

# **BENCHMARKING ART IMAGE INTERCHANGE CYCLES**

**FINAL REPORT 2011**

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# EXECUTIVE SUMMARY

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Many cultural heritage institutions are currently spending significant resources photographing their works of art for a variety of applications with distinctly different requirements. To create reproductions of their artwork, cultural heritage institutions employ a range of technology and a variety of workflows. A similar variety is used to publish these images in a number of output media. This project was undertaken to explore these workflows, their requirements, and the resulting image quality of the reproductions produced.

The main goals of this project were to: (1) determine the image quality inherent in the art image interchange cycles in use today, (2) understand the image quality expectations of the users, and (3) develop the capability to tie the two together. The three-year project started in April 2008 with financial support from The Andrew W. Mellon Foundation.

The following objectives were developed to reach these goals:

- Determine the optimal reproduction processes presently available.
  - » Understand the workflow processes in use in cultural heritage institutions today.
- Document current workflows.
  - » Determine the image quality inherent in these processes in print and online.
- Develop a practical characterization test method.
- Document available targets for measuring objective image quality.
  - » Understand the image quality expectations of the users involved.
- Define quality criteria based on objective and subjective metrics.
- Develop a method to connect objective, measurable image quality to subjective image quality as perceived by observers.
- Benchmark current quality.
- Develop a framework to serve as a guideline for museums to follow when reproducing fine art.

To work towards these objectives, three main bodies of research were conducted. First, background research was conducted on the workflows, the test targets used, the related standards, and the geography of fine art book printing. Second, a series of experiments were developed to evaluate the image quality attainable with the reproduction workflows in practice today. Finally, interviews were conducted with various participants in the image interchange cycle.

Seventeen institutions captured a variety of artwork and objective targets for the experimental part of this project. The objective targets were included with the goal of finding measurable image characteristics that correlated with the subjective results. Six distinct experiments were developed in order to benchmark art image interchange cycles for printed and on-screen reproductions. Interviews were conducted at various points of the project to gain a better understanding of the observers in the experiments and of the various exchange points in the image interchange cycle. Based on the experimental results and the interviews, a set of guidelines was developed.

## Executive Summary

Key findings of the project were as follows:

- Through the experimentation it was possible to develop a method to connect objective, measurable image quality to subjective image quality as perceived by observers.
- Workflows still vary considerably, but some commonalities were found for workflows producing images that were generally ranked highly across the experiments. These workflows were used as a basis for the development of the recommended guidelines.
- Workflows covering the whole image interchange cycle should be documented in detail. No undocumented processing should be performed along the image interchange cycle.
- ICC profile-based color management should be used to achieve best results.
- The use of targets to ensure a proper capture setup is recommended.
- Following standardized workflows, ISO printing standards, and viewing standards reduces the need for manual post-processing.
- Lighting conditions may have a strong impact on image appearance.
- Acceptable reproductions are achievable using a digital press.
- Defining imaging goals and talking to users is indispensable to help set expectations.
- Closing the communication loop in the image interchange cycle is of the utmost importance.

The findings of this project—as well as various discussions with stakeholders in the field—point to a number of paths forward for future research, services, training, and related activities.

- Benchmark the image quality of new forms of reproductions on new generations of displays (e.g., iPad, mobile devices).
- Study the effects of rendering 3D objects under several lighting directions and types of illumination using computational photography.
- Benchmark art image interchange cycles for 3D originals.
- Study of new light sources and their implications for reproductions.
- Study the use of appearance models to allow image use under various light sources.
- Development of training for attaining standardized workflows.
- Conduct round-robin testing using developed guidelines.
- Study of ways to better facilitate communication among multiple stakeholders.

Projects like this are an invaluable opportunity to bring the community together and move the field forward. This important work would not have been possible without the support of The Andrew W. Mellon Foundation.

# SECTION 1: INTRODUCTION

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Many cultural heritage institutions are currently spending significant resources photographing their works of art. There are a variety of reasons why cultural heritage institutions may wish to create reproductions of their artwork. Production of items such as exhibit catalogues, posters, prints, and postcards for sale in museum shops may be among the most obvious. Creating digital versions of the artwork for display on promotional websites or for online shopping is also of interest. Along with these commercial ventures, it is also certainly of interest to generate images to supply databases for research and teaching purposes, to serve as official records in the art conservation process, and to allow the sharing and enjoyment of cultural heritage.

A range of technology and a variety of workflows are being used to create these images. A similar variety can be found among the workflows used to publish the images in a number of output media. The purpose of this project was to benchmark the image quality of art image interchange cycles in use today.

It is important to first define the expression ‘art image interchange cycle.’ Images of artwork have a variety of sources: photographers in cultural heritage institutions, freelance photographers, and digitization services, among others. After these images are created, they are transferred to stock picture libraries, magazine and book publishers, graphic designers, art directors, print service providers, museum image databases, conservators, etc. These various entities use the images for a multitude of purposes, from printing books, catalogues, and magazines, to publishing websites, populating databases, and research. Finally, to close the cycle, others are using the images for various purposes, such as an art historian using images from the ARTstor database in a class.

Every entity touching the images along the image interchange cycle has expectations for image quality that might differ from those of others in the cycle. During this *image interchange cycle*, the images are being transferred among devices, platforms, and vendors, and are being used by people whose knowledge and skill in imaging varies widely. Commonly accepted industry standards and best practices for the image interchange cycle do not exist at this point in time. It is not surprising that the variety of workflows being applied poses many challenges, and might ultimately lead to decreased image quality and the potential for dissatisfied users.

The image quality requirements for each application may be decidedly different. An art conservator needs an accurate reproduction of a painting receiving attention, with a level of detail down to the cracks existing in the paint when the artwork is first received.<sup>1</sup> Other museum personnel, in contrast, may be looking for the most pleasing reproduction possible so as to offer museum goers items that invoke fond memories of their cultural heritage experience or virtual museum experiences.<sup>2</sup> The different types of imaging in cultural heritage institutions and the image quality expectations connected to them are often not clearly understood or communicated by the various parties involved.

Many art historians are heavy users of art reproductions for their research and teaching. The importance of color and the frequent inadequacy of its reproduction have been especially troublesome for many scholars. Fidelity to

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1 - Saunders, D. (2006). Digital images in conservation documentation: Quality, accuracy, and potential. *AIC Paintings Specialty Group Postprints* 18:1-15.

2 - Morovic, J. and Sun, P. (2002). Visual differences in colour reproduction and their colorimetric correlates. In *Tenth Color Imaging Conference: Color Science and Engineering Systems, Technologies, and Applications* (pp. 292-297). Springfield, VA: The Society for Imaging Science and Technology; Smith, R. (2011). The work of art in the age of Google. *NY Times*. Retrieved on June 28, 2010 from <http://www.nytimes.com/2011/02/07/arts/design/07google.html>.

## Section 1: Introduction

the original has always been seen as particularly critical, and, of course, image quality is mentioned over and over again as a key element of a good reproduction.<sup>3</sup>

There was a lack of prior research on the evaluation of the image quality of images found in art image databases (see Figure 1-1). While user interfaces and usability of databases have received a lot of attention, very little research was found on the implication of the available image quality on the usefulness of a database for research. One reason for this dearth could be that users do not know what they can demand in terms of image quality. Visual literacy research, while available, does not focus on these specific applications. Another barrier to research of this nature is that image quality studies are complex and expensive to undertake.



Figure 1-1. Illustration of a variety of different reproductions found in the same database

In recent years, it has become a widely accepted fact that high-quality images can be repurposed and are worth maintaining. What is often still missing are art image interchange cycles where as much attention is paid to repeatable, well-managed acquisition processes as users have come to expect from digital repositories. To quote Steven Puglia of the National Archive and Records Administration: “We feel that the managed environment needs to be extended beyond the digital repository and forwarded in time to include the digitization process...”<sup>4</sup>

Reproduction of fine art can be difficult. The color and texture of the art object need to be accurately represented, and the printing often happens half a world away. It is of interest to limit the number of times an artwork is imaged in order to minimize the potential of damage and, of course, to keep costs low. All of this work has to be done with decreasing budgets and often with no dedicated in-house reproduction department.

3 - Bakewell, E., Beeman, W., McMichael Reese, C. and Low Schmitt, M. (1988). *Object, image, inquiry: The art historian at work*. Santa Monica, CA: Getty Art History Information Program.

4 - Puglia, S., De Vorsey, K., and Rhodes, E. (2008). From digitization to repository—A case study in creating a managed environment. In *Archiving 2008* (pp. 7-12). Springfield, VA: The Society for Imaging Science and Technology.

Adding to the difficulty of successfully reproducing fine art is the fact that these reproductions are viewed under various lighting conditions such as might be found in a museum shop, living room, or classroom. Lighting conditions also vary even during image evaluations that are conducted under a light booth, in a gallery, or in an office. This leads to significant issues with color reproduction due to metamerism, color appearance, and consistency that have to be dealt with in the art image interchange cycle.

Research has been conducted previously on the capture stage of the art image reproduction cycle.<sup>5</sup> This report found that current capture processes were variable and that these varied processes can result in significant perceptual differences in the color appearance and image quality of digital images.

One thing that all parties who use fine art reproductions would agree on is the need to keep the best interests of the artwork itself in mind. It is of interest, then, to make one image that will adequately meet the needs of all potential users. To achieve this, multi-spectral reproduction may be required. Research in this area is progressing rapidly. Some institutions are experimenting with such practices. However, the recommended spectral imaging processes and equipment are, at present, not practical or cost-effective for many museums and other cultural heritage institutions. To best meet the needs of the broad spectrum of users reproducing fine art, it is desirable to understand the optimal reproduction processes presently available. Additionally, a framework to follow when reproducing fine art could prove quite helpful to many institutions, regardless of size.

The main goals of this project were to: (1) determine the image quality inherent in the art image interchange cycles in use today, (2) understand the image quality expectations of the users involved in this interchange cycle, and (3) develop the capability to tie the two together. The researchers were fortunate to be able to use the printing facilities at RIT to produce the printed samples. This was a unique opportunity that allowed us to conduct a project of a size unmatched to date (see Figure 1-2). Additionally, the facilities at the Munsell Color Science Laboratory at RIT were used to develop and conduct our experimentation (see Figure 1-3).

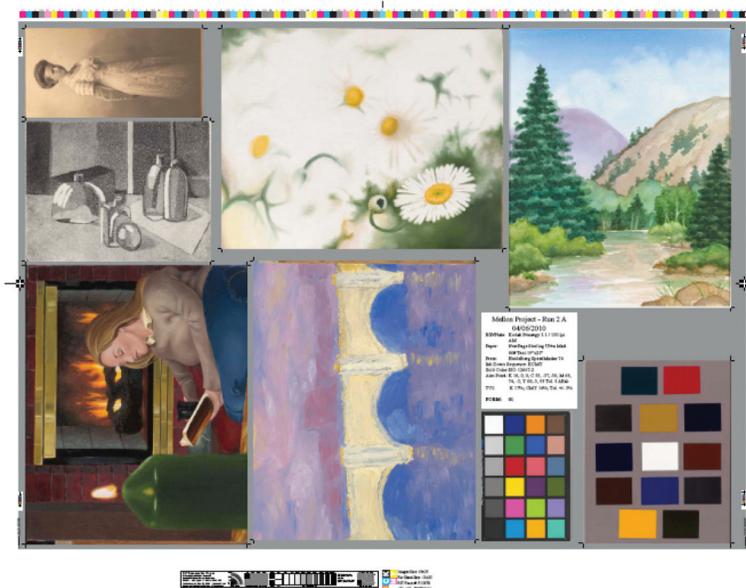


Figure 1-2. Sample press sheet printed at the RIT Printing Applications Laboratory

5 - The final report of the previous benchmarking project can be downloaded at <http://artimaging.rit.edu>. (Berns, R.S., Frey, F.S., Rosen, M.R., Smoyer, E.P.M., & Taplin, L.A. (2005, April). *Direct digital capture of cultural heritage: Benchmarking American museum practices and defining future needs – Project report*. Rochester, NY: Munsell Color Science Laboratory. Retrieved from [http://www.cis.rit.edu/museumSurvey/documents/Benchmark\\_Report\\_April.pdf](http://www.cis.rit.edu/museumSurvey/documents/Benchmark_Report_April.pdf))

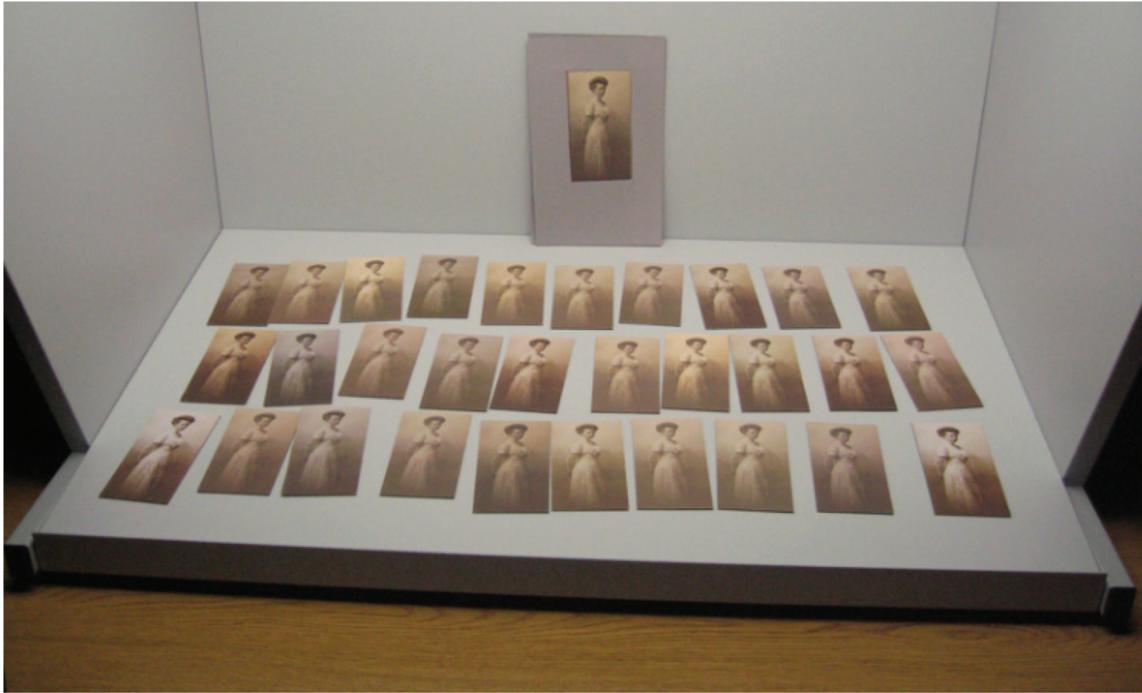


Figure 1-3. Experimental set-up for the hard copy experiment conducted at the Munsell Color Science Laboratory<sup>6</sup>

## OBJECTIVES

The following objectives were developed to reach these goals:

- Determine the optimal reproduction processes presently available.
  - » Understand the workflow processes in use in cultural heritage institutions today.
- Document current workflows.
  - » Determine the image quality inherent in these processes in print and online.
- Develop a practical characterization test method.
- Document available targets for measuring objective image quality.
  - » Understand the image quality expectations of the users involved.
- Define quality criteria based on objective and subjective metrics.
- Develop a method to connect objective, measurable image quality to subjective image quality as perceived by observers.
- Benchmark current quality.
- Develop a framework to serve as a guideline for museums to follow when reproducing fine art.

