquisition/Control Group – sub. 1-3: Comparison of perspective accuracy from initial to final drawing projects.
Figure 4.8 – Design-Drawing Skill Acquisition/Control Group – sub. 4-6: Comparison of perspective accuracy from initial to final drawing projects.
Figure 4.9 – Design-Drawing Skill Acquisition/Test Group – sub. 1-3: Comparison of perspective accuracy from initial to final drawing projects.
Figure 4.10 – Design-Drawing Skill Acquisition/Test Group – sub. 4-6: Comparison of perspective accuracy from initial to final drawing projects.
TEST GROUP

Design Drawing skill change shown from First to Final Projects
Red lines indicate correct perspective grid, ellipses, center lines or profiles
Blue dot indicates perspective/ellipse/proportion discrepancy

SUBJECT # - INITIAL PROJECT

07

08

09

FINAL PROJECT

Figure 4.11 – Design-Drawing Skill Acquisition/Test Group – sub. 7-9: Comparison of perspective accuracy from initial to final drawing projects.
TEST GROUP

Design Drawing skill change shown from First to Final Projects

Red lines indicate correct perspective grid, ellipses, center lines or profiles

Blue dot indicates perspective/ellipse/proportion discrepancy

SUBJECT # - INITIAL PROJECT | FINAL PROJECT

10

11

12

Figure 4.12 – Design-Drawing Skill Acquisition/Test Group – sub. 10-12: Comparison of perspective accuracy from initial to final drawing projects.
**TEST GROUP**

*Design Drawing* skill change shown from First to Final Projects

**Red** lines indicate correct perspective grid, ellipses, center lines or profiles

**Blue** dot indicates perspective/ellipse/proportion discrepancy

**SUBJECT # - INITIAL PROJECT**

<table>
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<th>Final Project</th>
</tr>
</thead>
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</tr>
</tbody>
</table>

*Figure 4.13 – Design-Drawing Skill Acquisition/Test Group – sub. 13-15: Comparison of perspective accuracy from initial to final drawing projects.*
TEST GROUP

Design Drawing skill change shown from First to Final Projects

- Red lines indicate correct perspective grid, ellipses, center lines or profiles
- Blue dot indicates perspective/ellipse/proportion discrepancy

SUBJECT #  -  INITIAL PROJECT  

16

FINAL PROJECT

Figure 4.14 – Design-Drawing Skill Acquisition/Test Group – sub. 16: Comparison of perspective accuracy from initial to final drawing projects.
4.2 Analysis

4.2.1 Analysis, Assessment of Testing Data from the 2012 Test Group

The primary criterion for analysis of the Testing data from the Test Group includes:
- Perspective - 2pt (3pt applicable but not formally covered in the class)
- Ellipses - correct angles and minor/major axes
- Indexing – unit indexing in perspective (multiplication)

The secondary criterion for analysis of the Testing data from the Test group includes:
- Shading
- Highlights
- Core - darkest shading
- Reflections - reflected light in shading, shadows
- Cast shadows

The intent in the analysis of the Test Data is to determine the effects of the IVS Assignments over a four-week period of the class session. The test image (included on the left side of the Data sheets) was only seen by the students twice – both times for one minute during the test periods so there was little chance of students preparing on this specific image. All tests were unannounced and not described beforehand. The strict constraints, therefore, reveal a fairly accurate account of the students’ basic ability to draw and visualize these geometric objects.
Table 4.15 – Assessment of Testing Data - Test Group. Most subjects showed improvement in most categories of design drawing skills.

Figure 4.15 shows a spreadsheet of analysis of the study subjects’ performance in the first (benchmark) and final tests. Only three assessment ratings were applied largely because of the reduced accuracy of the drawings due to significant time constraints and freehand requirements. Improvement (+1), No Improvement (0), and Regression (-1) were used to categorized changes and variations in each subject’s design drawing ability.
The conclusions one may draw from this data are that:

- The majority of study participants improved their abilities in almost all of the categories in the 4-week period of IVS assignments and testing.
- 9 out of 16 participants did not improve in one or more categories.
- 2 out of 16 participants showed skill-regression in two or more categories from the first to last test. It should be noted that Subject 14 did not, to the Key Personnel’s knowledge, complete any of the IVS assignments. While this may represent a logical reason for lack of improvement in some categories, this misstep of Subject 14 has significant repercussions for the project drawings he completed later in the course.
- There appears to be a corollary between the success rates indicated here and the Project Data analyzed and assessed in the next section.