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<sup>6</sup> - It can be clearly seen how different the reproductions look compared to the original photograph in the back of the viewing booth.

## PARTICIPANTS

As a result of the first benchmarking project, an online group called ImageMuse was formed. This group was spearheaded by Alan Newman, head of Imaging at the National Gallery of Art in Washington, DC. ImageMuse is a discussion group of museum imaging and publishing professionals dedicated to sharing their knowledge. Seventeen institutions—all ImageMuse members—took part in our experiments (see Table 1-1).

Table 1-1. Cultural heritage institutions that participated in this project<sup>7</sup>

Participating Institutions	
The Metropolitan Museum of Art	Art Institute of Chicago
MoMA - The Museum of Modern Art	Minneapolis Institute of Arts
The Guggenheim Museum	The National Gallery, London
Harvard Art Museum	Victoria & Albert Museum
Harvard College Library	Berkeley Art Museum and Pacific Film Archive
Northeast Document Conservation Center	The Getty Center
Museum of Fine Arts, Boston	The National Gallery of Art, Washington
The Beinecke Rare Book and Manuscript Library at Yale University	Yale University Art Gallery
	Yale Center for British Art

The relationships with these institutions have been developed over many years. It has always been of utmost importance to the researchers to keep the results of our experimentation anonymous. Projects like this one are not a contest, but a rare opportunity to move the field forward.

<sup>7</sup> - One participant not listed in the table is the Memorial Art Gallery (MAG) in Rochester, NY. As a medium-size institution, the MAG helped by sharing information on its art image interchange cycles.



## SECTION 2: BACKGROUND

Before starting the experimentation, several areas needed to be studied to gain a better understanding of the workflow processes used in cultural heritage institutions today. The following sections contain: 1) a summary of the current imaging guidelines and actual workflows used by institutions today, 2) a review of test targets, 3) a review of relevant standards, and 4) a study of the geography of fine art book printing. The findings from these four areas were used to help interpret the results from the experimentation and the interviews.

### CURRENT GUIDELINES AND WORKFLOWS

Ten of the 17 participating institutions shared written documentation of their general workflow processes. A review of these documents was conducted, and is summarized in Table 2-1. The reported steps—listed in column two of Table 2-1—generally address what happens to the image file following image capture. The detail and depth of the guidelines varied, but all covered the general topics listed.

As part of the imaging of the pictorial and objective targets<sup>1</sup> (and production of guide prints for a subset of the institutions) for the experimentation, each institution filled out the same questionnaire regarding the workflows used. (This questionnaire can be found in Appendix C.) It may also be noted that information regarding the steps taken for the image files for some institutions—including color corrections, sharpening, and contrast and saturation adjustments—was preserved in the layers of the print files that were delivered to RIT. One example of a reported workflow is depicted in Figure 2-1. For the imaging of the targets, there were additional steps taken that were not included in the general workflow descriptions initially provided. These additional steps are listed in column three of Table 2-1. Points of interest include the importance of lighting, flat-fielding, and camera calibration in the image capture, as well as the display background when viewing the artwork image. It was also interesting that the orientation in which the artwork was viewed mattered. The information collected in this part of the project was used as input to develop the guidelines described in Section 5. In order to maintain the anonymity of the participating institutions, no further information about the workflows has been included in this report.

Table 2-1. General steps in documented fine art reproduction workflows

Workflow Process General Function	Specific Workflow Process Steps and Considerations	Additional Steps and Considerations
1. Image capture	Objective targets used	Lighting set up used to illuminate the artwork including polarization
		Camera calibration
		Flat-fielding
2. Proofing and image file preparation	Monitor Calibration	N/A
	Working color space	Screen background used for file viewing
	Viewing environment	Physical image size on the screen
	Sharpening	Image orientation
	Resolution and file size	N/A

<sup>1</sup> - See Figures 3-1 and 3-2 in the Experiments section.

Section 2: Background

Workflow Process General Function	Specific Workflow Process Steps and Considerations	Additional Steps and Considerations
3. Image delivery	File format	Image layers for documentation of image processing conducted
	ICC color management	
	Delivery media	
	Guide prints and proofs	
4. Image archiving	Archiving protocol	Proper handling and storage of guide prints
	Metadata	
	Image naming	

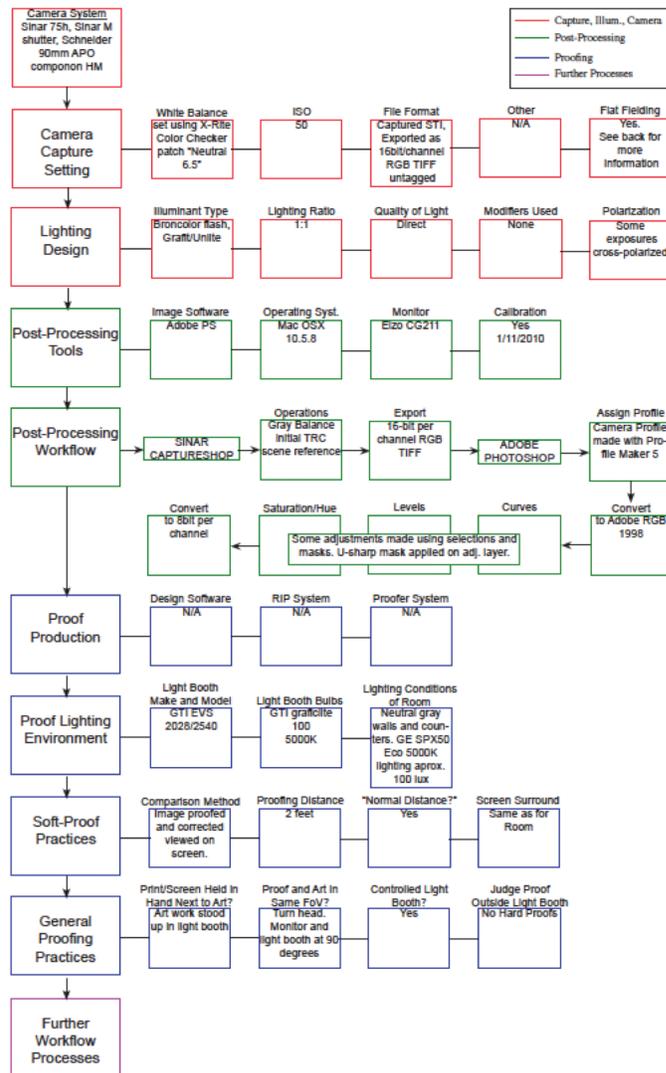


Figure 2-1. Workflow used by one of the participating institutions

## REVIEW OF TEST TARGETS

### What are Test Targets?

“The term *test target* has a different meaning to different people. In general, test targets represent known values from an object or in a digital file, e.g., color patches, digital dots, or lines with known dimensions.”<sup>2</sup> These known values are compared to reproductions and then analyzed to determine how different from or similar to the target the system performed. There are two different types of test targets used in print production: analog targets (also known as physical objects) used for capture, and digital targets (also known as synthetic targets) used in process control.

According to Chung<sup>3</sup>:

The Macbeth ColorChecker is an example of an analog target with 24 physical color patches. When captured by an input device and reproduced, we can compare tone and color relationships. The IT8.7/3 target is a digital file and it consists of hundreds of patches with known CMYK & LAB values. When printed, we can assess print quality quantitatively with the use of optical instruments and associated analysis techniques.

### Why Use Test Targets?

A number of common test targets used in industry are the GretagMacbeth ColorChecker, a neutral gray/white balance target for input devices, and the IT8.7/4 for output devices. The input device analog targets are placed in a photographed scene to provide a reference for neutral balance, white point, or black point in post- production. Other input test targets such as the Universal Test Target (UTT)<sup>4</sup> or the Golden Thread™ System<sup>5</sup> device level target are imaged separately and come with a software package for analysis. The output device digital targets have commonly been used for characterizing print devices, as well as for implementing process control. Furthermore, test targets have become much more sophisticated, in that they can be used to analyze a number of printing variables, such as resolution, registration, addressability, gray balance, smoothness of tonal reproduction, and dot gain.<sup>6</sup> The targets used in analyzing these factors are digital files that are placed in a small region of a page layout. When printed, these targets can reveal a great deal of information about the output device performance as well as in-line process control. For example, registration marks are widely used in industry. These are very useful in checking the registration of each ink. Gray-balance targets are an important tool in generating neutral gray when process inks are being laid down. “This target combines yellow, magenta, and cyan ink [chromatic gray] to determine if each color is being printed at its proper strength and in the proper proportions relative to the other colors.”<sup>7</sup> Such a target, as it provides more control over the tone reproduction of the image, produces a neutral gray, and thus, accurate, color.

2 - Chung, R. (2003). Introduction. In Sigg, F. & Chun, E.M. (Eds.) *Test Targets 3.1* (pp. ii-iii). Rochester, NY: RIT School of Print Media.

3 - Ibid.

4 - [www.image-engineering.de](http://www.image-engineering.de)

5 - [www.imagescienceassociates.com](http://www.imagescienceassociates.com)

6 - Sigg, F. (2002). Test targets showcase: Using synthetic test targets to evaluate output devices. In Chung, R. & Sigg, F. (Eds.) *Test Targets 2.0* (p. 12) Rochester, NY: RIT School of Print Media.

7 - Coudray, M. (2000). *A six-color cure for screen printed halftones*. Retrieved on June 28, 2010, from [www.screenweb.com/content/a-six-color-cure-for-screen-printed-halftones](http://www.screenweb.com/content/a-six-color-cure-for-screen-printed-halftones)

## Analyzing a Test Target

Test targets can be analyzed in three ways: (1) with an instrument that measures color or density information or that magnifies and captures the target, (2) with a software package that analyses the files created, and (3) visually, by simply looking at the target. Measurement devices such as densitometers and spectrophotometers provide density measurements as well as color and spectral reflectance information that permit a wide variety of in-depth analysis. High quality capture of certain targets allows for dot patterns and line resolution to be discerned. Targets that are analyzed visually are generally pass/fail and very effective for a quick check in determining that no major problems have arisen.

This evaluation of the various test targets in the graphic arts industry allowed the researchers to categorize them. Figure 2-2 is an image of all four pages of the listing to show the depth of information provided (see Appendix B for the tables in their entirety – please note that this is not a comprehensive listing). The tables show a number of readily used targets in the graphic arts industry with their general category and a description of how they are intended to be used. The table headings are Target (displaying an image of the target); Topic (the general category); Name, Description, Quality Measure (what image quality attribute it is intended to be able to measure); Analysis (whether it is intended to be analyzed quantitatively with a device or a software, or visually), and Origin. For museums and companies in the graphic arts looking to use test targets, this table can provide an understanding of what is available and help them to rule out test targets that do not meet their needs.

Target	Topic	Name	Description	Quality Measure	Analysis	Origin
	Color	ColorChecker	Measurement of color quality - it consists of 24 color patches and a grayscale. The ColorChecker is used to ensure color accuracy in printing and reproduction.	Color Accuracy	Measurement	USA
	Color	D50 Illuminant	Measurement of color quality - it consists of 24 color patches and a grayscale. The D50 Illuminant is used to ensure color accuracy in printing and reproduction.	Color Accuracy	Measurement	USA
	Color	Munsell ColorChecker	Measurement of color quality - it consists of 24 color patches and a grayscale. The Munsell ColorChecker is used to ensure color accuracy in printing and reproduction.	Color Accuracy	Measurement	USA
	Density	Densitometer	Measurement of density - it consists of a series of lines and dots. The Densitometer is used to ensure density accuracy in printing and reproduction.	Density Accuracy	Measurement	USA
	Resolution	Resolution	Measurement of resolution - it consists of a series of lines and dots. The Resolution target is used to ensure resolution accuracy in printing and reproduction.	Resolution Accuracy	Measurement	USA
	Registration	Registration	Measurement of registration - it consists of a series of lines and dots. The Registration target is used to ensure registration accuracy in printing and reproduction.	Registration Accuracy	Measurement	USA
	Color	ColorChecker	Measurement of color quality - it consists of 24 color patches and a grayscale. The ColorChecker is used to ensure color accuracy in printing and reproduction.	Color Accuracy	Measurement	USA
	Color	D50 Illuminant	Measurement of color quality - it consists of 24 color patches and a grayscale. The D50 Illuminant is used to ensure color accuracy in printing and reproduction.	Color Accuracy	Measurement	USA
	Color	Munsell ColorChecker	Measurement of color quality - it consists of 24 color patches and a grayscale. The Munsell ColorChecker is used to ensure color accuracy in printing and reproduction.	Color Accuracy	Measurement	USA
	Density	Densitometer	Measurement of density - it consists of a series of lines and dots. The Densitometer is used to ensure density accuracy in printing and reproduction.	Density Accuracy	Measurement	USA
	Resolution	Resolution	Measurement of resolution - it consists of a series of lines and dots. The Resolution target is used to ensure resolution accuracy in printing and reproduction.	Resolution Accuracy	Measurement	USA
	Registration	Registration	Measurement of registration - it consists of a series of lines and dots. The Registration target is used to ensure registration accuracy in printing and reproduction.	Registration Accuracy	Measurement	USA

Figure 2-2. Test targets used within the graphic arts

## Test Targets Used in Museum Workflows

Most of the participating institutions reported the use of a test target at the capture stage; some institutions are also using the targets further along in the workflow. Along with these variations in usage is a range of understanding in how to implement test targets into a workflow. Analyzing the workflows showed not only that each institution's

workflow differed, but that a number of museums use the same target in different ways. For example, the most common target used—the Macbeth ColorChecker 24—was often captured alongside the artwork, and at other times in addition to the artwork. Still other museums do not capture a ColorChecker at all. After the input stage, each institution has their own method of utilizing such a target, and often they are not used at all.

There are competing ideas as to what works best. In some cases, the approach taken appears to be successful, but in others, personnel seem to lack understanding of how to use a test target to their advantage. For example, one institution imaged a Macbeth ColorChecker, but had no recorded use for the digitized target as a reference downstream.

In conversations with fine art printing professionals, the consistent conclusion was that it was beneficial in printing to have a reference target that has traveled with the digitized artwork from capture. Although certain imperfections may be present, they thought that this reference allowed the printer to have both a qualitative and quantitative measure on which to base the output. In most cases, the printer does not have the original artwork present, so this reference becomes the only reference to the original scene and thus, is perceived as quite valuable.

In summary, the conclusions from the test targets review were as follows:

- The use of test targets for camera setup is seen by many as very beneficial.
- The research indicated that there was great variation in the levels of test target implementation and understanding.
- Within museums, test targets are at times viewed as misleading due to issues with metamerism. This has to be taken seriously and addressed with future research.
- Multiple printing/color professionals agreed that it is beneficial to have a qualitative color reference within the print-ready file that has traveled with the artwork from capture. However, it has to be clearly understood what this reference can and cannot do—it is certainly not a color management tool.