4.2.2 Analysis, Assessment of Project Data from Control, Test Groups

In order to most objectively analyze the Project drawings data from both Control and Test groups, a perspective grid system was overlaid (in red) on each drawing to highlight discrepancies, the most obvious of which were noted with a blue dot.

The perspective grids also showed how accurate many of the drawings were from a design drawing quality standpoint.
Although the Test drawings assessed in 4.2.1 included numerous evaluation criterion such as light, shading, core, reflections, and cast shadows, the analysis of the Project Drawings from both Control and Test Groups will focus on perspective, ellipses, indexing and proportion, four specifics covered equally in course material from both classes before the introduction of the Integrated Visualization System.

Assessment of the drawings from both groups include the following findings:

1 – Discrepancy rates in the Control Group of 2.16 errors average per Initial drawing improved to 1.5 errors average per Final drawing. This translates to an improvement rate of 31.6% between initial and final drawings.

2 – Discrepancy rates in the Test Group of 1.75 errors average per Initial drawing improved to 0.69 errors average per Final drawing. This translates to an improvement rate of 60.5% between initial and final drawings.

Discrepancy rates from both groups are close (Control 2.16 to Test 1.75) in the Initial Project drawings. Discrepancy rates for Control group Final Project drawings are more than twice that of Test group Final Project Drawings (Control 1.5 to Test 0.69) Improvement percentages are significantly different: Control 31.6% compared to Test 60.5%.

Interestingly, the Control group had a broader range of discrepancy ratios from Initial to Final project drawings with 1 out of 6 subjects with no errors for both drawings. There were no subjects in the Test Group who had no errors for both drawings.
Anecdotally, Final Project drawings from the Test Group generally showed stronger comprehension of secondary design drawing factors of light, shading, core, reflections, cast shadows when compared to the same Final drawings from the Control Group. In the Test Group 7 out of 16 Final Project drawings contained cast shadows. In the Control Group, no Final Project drawings contained cast shadows. Subject 14 from the Test Group, noted in 4.2.1 as not completing the IVS assignments and experiencing skill regression in the testing, incurred an average discrepancy rate from the Initial to Final Project drawings (2 to 1) but showed less knowledge rendering light values in the Final drawing than other subjects from the Test group.

The **Hypothesis**, in section 3.2, states that the Integrated Visualization System, when incorporated into the syllabus of an established Design Drawing course, will accelerate the students’ design-drawing skill acquisition rate faster than the same syllabus without the IVS. The reduction in the rate of design-drawing discrepancies (errors) recorded between the Control (31.6%) and Test (60.5%) groups indicates that the Test Group did, in fact, improve their design-drawing skills at a faster rate than the Control Group over the same time period. As predicted, the evidence shows that drawing skill acquisition rates were accelerated **both on an individual and aggregate levels**.
Of particular significance, the assessment of the data also reveals that the drawing performance of the average to below-average student in the Test group also increased dramatically when compared to same from the Control group. Typically, most Industrial design classes will have one or two exceptional students before individual skill sets quickly degrade into average or below-average quality.

4.3 Significance

4.3.1 Design Education

What is a most effective pedagogy for drawing in Industrial Design Education?

Industrial Design is the practice of improving or creating function, value, and aesthetics to mass-produced artifacts within specific or global communities and cultures. At the core of the design effort is a Process or methodology for examination of phenomena, analysis, evaluation, categorizing, generation of new and alternative ideas, and implementation of concepts to production.

Industrial Design represents a creative activity that requires interaction with different groups within a professional or cultural setting. Designers may lead or follow the group depending on the hierarchy and dynamics. Two of the skills they train to do are draw and visualize: to communicate their own thoughts as well as those of others in the group, to help bring to fruition the ideas of the group.

The value of drawing as a language, a communication and design tool across cultures,
has been well documented from graphic, industrial design, engineering, architectural, psychological, and cognitive points of view. It works well in concert with digital media and physical modeling. Drawing helps to bring together disparate groups and generate ideas and concepts not previously considered or thought possible.

The challenge in Design Education is to develop a curriculum imparting the necessary skills and knowledge expected of students graduating and entering the profession. Given industry demands of broader skill sets – digital modeling and graphic languages in addition to traditional drawing, prototyping, and designing skills – against immovable 4-year student development cycles, it is little wonder that many students’ efforts are spread too thin to become expert in any one discipline, especially drawing.