## REVIEW OF RELATED STANDARDS

Standards are the basis of many of the workflows used in the art image interchange cycle. It was therefore important to review relevant related standards. This review of standards is a continuation of a review conducted by Murphy<sup>8</sup>. Her review focused on capture. While this review is still relevant, some standards have been updated and new standards have been introduced. This continuation of the review of relevant standards was focused on workflow and output.

Within the graphic arts and photography industries, many standards have been implemented to create consistent practices. This enables better communication and understanding of the workflows and procedures that otherwise are often unused or misused. Consistency of procedures also enables companies to produce accurate and repeatable results. Table 2-2 shows a listing of international standards and specifications that are used in the graphic arts and photographic industries for workflow and output procedures. These are the main standards that apply to the reproduction of fine artwork, and thus are standards that could be implemented within museums and other cultural heritage institutions.

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8 - Murphy, E.P. (2005). *A testing procedure to characterize color and spatial quality of digital cameras used to image cultural heritage*. MS Thesis, College of Imaging Science, Rochester Institute of Technology, Rochester, NY.

## Section 2: Background

The main areas that these standards pertain to are color-space test images, viewing conditions, proofing, printing aims, and characterization data. A document is available online that contains descriptions of each standard/specification. Within these descriptions are basic summaries of what can be found within the standard/specification document as well as their main applications. Appendix A shows how the related standards fit within the different areas of the workflows summarized in Table 2-1.

Table 2-2. List of relevant workflow and printing standards for the graphic arts industry

Title	Topic	No.	Date	Org.	Ed.	TCs
<b>Workflow Standards</b>						
Graphic technology - Prepress digital data exchange -- Part 1: CMYK standard colour image data (CMYK/SCID)	Test image	12640-1	1997	ISO		ISO/TC 130 (Graphic Technology)
-- Part 2: XYZ/sRGB encoded standard colour image data (XYZ/SCID)	Test image	12640-2	2004	ISO		ISO/TC 130 (Graphic Technology)
-- Part 3: CIELAB standard colour image data (CIELAB/SCID)	Test image	12640-3	2007	ISO		ISO/TC 130 (Graphic Technology)
-- Part 4: Wide gamut display-referred standard colour image data (AdobeRGB(1998)/SCID)	Test image	12640-4	n/a	ISO	UD	ISO/TC 130 (Graphic Technology)
Viewing condition -- Graphic technology and photography	Viewing conditions	3664	2009	ISO	3rd	ISO/TC 42 (Photography)
Graphic technology -- Displays for colour proofing -- Characteristics and viewing conditions	Proofing	12646	2008	ISO	2nd	ISO/TC 130 (Graphic Technology)
<b>Printing Standards</b>						
Graphic technology – Process control for the reproduction, proof and production prints – Part 1: Parameters and measurement methods	Measurement methods	12647-1	2004	ISO	2nd	ISO/TC 130 (Graphic Technology)
-- Part 7: Proofing processes working directly from digital data	Printing aims	12647-7	2007	ISO	1st	ISO/TC 130 (Graphic Technology)
Graphic technology – Methods of adjustment of the colour reproduction of a printing system to match a set of characterization data	Matching to characterization data	10128	2009	ISO	1st	ISO/TC 130 (Graphic Technology)
Graphic technology - Color characterization data for coldset printing on newsprint	Characterization data	TR 002	2007	ANSI CGATS	--	
Graphic technology - Color characterization data for SWOP® proofing and printing on U.S. Grade 3 coated publication paper	Characterization data	TR 003	2007	ANSI CGATS	--	

Title	Topic	No.	Date	Org.	Ed.	TCs
Graphic technology - Color characterization data for SWOP® proofing and printing on U.S. Grade 5 coated publication paper	Characterization data	TR 005	2007	ANSI CGATS	--	
Graphic technology - Color characterization data for GRACoL® proofing and printing on U.W. Grade 1 coated paper	Characterization data	TR 006	2007	ANSI CGATS	--	

## THE GEOGRAPHY OF FINE ART BOOK PRINTING

Another area of interest was the geography of fine art book printing. If the printing of a book happens half a world away, communication between the publication staff and the printer gets more difficult. This was a pilot study that was not meant to be comprehensive, but was meant to help paint a picture of the current state of fine art book printing. This pilot study was completed in early 2010, and therefore the data covers books printed through 2009. This data was also compared to two previous pilot studies.

### Methodology

For this study, only the physical makeup of the books was concerned. Data was collected for 35 to 40 random books within each category per bookstore (depending on the size of the bookstore). The only restrictions on choosing the books were that they had to fit the requirements of the assigned category, and they had to cost at least US\$25.00.

Eight different bookstores in New York and Texas were visited in order to diversify the data collection. Visual inspection with a magnifying glass was used to verify that indeed the prints were either full color or black and white. Four different categories were studied:

1. Hard bound books with only black and white inside
2. Hard bound books with full color inside
3. Soft bound books with only black and white inside
4. Soft bound books with full color inside

Books covering four different subjects were selected:

1. Photography
2. Architecture
3. Artist's monograph
4. Art history and criticism

For each book, the following information was recorded: category, subject, title, publisher, ISBN, country of manufacture, printer, number of pages, price, and year of publication. Several factors were not taken into consideration. For example, the paper stock and the finished size of the book were not recorded. Extras such as

## Section 2: Background

CDs were not taken into account. Features like pop-ups and gatefolds were not observed. All these characteristics contribute to the complexity of the book and also influence the price.

## Results

Since fine arts books are mostly printed in full color and hard bound, we did not end up with a balanced number of samples from each category (see Figure 2-3, n=252). This made the comparison of categories slightly biased.

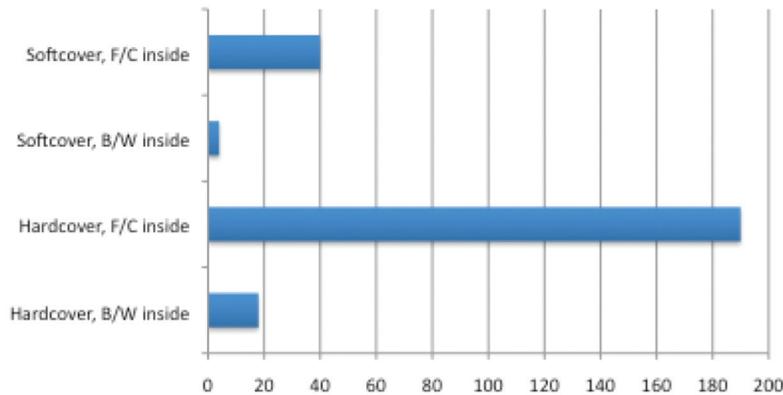


Figure 2-3. Total books surveyed by category

Of the books surveyed, 8% were printed in the United States, 51% were printed in Europe, and 41% were printed in Asia. As seen in Figure 2-4, the books printed outside of the US come from many different countries, with Italy, China, and Singapore together representing over 60% of the books.

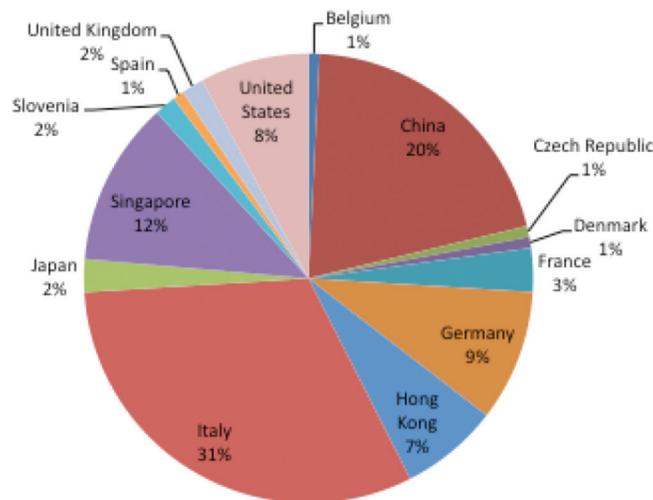


Figure 2-4. Percentage of books printed by country

Breaking down the books by category showed that the more complex a book is, the more likely it is that it will be printed overseas (see Figure 2-5). Hard cover books were more likely to be printed in Europe, while soft cover books were more likely to be printed in Asia.

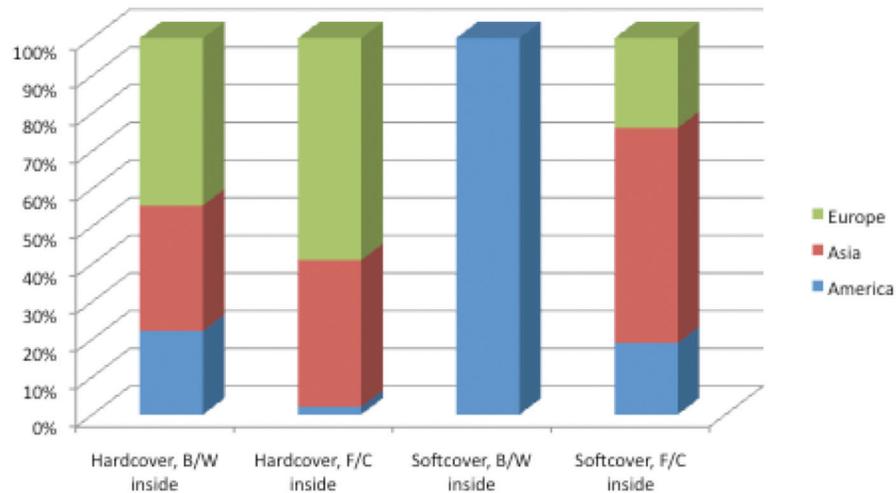


Figure 2-5. Books printed in Europe, Asia and the US by category

Analyzing the data by year revealed that Italy has significantly grown its market share during the last three years, followed by Germany, China and Singapore (see Figure 2-6). Even though the US has never been a major location for fine art book printing, its market share decreased during the period from 2000 to 2005.

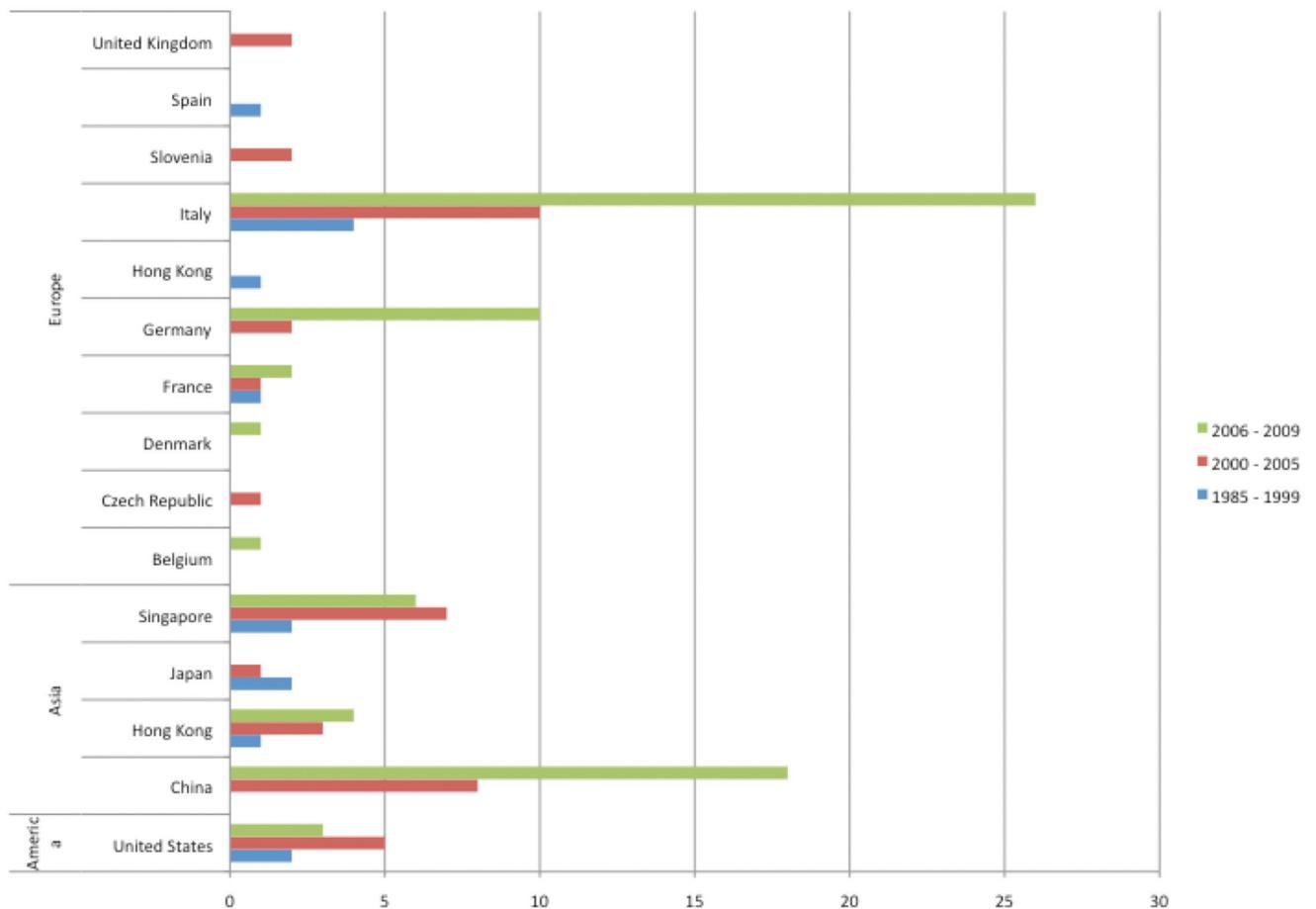


Figure 2-6. Geography of fine art books printed over different time periods

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All paperback one-color books published in the US were also printed in the US. By contrast, all hardcover, full-color and black and white books were printed overseas. Books printed overseas were produced mostly in Asia and Europe. It is important to highlight that the prices for the different continents were in the same range. Some interesting trends also emerged: for example, almost no book printed in Europe cost less than \$10 per 100 pages, and most of them were priced between \$20 and \$40.

## SECTION 3: EXPERIMENTS

Research has been previously conducted on the capture stage of the art image reproduction process. This research found that current capture processes are variable and that these varied processes can result in significant perceptual differences in the color appearance and image quality of digital images.<sup>1</sup> The present study examined the perceptual image quality of the entire reproduction process with an emphasis on the end use of the art image interchange cycle.

In the realm of imaging and, more specifically, image reproduction, image quality is generally defined by several characteristics including the color and tone rendition, sharpness, and uniformity. Objective measures have been developed for these characteristics, as well as other more technology-specific characteristics. While the relationships between single characteristics and perceived image quality is generally known, defining image quality as a function of all of these characteristics is more complex and can vary with the technology, the original, and the observer. The use of human observers remains the simplest and the most reliable evaluation method for overall perceptual image quality. In this study, renditions of original artwork were generated following a variety of workflows and using different printing technologies. The relative image quality was subsequently evaluated by human observers. Objective targets were also imaged and reproduced in an effort to understand the image characteristics important to the perceived image quality of fine art reproductions.

To evaluate the image quality attainable with the reproduction workflows in practice today, a series of experiments were conducted where participating cultural heritage institutions captured a variety of ‘artwork’ and objective targets. The objective targets were included with the goal of finding measurable image characteristics that correlated with the subjective results. It was hypothesized that color and tone reproduction, sharpness, and uniformity might be among the key image characteristics in determining the perceptual quality of fine art reproductions. As such, the objective targets included: a Macbeth Color Checker and a paint patch target for assessing color and tone measurement throughout the reproduction process, and the Universal Test Target<sup>®</sup> from Image Engineering for assessing color, tone, sharpness, and uniformity at capture (see Figure 3-1).

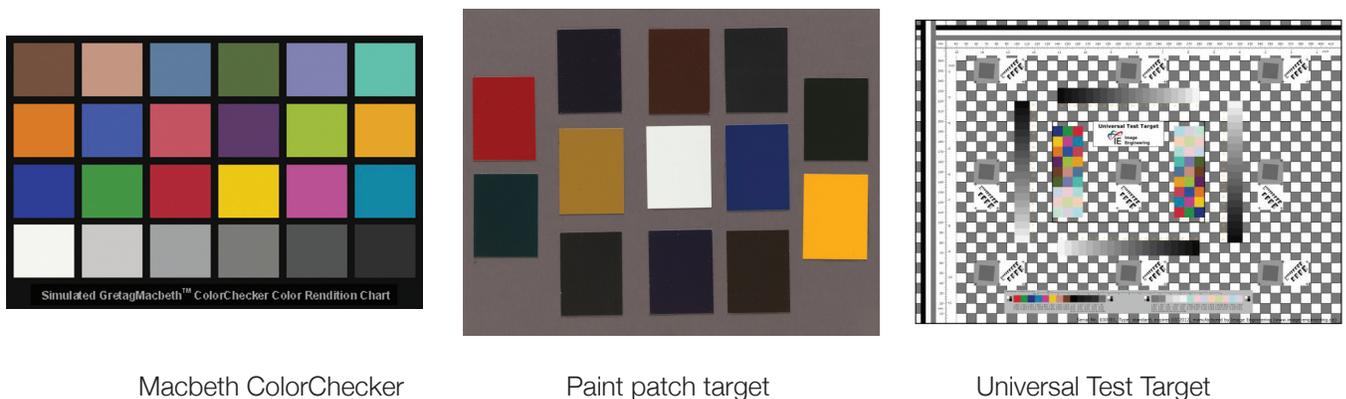


Figure 3-1. Objective targets used in the study

<sup>1</sup> - Berns, R.S., Frey, F.S., Rosen, M.R., Smoyer, E.P.M., & Taplin, L.A. (2005, April). *Direct digital capture of cultural heritage: Benchmarking American museum practices and defining future needs – Project report* (Technical report). Rochester, NY: Munsell Color Science Laboratory. Retrieved from [www.cis.rit.edu/museumSurvey/documents/Benchmark\\_Report\\_April.pdf](http://www.cis.rit.edu/museumSurvey/documents/Benchmark_Report_April.pdf)

### Section 3: Experiments

The familiar Macbeth Color Checker is a target that was created in the 1970s specifically for the evaluation of photographic color reproduction.<sup>2</sup> The paint patch target was constructed for this study by performing drawdowns with the same paints used to make the oil paint pictorial targets (see Table 3-1). Patches were clipped from the most uniform areas of the drawdowns for use in the target. Finally, the Universal Test Target (UTT) is a commercially available target developed to evaluate the quality of the image capture.<sup>3</sup>

Table 3-1. Paints used in creating the artwork for the experiments

Oil Paints (Other paintings)	Acrylic Paints (Firelight)	Watercolors (Mountain)
Cadmium Yellow	Cadmium Yellow	
Sap Green	Sap Green	Sap Green
Burnt Umber	Burnt Umber	Raw Umber
French Ultramarine	French Ultramarine	
Paynes Gray	Paynes Gray	
Cobalt Blue	Cobalt Blue	Cobalt Blue
Titanium White	Titanium White	
Burnt Sienna	Burnt Sienna	
Ivory Black	Ivory Black	
Yellow Ochre	Yellow Ochre	Yellow Ochre
Phthalo Blue	Phthalo Blue	Phthalo Blue
Viridian Hue	Viridian Hue	Viridian Hue
Cadmium Red Deep Hue	Cadmium Red Deep Hue	Alizarin Crimson

The artwork used in this study included eight pictorial works intended to provide a variety of images for exploring the impact of scene content and various image media while keeping the number of test stimuli manageable. All artwork was commissioned or acquired from sources that allowed for unrestricted reproduction rights. The pieces included an aquatint entitled 'Still Life', a historic platinum print photographic portrait ('Photograph'), an acrylic painting entitled 'Firelight', a watercolor entitled 'Mountain', and four oil paintings: 'Daisies', 'Orchid', 'Night Sky', and 'Inspired by Monet's Waterloo Bridge' ('Bridge'). The artwork is shown in Figure 3-2.

2 - McCamy, C.S., Marcus, H., & Davidson, J.G. (1976). A color-rendition chart. *Journal of Applied Photographic Engineering*, 2(3), 95-99.

3 - Other commercially available test targets used for assessing image quality at capture in fine art reproduction include the Golden Thread® target from Image Science Associates.

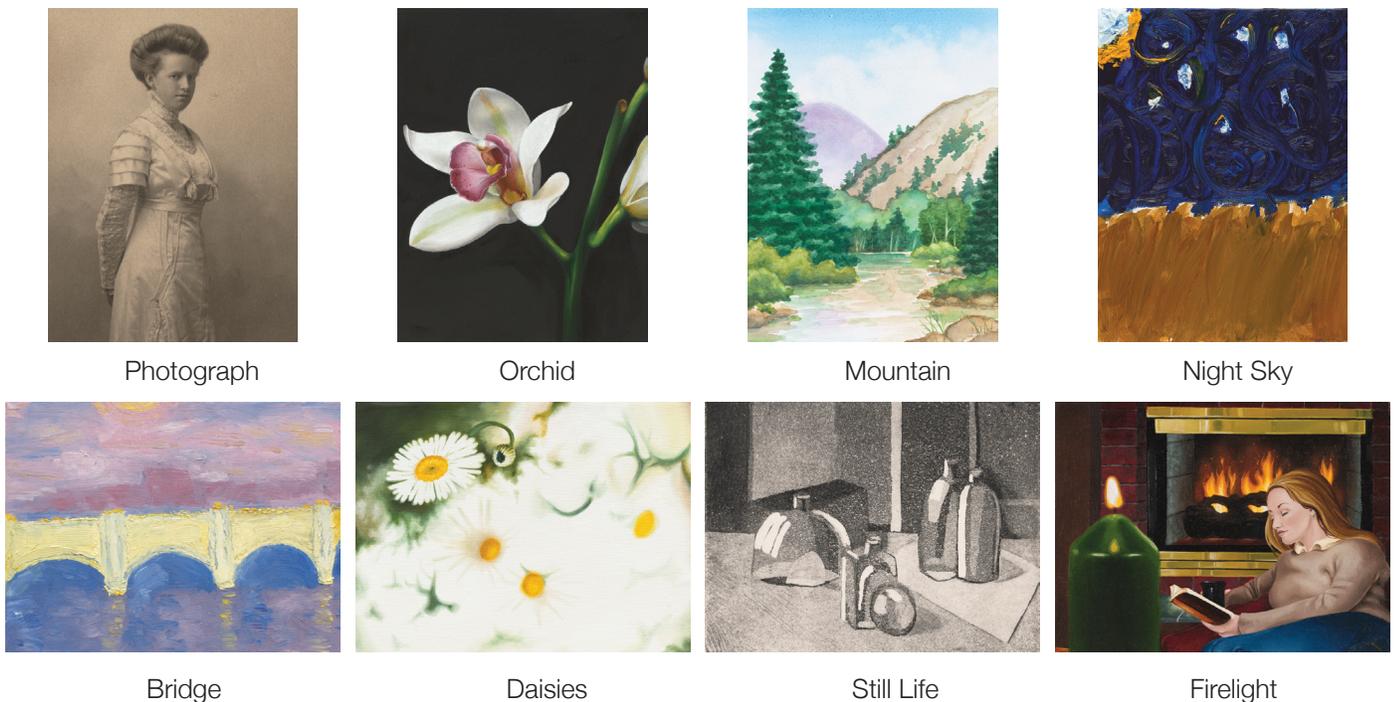


Figure 3-2. The artwork included in the experimentation

The aquatint (*Still Life*) and photograph were included to expand the range of media and to represent monochromatic art such as early photography and works on paper, which can be surprisingly difficult to reproduce.<sup>4</sup> The photograph was obtained from the collection of photographs at the Image Permanence Institute, Rochester Institute of Technology (RIT). The *Daisies* painting is a relatively light, or high-key, scene. In contrast, the *Firelight* and *Orchid* paintings were commissioned to provide originals that are relatively dark but that cover a high dynamic range. Many fine art works, especially the early Dutch masters, fit this description. The *Bridge* painting, which has a mixture of blues and purples, was included because research has shown that some blues are difficult to reproduce, due to differences in the way the camera and the human eye “see” certain blue pigments.<sup>5</sup> At least in part for this reason, Monet’s ‘Waterloo Bridge’ has been cited as a painting that has been difficult to acceptably reproduce.<sup>6</sup> The *Night Sky* painting features a mixture of blues that were also expected to be particularly difficult to simultaneously reproduce well. The *Mountain* painting was commissioned so that watercolor would be represented in the image set. Again, blue and purple were featured in this work.

Each institution delivered digital files and information regarding its workflow. If the institution normally would provide guide prints<sup>7</sup> to their printers, then they were directed to supply them for this study. Prints from the digital files were then generated on the Heidelberg Speedmaster at the RIT Printing Applications Laboratory (PAL) using Prinergy Workflow 3.0.2.2<sup>®</sup> and Kodak Thermal Gold<sup>®</sup> plates on a VLF 5080 Quantum<sup>®</sup> plate setter and following the ISO 12467 protocol. Images of the press and the lab setting are shown in Figure 3-3. All of the pre-

4 - Discussion between the researchers.

5 - Berns, R.S. (2000, May). *The science of digitizing two-dimensional works of art for color-accurate image archives – Concepts through practice* (Technical report). Rochester, NY: Munsell Color Science Laboratory. Retrieved from [www.cis.rit.edu/mcsl/research/PDFs/Berns\\_art\\_digitize\\_lowres.pdf](http://www.cis.rit.edu/mcsl/research/PDFs/Berns_art_digitize_lowres.pdf)

6 - Discussion between the researchers.

7 - Guide prints are often generated as part of the art image reproduction process to give the print shop direction on how the color and contrast of the printed image should appear under specified lighting conditions.

### Section 3: Experiments

press operations were performed by the same person, including the transformations from RGB to CMYK and the creation of the print plates, and all of the print runs were conducted by the same press operator. For the institutions providing guide prints, adjustments were made on the press to achieve a closer visual match to the guide prints under D50 lighting conditions. Visual assessments were made by the researchers and PAL personnel to determine if such adjustments were necessary.<sup>8</sup>



Figure 3-3. The Heidelberg Speedmaster at RIT's Printing Applications Laboratory

Using the prints made from the delivered digital files, a series of psychophysical experiments were conducted to generate relative visual ratings of image quality. These included a study of the impact of viewing lighting on the perception of image quality, an evaluation of the fine art reproduction workflow on perceived image quality both in print and on an LCD display, an evaluation of the effect of the presence of the original on perceived image quality in print and on an LCD display, and a comparison of the perceived image quality of offset lithographic prints to electrophotographic prints. A list of the experiments conducted and the objectives of each is provided in Table 3-2.

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8 - Only minor adjustments were possible on the press. Larger adjustments would have required new plates, which was cost-prohibitive for this study. Larger adjustments were also mostly unnecessary, as most of the initial print runs produced prints that closely approximated the provided guide prints.

Table 3-2. Experiments conducted as part of the Current Practices in Fine Art Reproduction project

Experiment Number and Title	Objective
Experiment I - The Impact of Lighting on Perceived Quality of Fine Art Reproductions (hard copy)	Evaluate the effect of changes in viewing illumination on the perceived quality of printed fine art reproductions
Experiment II - Evaluating CATs as Predictors of Observer Adjustments in Soft Copy Fine Art Reproduction (soft copy)	Evaluate trends in color adjustments made by museum, library, and archive personnel to artwork reproductions presented on displays in order to better understand how images should be processed to effectively represent original artwork on-screen
Experiment III - The Impact of Workflow on Perceived Reproduction Quality of Fine Art Images (hard copy and soft copy)	Understand the relative reproduction quality being achieved by fine art workflows in use today
Experiment IV - The Impact of Workflow on Perceived Quality of Fine Art Images (hard copy and soft copy)	Understand the relative perceived quality being achieved by fine art workflows in use today in generating images being evaluated without the original artwork present
Experiment V - The Impact of Workflow on Perceived Quality of Fine Art Images being Viewed on the Web (soft copy)	Understand the relative quality being achieved by fine art workflows in use today in generating images to be viewed on the web
Experiment VI - The Perceived Image Quality Of Printed Fine Art Reproductions (hard copy)	Compare the relative perceived image quality of prints made on an offset lithographic press to those made on an electrophotographic digital press

The experiments involving print reproductions primarily took place in a D50 viewing booth in the Display and Perception Lab in the Color Science Hall at RIT. The experimental setup is shown in Figures 3-4 and 3-5.



Figure 3-4. Hard copy experimental setup



Figure 3-5. Hard copy experiment process

The observers who participated in the experimentation for this project generally consisted of individuals in the cultural heritage community. The observers included librarians, photographers, curators, art teachers, conservators, and imaging science students and staff with an interest in fine art reproduction. Observers were tested for color vision anomalies with Ishihara plates. One observer in Experiment I had color vision test results that showed evidence of a significant red-green anomaly. His results were analyzed separately.

## EXPERIMENT I: THE IMPACT OF LIGHTING ON THE PERCEIVED QUALITY OF FINE ART REPRODUCTIONS

Art reproductions are viewed under various lighting conditions. These may include light booths, office fluorescents, museum shop lighting, living room lamps, and gallery lighting. It is therefore important to understand and quantify the significance of this effect on perceived image quality. For this reason, an experiment was conducted using renditions of *Daisies*, *Night Sky*, *Photograph*, and the paint patch target from three participating institutions. This experiment evaluated the impact of changes in the color of the lighting under which the artwork and reproductions are being viewed on the perceived image quality.

### Methodology

The experiment was conducted under two lighting conditions: the D50 booth in the Display and Perception Lab as well as the 'Horizon' lighting setting of a Macbeth light booth in a neighboring viewing room. A D50 light booth was used because this is the standard lighting condition in graphic arts workflows for print production. The Horizon lighting condition was chosen because its warm light is more representative of that typically used in galleries. The correlated color temperatures of the viewing booths, as measured with a PhotoResearch 650, were 4911°K for the D50 booth and 2323°K for the Horizon setting of the Macbeth booth. The spectral power curves for the two light sources used in the experiment are shown in Figure 3-6.