An intent behind the study was to find opportunities to synthesize the disparate subject matter required within the industrial design curricula incorporating pedagogical techniques to maximize educational returns, in essence, make education more efficient. The beneficiaries of these pedagogical refinements include all elements of the design development system: the students, professors, design firms and the end clients.

Completion of the research study of the Integrated Visualization System indicates a promising link to accelerated design-drawing skill development within the context of a prototypical Industrial Design program. Importantly, the system uses design skills together, symbiotically, rather than separately, divisively, a problem that
has plagued education and practice since the advent of the computer.

Other benefits of this system to the student, if implemented into each year of a design education, may be threefold:

1 - a higher base level of visual literacy (VL) for the average student who takes advantage of the visual benefits found in each of the IVS Steps if integrated into a standard design project. Ample research points to traditional two- and three-dimensional creative activities as classic drivers of visual literacy (Sless, 1984; Anderson, 2002; Flood et al, 2004; Felton, 2008)

2 – A more balanced understanding of visualizing products when using photographic references for rendering on the computer. Current software enables the designer to render images more exciting than the real product, a self-defeating process.

3 – A higher base-level of design drawing skills for the bottom three-quarters of a design class translates into more job opportunities open for the average design student.

4 – Most importantly for the just-graduating student, evidence of a more integrated design process, always a critical feature of a good design portfolio.

On a macro-level, the Integrated Visualization System offers a practical, neatly packaged pedagogy for On-Line Education. None of the Four Steps require prior experience to complete, although craftsmanship and skill should both increase with
regular use. A major factor in effectiveness of On-Line education is managing the implementation of course materials and assessing the quantity and quality of the individual learning process. The IVS, with its built-in self-check/self-assess sequential procedures, provides a flexible system for a range of instructor involvement while minimizing the impact of absence. Furthermore, this Online education can be catered to disciplines outside of Industrial design: Engineering, Illustration, Architecture, Business, Art and any other person interested in a creative process.

4.3.2 Design educators

In review of this research, the significance for Design Educators may be seen in a negative light. In presenting the rational for and concept of the prototype to two Design Schools during the past year, I received responses from both students and an educator who expressed significant reservations about the idea and its implications for both groups:

- The students felt the idea might radically and uncomfortably change the way they were learning to become designers.
- The educator became quite agitated expressing the concern he had that if implemented, the System would negatively impact the curriculum he had spent a (long time) developing.

Both entities felt that the computer and digital curriculum would be adversely affected. Of course, this was the opposite of the intended effect. The objective behind the
extensive literature and practical research was to find a way to integrate the learning process of both drawing and computers so that both disciplines might benefit as Natasha Radclyffe-Thomas (2008) recommends. Education has tried to keep up with the pace of change in technology but not yet had the chance to design a system to use all discipline pedagogies in concert.

The purpose of the research has been to discover a way to improve design drawing education and minimize or eliminate the schism in practice and education between the different camps: drawing versus computers. The research indicates that, indeed, the IVS may be a way to accomplish this.

In implementation of the IVS in the Design 501 class in 2012, it became obvious very quickly, both in class and research results, that the existing syllabus of the course was still of primary importance. Drawing styles, exercises, projects and general knowledge could all remain the same except that the syllabus was augmented in such a way to accelerate the learning curve and skill development in the same amount of time as the Control group. All materials, tools, and software required by the IVS were designed to be as inexpensive as possible for the students and take the minimal amount of time out of the instructor’s established syllabus schedule to implement.

Although the Integrated Visualization System could be utilized as a stand-alone pedagogy, in practice it is a ‘dry’ procedure with not much excitement. Based on the
two studies (pilot study in Winter of 2012, Design 501 in Spring of 2012) performed, the IVS works best in conjunction with an existing Design Drawing syllabus.

Finally, an added benefit to educators is the success of one’s students both from a personal satisfaction point of view and the reputation of the Design School. Just as on athletic and business teams, an educational team (both faculty and students) that find a key to working together better across groups will all benefit in the long run.

4.3.3 Practice

From the view of the Design Practice, implementation of the IVS has a number of benefits:

- Integration with traditional “feeder” schools curricula in the long run should produce statistically more capable student groups on an annual basis for new hires. Not only do design firms have access to more students with the searched- and hoped-for entry-level skills but also the time and risk spent on the search process is correspondingly reduced.

- For those design groups with a variety of skill sets that don’t meet minimal requirements for professional work, the IVS offers a simple way of improving or refining an existing staff designer’s skill set.