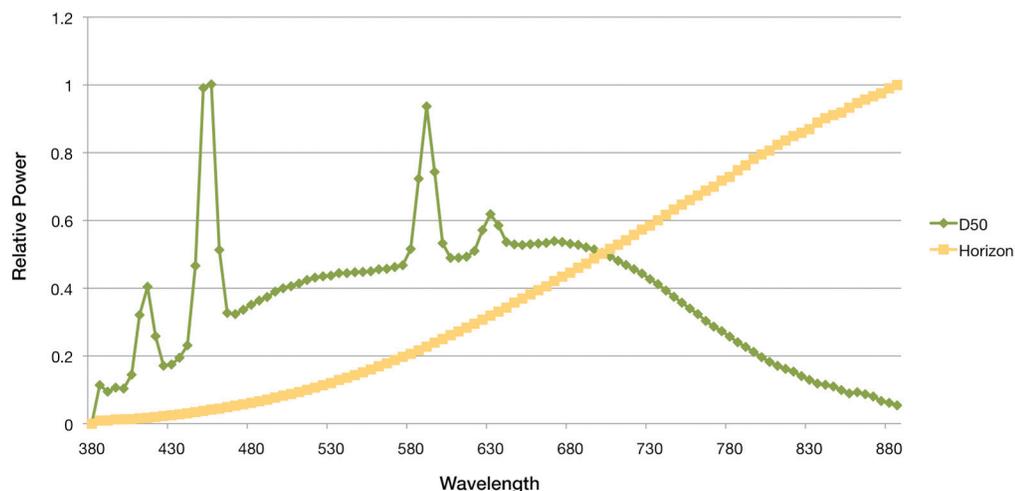


Figure 3-6. Spectral power curves for the lights in the two viewing booths used in the experiments

The prints for this experiment were made on NewPage Sterling 80# Gloss Text paper with Biolocity inks. This paper and ink combination was selected because it had recently been certified on the target equipment, eliminating the need for an additional paper certification run. However, the gloss-coated paper was not considered the ideal choice for artwork reproduction. For this reason, a matte finish varnish was used. Prints with and without the varnish were visually compared by the researchers and PAL personnel, and it was determined that the prints with the varnish provided a closer match to the guide prints under D50 lighting conditions. The prints made with additional visual adjustments on the Heidelberg Speedmaster for one of the institutions were then used as guide prints for an additional run made on the HP Indigo 5500 on the same paper used in the offset run. With the print sets made on the offset and electrophotographic presses for each of three institutions as well as visually adjusted

## Section 3: Experiments

prints made for two of the institutions, a total of eight reproductions were made for each piece of target artwork for the lighting experiment.

In the psychophysical experiment, the observers were shown two of the eight reproductions for each piece of the artwork and asked to determine which print was a better reproduction of the original. When this question was answered, a third print was presented and the observer asked to place it relative to the first two. This process continued until all eight of the reproduction prints were ranked. The testing was repeated in each light booth. A total of 16 observers participated in this experiment.

## Results and Discussion

The results of the psychophysical experimentation conducted using the prints made from the files delivered by the three participating institutions are shown in Figures 3-7 through 3-13. Figure 3-7 shows the mean rankings that the observers assigned the reproductions of the image set for each workflow and under each lighting condition.<sup>9</sup> The data plotted for W1-W3, W4-W5, and W6-W8 represent the workflows for the three participating institutions. W1, W5, and W6 represent the reproductions made using the electrophotographic press. W2, W4, and W7 represent the reproductions made following the ISO 12647 protocol. W3 and W8 represent the reproductions made by visually adjusting to the guide print during the print run. These results indicate that, when the rankings are averaged over the entire image set, there is little statistically significant difference for any of the prints under the D50 lighting conditions. However, the W2 ‘numbers’ workflow may be slightly better than two of the ‘digital’ workflows, W5 and W6. Under the Horizon lighting condition, however, the W1 digital workflow and the W4 numbers workflow were significantly better than the other workflows, and the W8 ‘visual’ workflow was significantly worse.

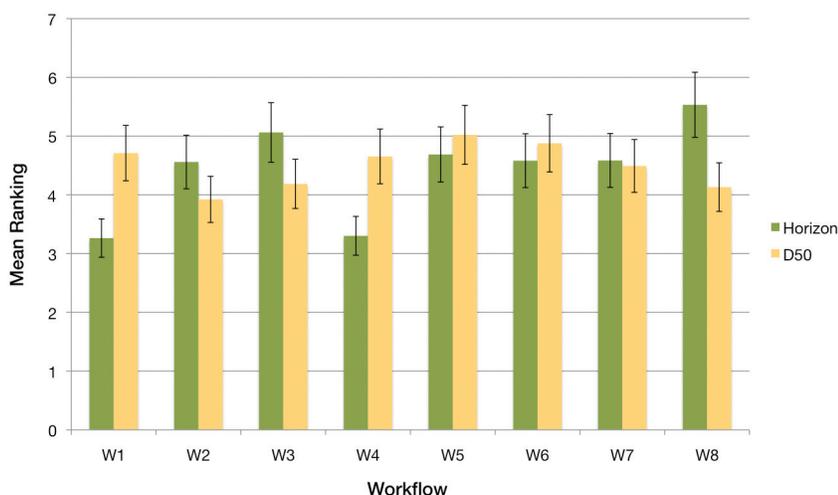


Figure 3-7. Mean rankings for the print reproductions made using the eight workflows averaged over the four images

Figures 3-8 through 3-11 show the results for each of the images individually. The results for *Daisies* are shown in Figure 3-8. These results indicate that the change in lighting had only a minor impact on the relative rankings for the various workflows. Statistically significant differences were only found for two of the digital workflows

<sup>9</sup> - In this experiment, the best reproduction was assigned a value of ‘1’ and the worst-perceived reproduction was assigned a value of ‘8’, making lower ranking values indicative of better reproduction.

(W1 and W5), and one of the numbers workflows. The D50 lighting yielded better relative rankings than the Horizon lighting for the digital workflow for one institution, while the digital workflow for another institution and the numbers workflow for the third institution had better relative rankings under Horizon lighting than D50. Still, for both lighting conditions, the W1 and W5 digital workflows were generally considered to be the worst renditions, while the W4 and W7 numbers workflows and the W8 visual workflow were considered to be the best reproductions.

Figures 3-9 and 3-10 show the results for *Night Sky* and the paint patch target, respectively. For these two images, there were fewer workflows that were ranked statistically equivalent under the two lighting conditions. Only the W4 and W6 renditions for *Night Sky* and W1, W4, and W8 for the target did not change relative rankings significantly. Some of the differences between the two light sources became more pronounced. The *Night Sky* print for W2 was one of the best prints under Horizon lighting while it was one of the worst under D50 lighting. The same is true for the W6 paint patch target. In contrast, the W2 and W3 renditions of this image were among the best under D50 lighting but among the worst under Horizon lighting.

The largest effect of the change in lighting conditions, however, can be seen for the results of *Photograph* as shown in Figure 3-11. For this image, the best renditions under Horizon lighting (W1, W4 and W5) were the worst under D50 lighting. The prints from the remaining workflows were equivalently good under D50 lighting and equivalently bad for Horizon lighting, although W7 and W8 were a little worse than the others. All of the renditions had statistically significant differences under the two lighting conditions. This result was a key finding for this experiment: it suggests that prints made to match under one lighting specification may look ‘just wrong’ under another lighting condition. This is an important point to understand when considering where prints will be evaluated and what viewing illuminant should be specified in the print workflow.

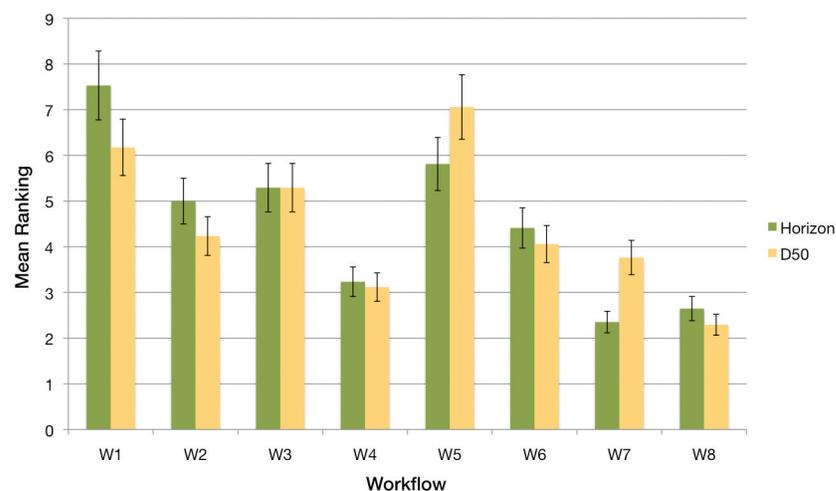


Figure 3-8. Mean rankings for the print reproductions of Daisies under D50 and Horizon lighting conditions

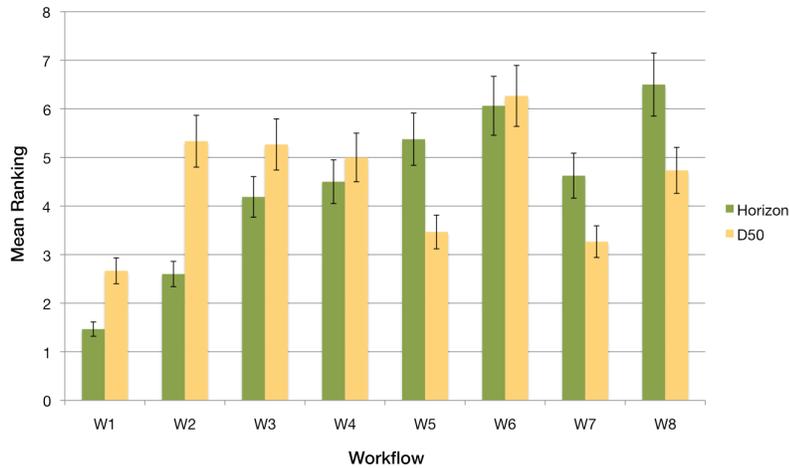


Figure 3-9. Mean rankings for the print reproductions of Night Sky under D50 and Horizon lighting conditions

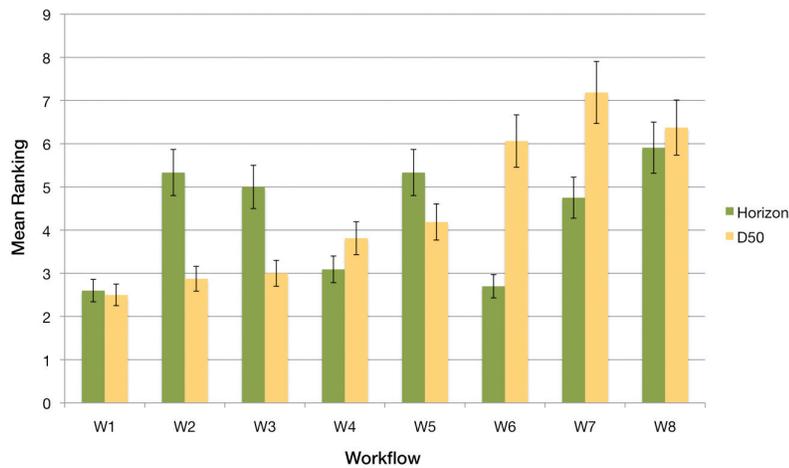


Figure 3-10. Mean rankings for the print reproductions of the paint patch target under D50 and Horizon lighting conditions

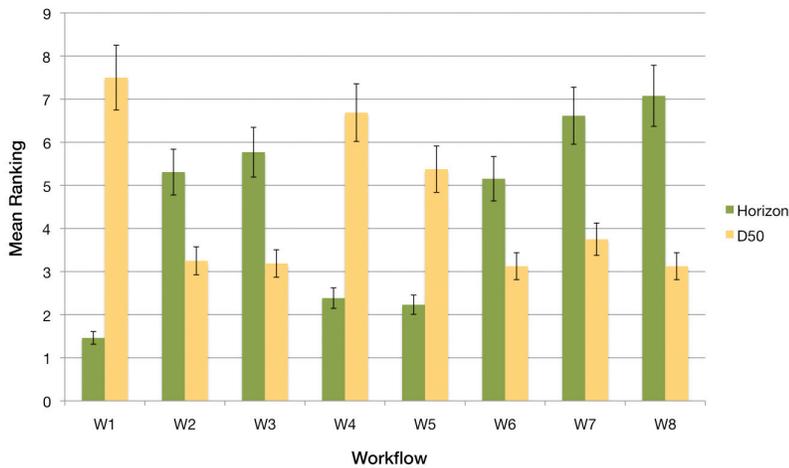


Figure 3-11. Mean rankings for the print reproductions of Photograph under D50 and Horizon lighting conditions

To better understand why the appearance of and, consequently, the rankings for *Photograph* changed so drastically under the two light sources, spectral measurements were made of this image. The spectral reflectance curves for measurements made at four locations on the original (shown in the left graph of Figure 3-12) are revealing. These curves are actually strikingly straight. This is in stark contrast to measurements made for paintings or prints, which are typically generated from four or more pigments, each reflective in a limited segment of the visual spectrum. (The right graph of Figure 3-12 provides an example of these expected measurements.) Such straight reflectance curves are exceedingly difficult to reconstruct using pigments. As a result, any reproduction of the original will be highly metameric, meaning that a reproduction that matches visually under one light source will not match under another, as was seen in this experiment.

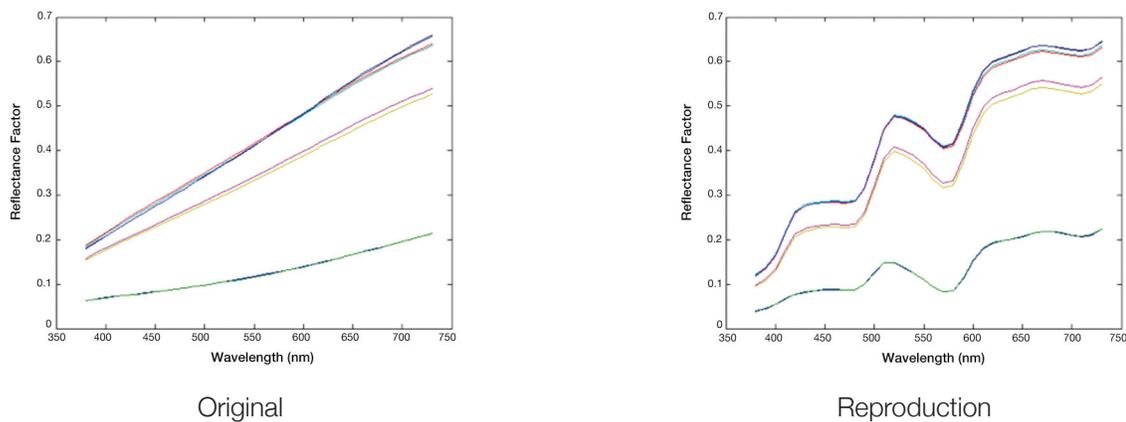


Figure 3-12. Spectral curves measured at four locations on the photograph original and one of the reproductions

Figures 3-13 and 3-14 show the acceptability results under D50 and Horizon lighting conditions, respectively. The results shown in Figure 3-13 indicate that the *Daisies* and *Photograph* prints were more consistently found to be acceptable than the *Night Sky* and paint patch target prints. Five of the workflows for both *Daisies* and *Photograph* yielded prints that were acceptable to about a third or more of the observers. The highest percentage of observers (about 75%) found the W8 workflow to be acceptable for *Daisies*, while over 60% of observers found the W3 workflow to be acceptable for *Photograph*. *Night Sky* only had three workflows with an acceptability rate of over 30%, while the paint patch target had none (although W1 and W2 were close). It is interesting to note that, although the paint patch reproductions used to create the images were rarely found to match acceptably with the original paints, the reproductions of scenes created with those paints were found to be acceptable three-quarters of the time for a given painting and under a given viewing condition.

The results in Figure 3-14 indicate that far fewer print renditions were found to be acceptable under the Horizon lighting conditions. Only three print renditions for *Daisies* and *Photograph* and one rendition for *Night Sky* were found to be acceptable by more than one-third of the observers, while the print found to be acceptable at the highest rate was only found to be acceptable just over 50% of the time. This result makes sense since the image files were created under the assumption that the prints would be evaluated under D50 lighting conditions. This is another important result of this testing: prints viewed under lighting conditions other than that specified in the print workflow may be more frequently found to be unacceptable reproductions of the original.

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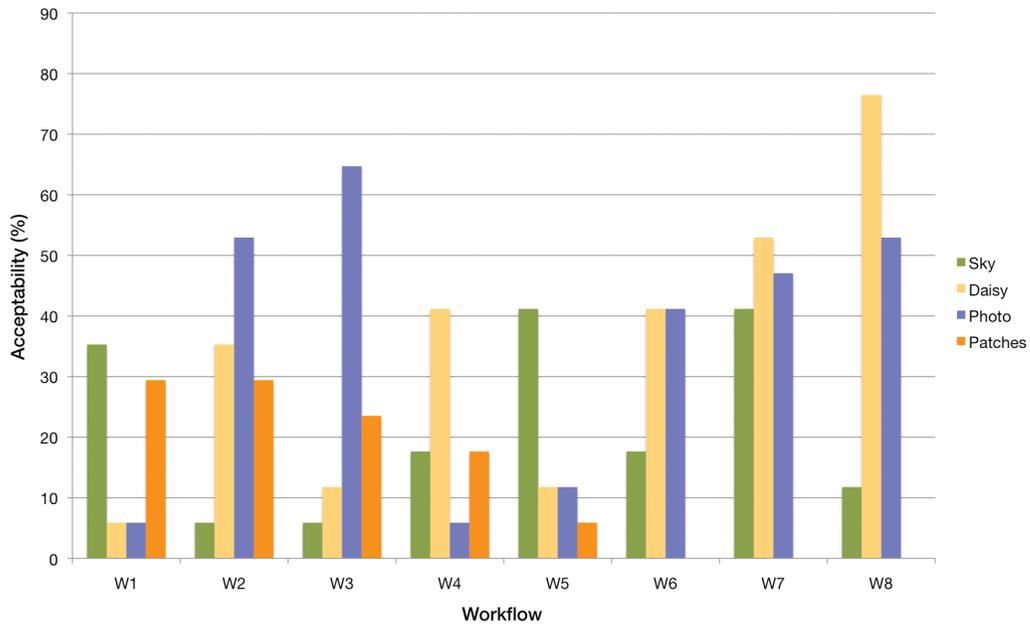


Figure 3-13. Percent of observers that found each of the print reproductions to be an acceptable representation of the original when viewed under D50 lighting conditions by workflow

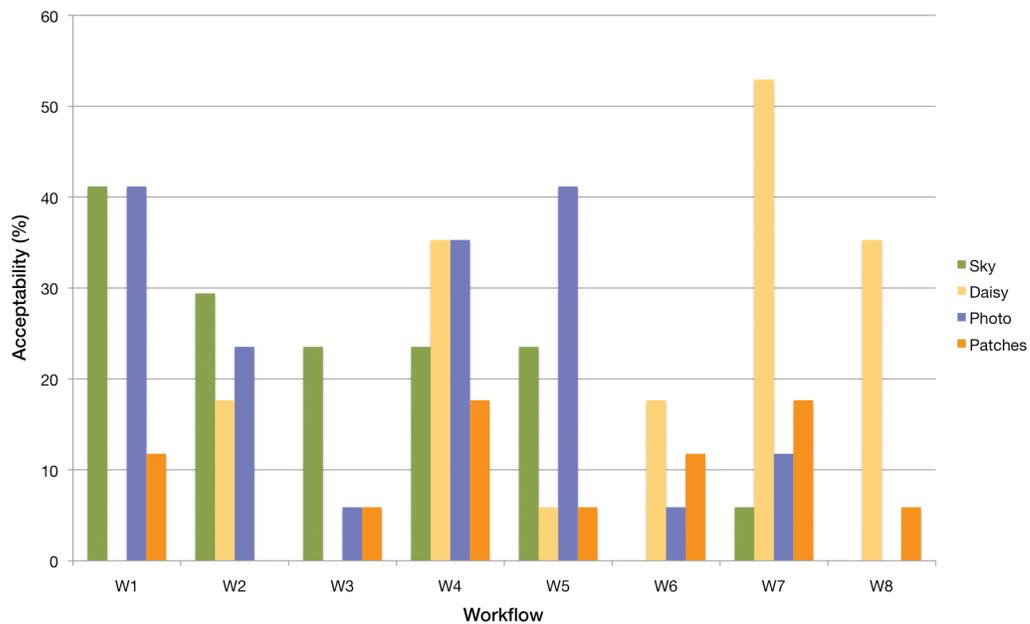


Figure 3-14. Percent of observers that found each of the print reproductions to be an acceptable representation of the original when viewed under Horizon lighting conditions<sup>10</sup> by workflow

<sup>10</sup> - CCT of 2323.

## Conclusion

The key findings of this experiment included the following:

- Prints made to match an original under one lighting condition may be clearly unacceptable under another.
- Prints that are viewed under lighting conditions other than those specified in the workflow are more likely to be considered unacceptable reproductions.

These are important points that must be kept in mind both when capture files are created and when they are being evaluated. Prints created for a D50 workflow that are evaluated under gallery lighting may produce disappointing results.

## EXPERIMENT II: EVALUATING CATS AS PREDICTORS OF OBSERVER ADJUSTMENTS IN SOFT COPY FINE ART REPRODUCTION

There is an accelerating need for images of fine art works for electronic display. Museums and other institutions are populating their web pages and databases with images of the art in their collections to provide electronic access to visitors and scholars. In addition, the use of soft proofing in cross-media color reproduction is increasing as the display and computing technologies that support this process develop. Pleasing and accurate representations of artwork are needed for use in image databases and web page display, and a soft copy match to the original artwork is required for soft proofing to be viable. Information regarding soft copy workflow is needed to build acceptance for the use of soft proofing in fine art reproduction. To achieve these goals, it is necessary to understand how to process captured images of artwork for use on computer displays. This involves understanding the differences in color perception on self-luminous displays relative to hard copy surfaces such as paper.

When looking at a piece of paper under incandescent lighting, the paper appears white. However, if the chromaticity of the paper under the incandescent light is set as an electronic display white point, observers will have a difficult time seeing the display color as white. Human observers are more likely to discount the illuminant color for hard copy than for self-luminous displays. ‘Discounting the illuminant’ refers to the cognitive ability of observers to interpret the colors of objects based on the illuminated environment in which they are viewed.<sup>11</sup> While this cognitive mechanism relies on the observers’ knowledge of the illuminant, and is, therefore, inactive when viewing self-luminous displays, sensory mechanisms are always active and automatically respond to stimulus energy.<sup>12</sup> Chromatic adaptation transforms are used to predict color appearance when the color of the light changes. Modern chromatic adaptation models are able to predict appearance matches across different media by accounting for incomplete chromatic adaptation. As a result, cross-media color reproduction is facilitated by using such calculations to predict color matches across different media and illumination conditions.<sup>13</sup>

### Methodology

In this experiment, observers were asked to adjust images from a camera to match the original artwork, which was displayed in a light booth. Three chromatic adaptation transforms (CATs)—Bradford,<sup>14</sup> Fairchild92,<sup>15</sup> and CAT02<sup>16,17</sup>—were selected to predict adjustments by observers. Bradford transformation is essentially a von Kries transformation with an additional exponential nonlinearity on the blue channel.<sup>18</sup> In this experiment, the linearized Bradford transformation was included, since it is the default chromatic adaptation in the latest ICC

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11 - Fairchild, M.D. (2005). *Color appearance models* (2<sup>nd</sup> ed.). Hoboken, NJ: Wiley.

12 - Ibid.

13 - Fairchild, M.D. (1991, August). Formulation and testing of an incomplete-chromatic-adaptation model. *Color Research and Application*, 16(4), 243-250.

14 - International Color Consortium. Specification ICC.1: 2004-10 (Profile version 4.2.0.0).

15 - Braun, K.M. & Fairchild, M.D. (1997, June). Testing five color-appearance models for changes in viewing conditions. *Color Research and Application*, 22(3), 165-173.

16 - Moroney, N., Fairchild, M.D., Hunt, R.W.G., Li, C., Luo, M.R., & Newman, T. (2002). The CIECAM02 color appearance model. In *Tenth Color Imaging Conference: Color Science and Engineering Systems, Technologies, and Applications* (pp. 23-27). Springfield, VA: The Society for Imaging Science and Technology.

17 - CIE Technical Committee 8-01. (2002). *A color appearance model for color management system: CIECAM02*. Vienna, Austria: CIE.

18 - Fairchild, M.D. (2005). *Color appearance models* (2<sup>nd</sup> ed.). Hoboken, NJ: Wiley.

profile specification (ICC Version 4.2.0.0). The simplified Bradford transformation does not account for incomplete adaptation, while the CAT02 and Fairchild92 models are both linear in nature and can predict incomplete adaptation. Another distinction is that the Bradford and CAT02 models transform from tristimulus values to a ‘spectrally sharpened’ cone space, while the Fairchild92 model converts to cone responses directly via the Hunt-Pointer-Estevéz (HPE) matrix. The von Kries predictions obtained using sharpened responsivities tend to be more color constant than von Kries predictions obtained using cone responsivities.<sup>19</sup> However, negative responsivities at some wavelengths are found in ‘spectrally sharpened’ cone space, thus making it physiologically implausible.<sup>20</sup> The matter of whether HPE or CAT02 matrices yield more accurate prediction for chromatic adaptation is still under debate.<sup>21</sup>

In this experiment, observers were asked to adjust the soft copy on the display to match the original in the light booth. Because it was of interest to understand how experts visually edit images, observers were asked to make adjustments rather than compare static stimuli (see Figure 3-15). The experimental setup included a 30” Apple Cinema Display. An LMT 1210 colorimeter was used to characterize this display, following the procedure proposed and detailed by Day, Taplin and Berns<sup>22</sup> to ensure accurate mappings between LCD digital counts and XYZ tristimulus values (see Figure 3-16). The display white point and luminance level were adjusted to match those of the light booth by using a Halon perfect reflecting diffuser (PRD). The luminance and chromaticity of the background of the light booth were measured using a PhotoResearch 650 spectroradiometer. The background of the software interface was also adjusted to match these settings (see Figure 3-17). The colorimetric performance of the display was evaluated. The mean and max CIEDE2000<sup>23</sup> color differences were 0.62 and 1.42, respectively.

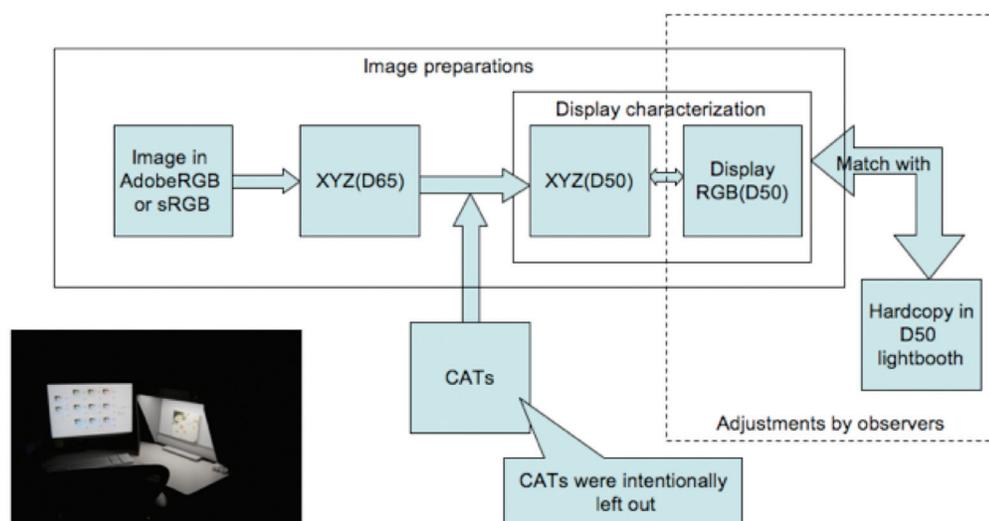


Figure 3-15. Workflow diagram for Experiment II

19 - Ibid.

20 - Ibid.

21 - Li, C. Chorro-Calderon, E. Luo, M.R., & Pointer, M.R. (2009). Recent progress with extensions to CIECAM02. In *Seventeenth Color Imaging Conference: Color Science and Engineering Systems, Technologies, and Applications* (pp. 69-74). Springfield, VA: The Society for Imaging Science and Technology.

22 - Day, E.A., Taplin, L.A., & Berns, R.S. (2004, October). Colorimetric characterization of a computer-controlled liquid crystal display. *Color Research and Application*, 29(5), 365-373.

23 - Luo, M.R., Cui, G., & Rigg, B. (2001, October). The development of the CIE 2000 color-difference formula: CIEDE2000. *Color Research and Application*, 26(5), 340-350.



Figure 3-16. Characterizing the LCD used in Experiment II

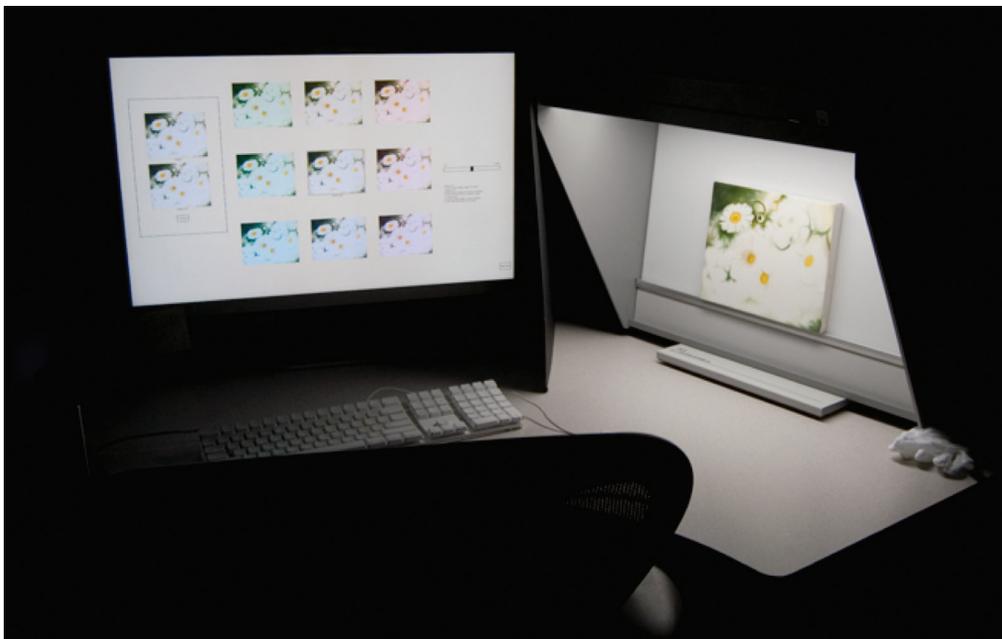


Figure 3-17. Display and viewing setup for Experiment II

Seventeen observers, with an age range from early 20s to mid-70s, participated in the experiment. The majority were involved in some aspect of artwork reproduction in museums, libraries or archives. These observers were divided into two groups that adjusted different sets of images. The first set included *Daisies*, *Night Sky*, *Orchid*, and *Photograph*, while the second set included *Orchid*, *Bridge*, *Daisies*, and *Still Life*. The first image in each set was used for training, and was thus excluded from the analysis.