- Integration of the IVS into a client relationship could benefit in two ways:

1. Help the client become a better visualizer to work alongside the designers he/she has hired.
2 – Establish a common language between the client and designer for the relationship and help the client comprehend the extend of the designer’s capabilities (i.e., more than what is apparent) when the former sees how complex the visualization process can be.

### 4.3.4 Business

Business, like the public, appreciates to varying degrees the benefits of design. With the Design industry as competitive as ever for a sustaining business relationship, consultancies are forced to continually re-invent themselves to stand out from other disciplines such as Engineering, Architecture, Visual Communication, and Marketing. Business can Reverse-Auction a design program for the lowest bid price with a group of competitors or simply go overseas and receive ‘free’ design for an engineering and manufacturing contract with an Asian supplier. In short, Industrial Design has become a Search-for-Low-Cost commodity. Business executives are often removed from the actual Design Process. If a design firm were to implement the IVS within the relationship, business executives might be able to understand and appreciate the design process and communicate within their own company with new-found visualization skills. In effect, this Integrated Visualization System could form a common mode of communication within a business required to work with Marketing, Sales, Engineering, Asian or European manufacturing. As has been discussed and proven, the individual steps of the system are not too complex for the average person. If asked to ‘Draw’ an idea, most adults are uncomfortable with that act, especially if facilitating or
participating in an important meeting. The IVS offers procedures for working through communication issues where talking will not suffice. Implementing an internal education program could lead to many of the benefits of social interaction, communication, and consensus-building described in Chapter 2.

4.4 Limitations

The Control Group, student subjects of the 2011 Design 501 class, numbered only 6 compared to 16 from the Test Group, student subjects of the 2012 Design 501 class. Aside from a less-than 100% participation in both groups, the low sampling index in the 2011 Control Group corresponds to the fact that the course instructor only retained data from the best 6 students. Therefore, it must be assumed that the aggregate output quality of the class work is lower than the Test Group’s, at least when measured before introduction of the Integrated Visualization System curriculum into the class syllabus. It is not known if, with the same participation as the Test group, the Control group’s error rates in the Drawing Project output would have been the same or different as recorded.

The four IVS assignments were completed by the 2012 Test Group student subjects without performing any of the model building designated in Step 1. All models used in Step 3, Photography, were constructed by the Key Personnel (Thornton Lothrop) because student time allotted to the IVS portion of the D501 Syllabus was limited. The
students had concurrent assignments in the same course. It was felt that the other steps in the process would be more valuable in the short term.

The limitations of a future study should be set carefully. A primary risk involved in this effort is the nature of a challenge to existing systems. Many educators have been involved in teaching for years. Any suggestion that their work in preparing students for the profession has fallen short is not welcome news and is likely to be met with dismissal if not derision. Furthermore many assessments across the industry are both subjective and anecdotal – there is no licensing system for Industrial Design as in other professions such as Architecture, Engineering, Medicine, etc. This topic has been discussed before within the governance of the IDSA, the national leadership of the discipline but no consensus or system for implementation has ever been agreed on.

The study may best be presented as an observed reflection based on limited versus comprehensive research. By implementing a pilot study of a pedagogic concept for teaching drawing in the confines of an Industrial Design curriculum, the observed data showed net changes in the quality of student work and, accordingly, should justify the problem and this thesis research question and provide an opening for future education forums.
4.5 Next steps

Following the success of the research, there may be some sobering, if potentially exciting, next steps for the continuation of development of the Integrated Visualization System.

1 – More research is needed in different contexts, both in and out of Industrial Design, to validate the research done to date. As has been noted, each class of students represents a new entity that will respond to the same curriculum/syllabus in a different manner. Continued integration of the IVS in an established syllabus at a specific school for at least 2 years would provide continuity and nominal trends data.

2 - Refine and streamline the IVS procedures to maximize comprehension for non-designers as well as designers. Simplify the implementation so that other instructors might integrate the IVS into their respective curriculum in Beta mode to generate more data and feedback for refinement.

3 – Research cognitive processes occurring during use of the system:
   - What are the students thinking as they go through the stepped process?
   - How are the students’ cognitive reflection exhibited in the work?

4 - Redefine the IVS to make it more interesting, engaging that might lead to a stand-alone system for Online implementation.

5 – How long should students use the system before their skills are sufficient to perform with out it. Should a system be designed for a final use/qualifying skill set?
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