Source images from different museums were downsized in Photoshop© to fit the display. A chromatic adaptation was usually needed if the white point of the source color space (AdobeRGB in this case) was different from that of the display. However, in this experiment, no chromatic adaptation was applied. The chromatic adaptation model

that predicted the observer adjustments most closely would be investigated so that a closer starting point could be determined.

To evaluate the performance of the chromatic adaptation models, the  $\Delta E_{00}$  color difference equation was used. Color difference equations were derived from comparisons of simple color patches under a controlled environment, and therefore might be insufficient to tell the color difference for complex images such as artwork reproductions. For example, an original and its halftone reproduction would look almost identical to each other, but calculating their color difference pixel-by-pixel would dramatically overestimate the ‘perceptual difference’ between the two. To eliminate details in images that could not be differentiated by human eyes due to spatial frequency, a spatial extension to the CIELAB system, S-CIELAB,<sup>24</sup> was used. The input image was initially converted into one luminance and two chrominance components. Each component image was then passed through a spatial filter that was selected according to the spatial sensitivity of the human eye for that color component. The final filtered images were transformed into XYZ format so that the color difference equation could be applied.<sup>25</sup>

The mixed-effect Analysis of Variance (ANOVA)<sup>26</sup> was used to understand the image differences. Several factors were identified in this experiment: Chromatic Adaptation Transform (CAT), Observer, and Image. CAT was a treatment factor and was fixed, as the three levels (the Bradford, Fairchild92, and CAT02 models) were of special interest. Observer was a random factor, because the participants in the experiment were not themselves of interest. Of more interest was how a large population of cultural heritage personnel performed visual editing. Similarly, Image would ideally have been a random factor. However, the number of images (three in each group) was not large enough to represent the whole population of images. A more reasonable alternative was to focus on these test images. All three main factors and their two-way interactions were included in the full mathematical model. A 0.05 confidence level was used to distinguish significant factors from redundant ones. The statistical analysis was conducted using Minitab® statistical software.

The user Interface was developed using Matlab® and the Psychophysics Toolbox®. Each image could be edited on a global and local scale. In the hue adjustment interface, shown in Figure 3-18, eight surrounding images were of the same lightness and same chroma as the central image, but each had a different hue. The image hue could be adjusted by clicking one of the images surrounding the central ‘current pick’ image. When one of the surrounding images was selected, it appeared in the center and all the other surrounding images shifted in hue based on the new central image. Once the hue adjustments were complete, observers moved on to the global adjustment interface as shown in Figure 3-19. Image brightness, contrast, saturation, and sharpness could be adjusted through the sliders to the right of the image. The global adjustments affected all colors in the image. Therefore, a third interface with local adjustment tools was available, which could be used to make certain colors appear correct without affecting other colors in the image (see Figure 3-20).

24 - Zhang, X., & Wandell, B.A. (1997, March). A spatial extension of CIELAB For digital color image reproduction. *Journal of the Society for Information Display*, 5(1), 61-63.

25 - Zhang, X., Silverstein, D.A., & Farrell, J.E. (1997). Color image quality metric S-CIELAB and its application on halftone texture visibility. In *COMPCON '97 Proceedings of the 42nd IEEE International Computer Conference* (pp. 44-48). Washington, DC: IEEE Computer Society.

26 - Dean, A.M. & Voss, D. (1998). *Design and analysis of experiments*. New York: Springer.



Figure 3-18. Image hue adjustment interface

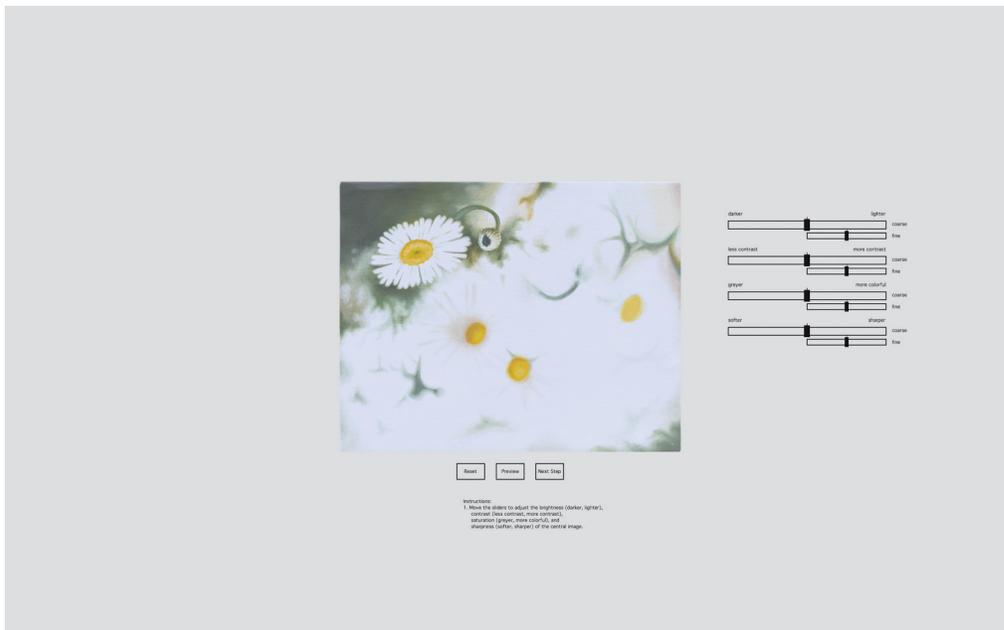


Figure 3-19. Global color adjustment interface

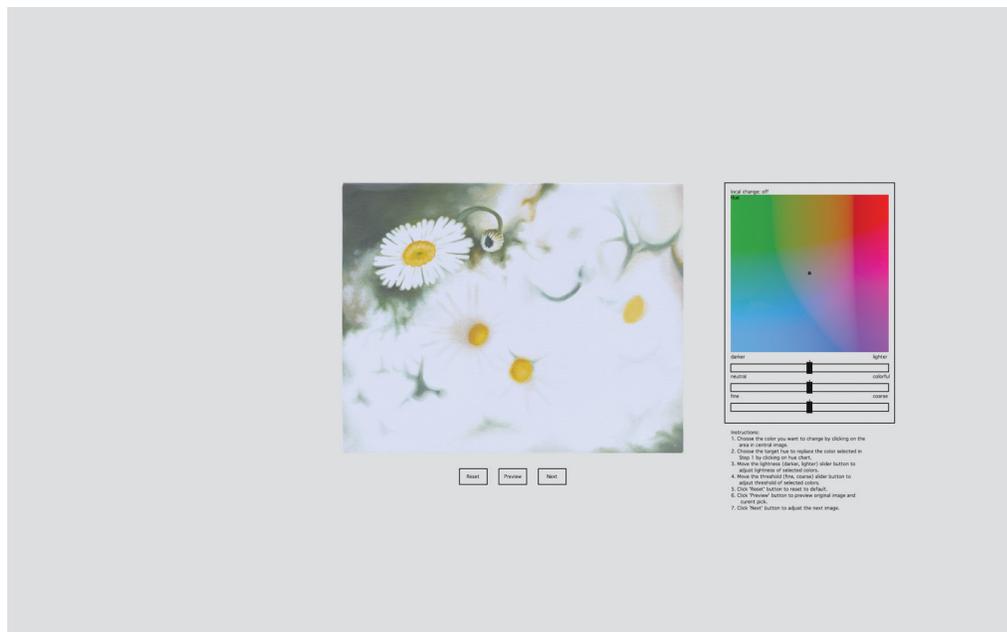


Figure 3-20. Local color adjustment interface

After local adjustments were completed, the images were compared with the CATs predictions. These were derived by fitting the corresponding color dataset, although what was predicted in the experiment applied to complex images rather than simple ones. In addition, while CATs are global operators, they by no means changed colors in the same amount. The refinement on a local scale became a useful complement to the global adjustments to ensure the most accurate results from observers.

## Results

In Figure 3-21, the hue adjustments in the  $a^*$  (red-green) and  $b^*$  (yellow-blue) colorimetric dimensions and the global adjustments in lightness, contrast, chroma, and sharpness for each image are shown. The value of 1 on the y-axis indicates an average adjustment of zero across observers for the dimension plotted. While the adjustments were image-dependent, certain general trends did emerge. As seen in the top center graph, observers increased  $b^*$  by a noticeable margin for all images except *Night Sky*. As the images were encoded in XYZ with D65 as the default white point, the images appeared bluish on the D50 display when compared with the original in the light booth. As a result, observers adjusted the images to appear more yellow. As seen in the bottom right graph, sharpness was enhanced for all images except *Still Life*. The increase in sharpness might result from the loss in detail when the images were captured or downsized. Different interpolation methods to downsize images in Photoshop© could complicate the workflow in preparing images.

Image-dependent information can also be deduced from Figure 3-21. The heavy impasto in the sky region of the original *Night Sky* was difficult to reproduce. The sharpness plot shows that observers increased the sharpness of *Night Sky* much more than they did for all the other images. Additionally, the increases in lightness and contrast were most evident for *Photograph*, indicating a loss of lightness dynamic range in the soft copy rendition of this image.

## Section 3: Experiments

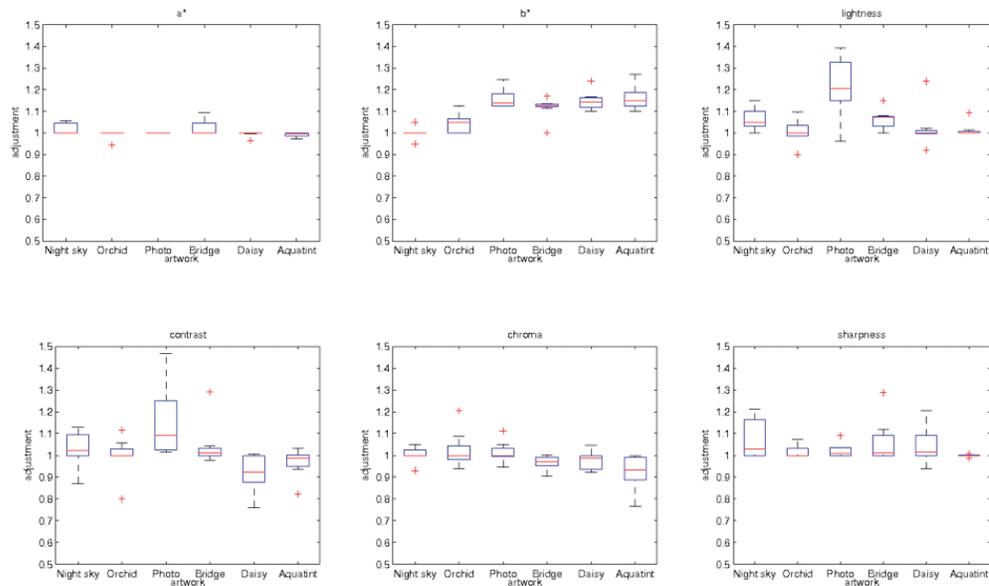


Figure 3-21. Global color adjustments for each image

Local adjustments are shown in Figure 3-22. The y-axis represents the hue angle (in unit of degrees) and the x-axis represents chroma. The cross 'x' at one end of each line is the color selected for adjustments, and the diamond  $\diamond$  is the target color. Lines of the same color were local changes made by one observer. For *Night Sky* (the top left graph), most adjustments were made at two hue angles, around  $50^\circ$  and  $270^\circ$ . The adjustments made around  $50^\circ$  generally involved increases in chroma, indicating the yellowish color in the rendered soft copy was not chromatic enough. This may have been the result of the shift in the white point from D65 to D50, or of changes during global hue adjustment to make the blue color of the sky look correct, which left the yellows in need of additional refinement. The colors adjusted around  $270^\circ$  were mostly of lower chroma.

For *Orchid* (the top central graph), local changes were made to colors of chroma lower than 30. Please note that the longest line in the plot is misleading, as the hue was not changed that drastically. Instead, the hue angle was changed from slightly positive to slightly negative, which caused a change through the  $0^\circ$  point. For *Photograph* (the top right graph), almost all adjustments were increases in chroma to colors around  $70^\circ$  on the hue axis. This was due to the relative neutrality of the image: its dominant hue was around  $70^\circ$ .

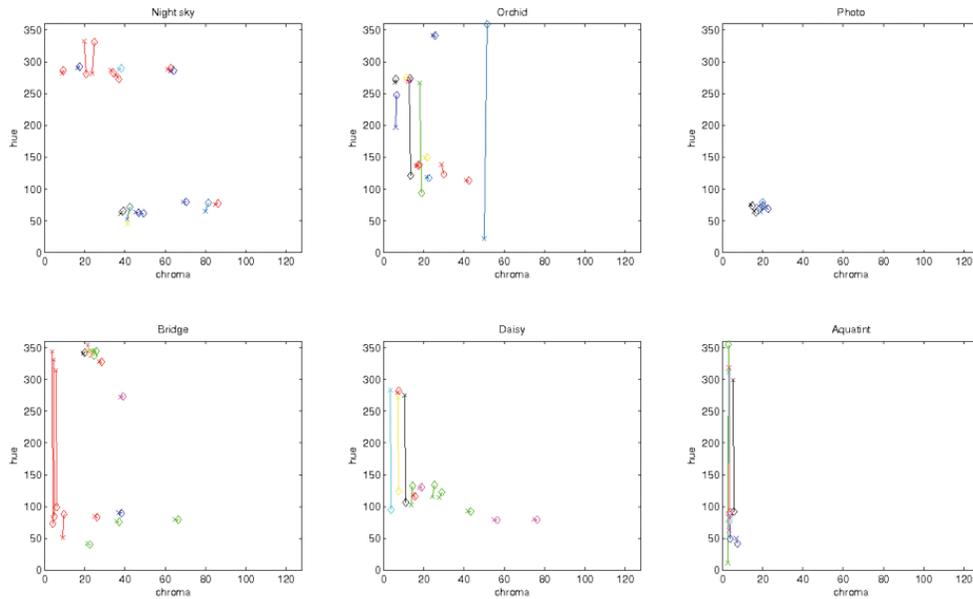


Figure 3-22. Local color adjustments for each image

Almost all significant local changes in hue occurred in colors of low chroma. This may be a result of the changes made during global adjustments. Observers may have concentrated more on the central object in the scene (such as the bridge or orchid) in this phase, while areas of lower chroma (usually the background) underwent more changes during local adjustments.

### Chromatic Adaptation Models

The Fairchild92, CAT02, and Bradford models were implemented and evaluated to determine which model better predicted the adjustments made by observers. The *Daisies* image source file and renditions as adjusted by one observer and predicted by all three models are shown in Figures 3-23 and 3-24 as an example.



Figure 3-23. 'Daisies' source image in D65 XYZ



Figure 3-24. Adjusted images by one observer and each chromatic adaptation model

The source image in Figure 3-23 appeared more bluish on the D50 display than the original artwork in the D50 light booth, given the absence of chromatic adaptation before adjustments by observers. The adjusted image by one observer matches with the predictions by three chromatic adaptation models more closely in Figure 3-24 than with the source image in Figure 3-23.

The S-CIELAB model was evaluated by comparing *Daisies* as predicted by the Fairchild92 model before and after spatial filtering. Details such as the canvas became unnoticeable after filtering (see Figure 3-25). Color difference was calculated between the observer-adjusted image and the images processed through the chromatic adaptation models and spatial filtering by the S-CIELAB model. The color differences for the spatially filtered images were only slightly smaller than the color differences prior to spatial filtering. One important reason why the color differences were not more significant may have been that the viewing distance—which is assumed to be constant in the S-CIELAB model—did not remain unchanged in the experiment, as observers were likely to lean forward and sit close to the screen when making adjustments.

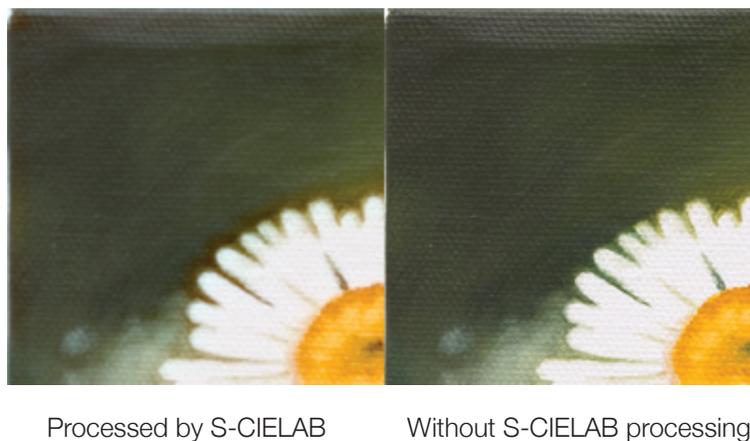


Figure 3-25. Close up of ‘Daisies’ by Fairchild92 model with and without S-CIELAB processing

The error distribution map of *Daisies* when the S-CIELAB model was used between the image as adjusted by one observer and the predictions of the CATs is shown in Figure 3-26. The observer adjustments were predicted well by

all three models, with a mean image difference between 3 and 4. The color of the daisy petals was better predicted than other parts of the painting, as indicated by the deep bluish color in the image difference map.

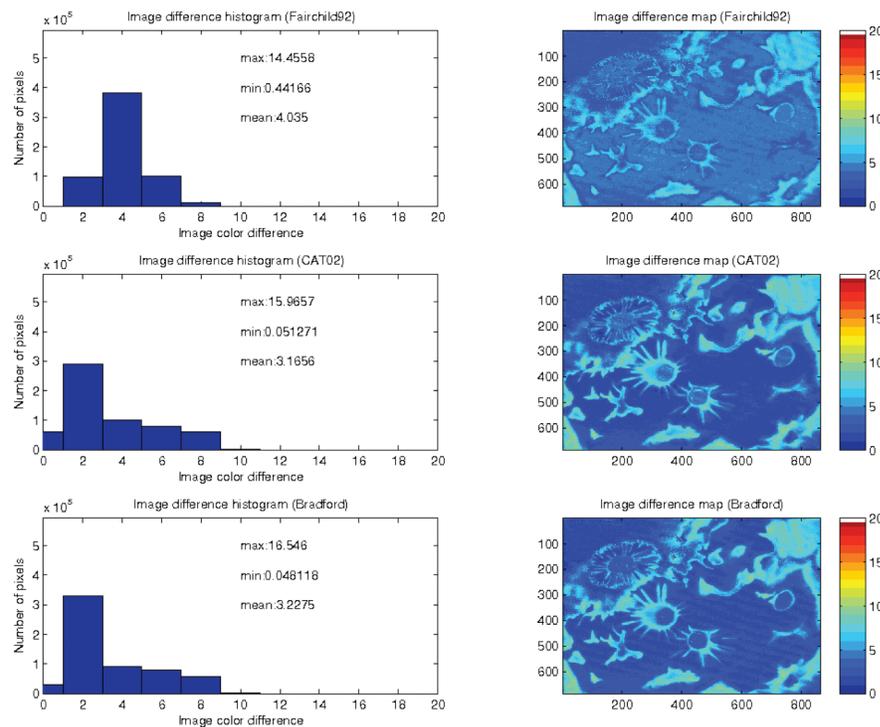


Figure 3-26. Image difference map for 'Daisies' as adjusted by one observer

An ANOVA analysis was performed to determine the main effects and interactions that contributed significantly to the image differences. The analysis was performed on the two sets of images separately. For Group 1 (*Night Sky*, *Orchid*, and *Photo*), the interaction between Observer and Model was insignificant ( $p = 0.376$ ), indicating that no model predicted certain observer adjustments significantly better than the adjustments by other observers. This was a reasonable result because these models were designed to match with the cone responsivities (or color matching functions) of average observers. The main effect, CAT, was significant ( $p = 0.014$ ), together with the interaction between Image and Observer ( $p = 0.001$ ), and that between Image and Model ( $p = 0.001$ ). The Image and Observer main effects were insignificant ( $p$ -values of 0.345 and 0.229, respectively), but these were retained in the model due to hierarchy. The *adjusted R*<sup>2</sup> of the final model was over 95%. Given the significance of interaction terms in the model, an interaction plot was made to better understand the data (see Figure 3-27). This data indicates that the performance of the Fairchild92 model was better than that of the other two models for *Night Sky* and *Orchid* but not for *Photograph*, as indicated by the lower mean image difference of the first two paintings with the Fairchild92 model.

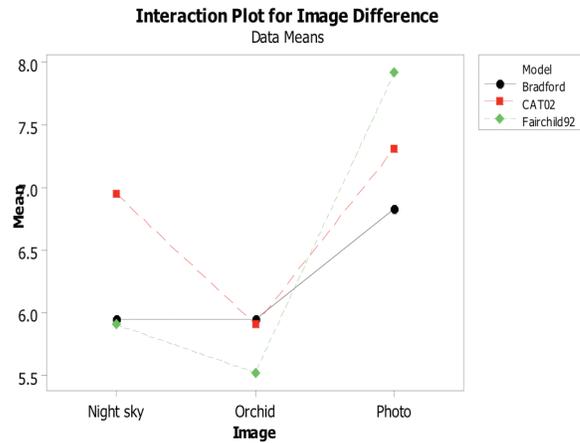


Figure 3-27. Interaction plot between Image and CAT effects for the first set of images<sup>27</sup>

In Figure 3-28, the interaction between Image and Observer is examined. No single image was consistently predicted to have the least mean colorimetric errors (and thus be closer to the adjusted image) across all observers. The confounding effect between Image and Observer might result from a few factors. First, color matching for one observer might not hold for others, given the variability in human visual sensitivity to colors. Moreover, different observers might compromise differently between different parts (or colors) of the painting when adjusting images to match with the originals. Secondly, observers were asked to adjust three images in 30 minutes, while they might often take hours to make adjustments to a single image in their day-to-day work. Finally, the observers were unfamiliar with the image editing software, and confirmed in their feedback that the software had a learning curve.

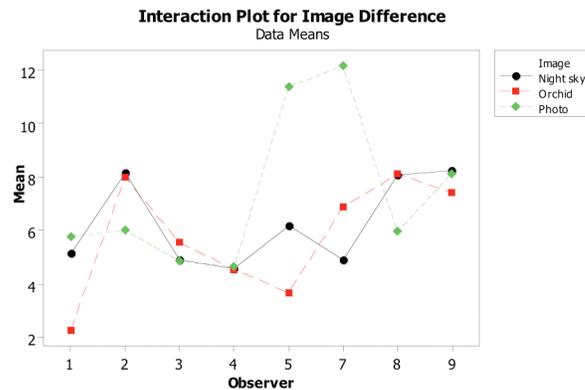


Figure 3-28. Interaction plot between Image and Observer effects for the first set of images

The ANOVA analysis of the second set of images (Group 2: *Bridge*, *Daisies*, and *Still Life*) indicated that the interaction between Image and Observer was significant ( $p = 0.001$ ), in agreement with the results from the first image set. The interaction between Image and CAT was also significant ( $p = 0.002$ ). The interaction plot is shown in Figure 3-29. The Fairchild92 model outperformed the other two models for *Bridge* and *Daisies* but not for *Still Life*, which is similar to *Photograph* in appearance as neither had strong chromatic colors.

<sup>27</sup> - The y-axis is the mean image difference as a function of the test image.

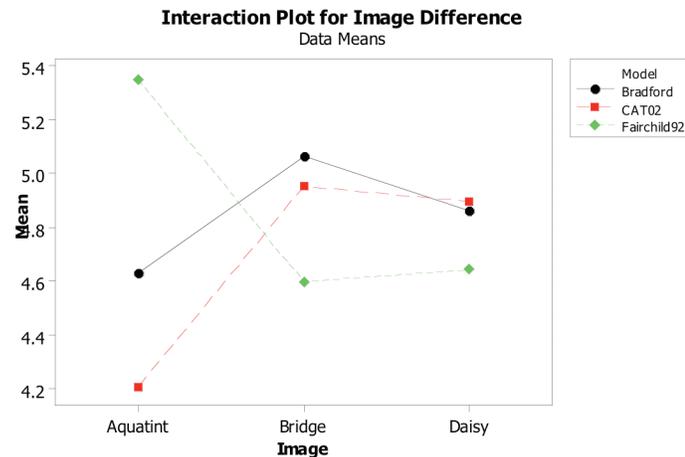


Figure 3-29. Interaction plot between Image and CAT effects for the second set of images

No one chromatic adaptation model was found to better predict adjustments by observers across all images included in the experiment. The Fairchild92 model generally matched with the visual editing by observers more closely than the Bradford or CAT02 model except for images with a near-neutral appearance. The predictions by the Bradford transformation were not much worse than the other two, and—given its inability to discount the illuminant and simplicity in implementation—the performance of the Bradford model was better than expected. However, the common practice of comparing displays and reflection prints side-by-side produces unpredictable color appearance,<sup>28</sup> as viewing soft copy and hard copy simultaneously may cause the state of adaptation to be unstable. It has been noted that a short-term memory matching technique produced more reliable results.<sup>29</sup>

## Conclusions

An experiment investigating current soft proofing of artwork reproductions was conducted. During this experiment, observers were asked to adjust images on a calibrated LCD display to create a visual match to the original artwork in an adjacent viewing booth. While some general trends could be extracted from adjustments by observers, the adjustments were highly image-dependent. The significance of the interaction between Observer and Image highlighted their confounded effect. Color adjustments by observers were compared with predictions by the Bradford, Fairchild92, and CAT02 chromatic adaptation models. Based on the mixed-effect ANOVA analysis, the Fairchild92 model outperformed the Bradford and CAT02 model for all of the images tested with the exception of those with a more neutral appearance. The S-CIELAB model was used to remove unperceivable details at certain spatial frequencies, but its effect was limited by the fact that the viewing distance did not always remain constant during adjustments.

Visual editing made by experts in museums sometimes involves more complex lighting, such as daylight from windows and skylights in conjunction with fluorescent light from office fixtures. To account for different viewing conditions, such as changes in illuminance level and background or surround, a color appearance model should be included in future work rather than a chromatic adaptation transform alone. To that end, the lighting conditions in a local museum were measured. These measurements will be used to select more realistic parameters in the color appearance models so that color may be more accurately calculated in cross-media fine art reproduction.

28 - Fairchild, M.D. (2005). *Color appearance models* (2<sup>nd</sup> ed.). Hoboken, NJ: Wiley.

29 - Ibid.

## EXPERIMENT III: THE IMPACT OF WORKFLOW ON PERCEIVED REPRODUCTION QUALITY OF FINE ART IMAGES

### Creation of Test Images

Among the main objectives of this project was to understand the relative reproduction quality being achieved by fine art reproduction workflows in use today. To accomplish this, an experiment was conducted in which prints made from files contributed by 17 institutions and image files for computer display from 15 institutions were visually evaluated to determine their relative quality. The institutions that participated in this experiment (see Table 3-3) included a range of sizes—from the Yale Gallery of the British Arts to the Metropolitan Museum of Art—as well as a range of print production—from the Northeast Document Conservation Center, which rarely conducts print runs of its works, to the National Gallery of Art, which provides a plethora of printed products of its collection and other exhibited artwork.

The *Still Life*, *Bridge*, *Daisies*, *Firelight*, *Mountain*, and *Photograph* pieces and the Macbeth ColorChecker, paint patch target and the Universal Test Target (UTT) were circulated to the participating institutions. Each institution delivered files of the artwork, along with information on their workflow and guide prints if these were typically part of their regular workflow. Two museums provided two sets of files: one provided files for two different cameras and one provided files made in different color spaces. The files represented a total of five different camera manufacturers, although 16 of the 19 files supplied for each piece of artwork were generated with cameras from three manufacturers. The files mostly used the AdobeRGB color space, although there were a few in the ProPhotoRGB space and a few in the eciRGB color space. From the files provided, renditions of the artwork and targets (with the exception of the UTT) were printed at the RIT Printing Applications Laboratory.

Table 3-3. Cultural heritage institutions that participated in the workflow experiment

Participating Institutions	
The Metropolitan Museum of Art	Art Institute of Chicago
MoMA - The Museum of Modern Art	Minneapolis Institute of Arts
The Guggenheim Museum	The National Gallery, London
Harvard Art Museum	Victoria & Albert Museum
Harvard College Library	Berkeley Art Museum and Pacific Film Archive
Northeast Document Conservation Center	The Getty Center
Museum of Fine Arts, Boston	The National Gallery of Art, Washington
The Beinecke Rare Book and Manuscript Library at Yale University	Yale University Art Gallery
	Yale Center for British Art

For the lighting experiment, the prints were made on NewPage Sterling 80# Gloss Text paper with Biolocity inks. While the Biolocity inks were again used in generating prints for the workflow experiment, the gloss-coated paper was not considered an optimal choice for artwork reproduction. Therefore, prints made for this experiment were run on NewPage Sterling Ultra 80# Matte Text. This paper was selected after consultation with a local fine art printer, conversations with paper suppliers, visual examination of samples of possible media, and confirmation that the selected paper would run properly in the HP Indigo digital press. A certification run was conducted on the Heidelberg Speedmaster using this paper and ink combination prior to the actual print runs in order to ensure

proper color management. In this run, the solid ink densities that yield the smallest color difference values are determined when the ink is dry. (Ink ‘dry back’—the change in ink density between the wet ink values and the values after the ink has been allowed to dry for a specified time, usually a period of days—was measured.) This certification run resulted in a custom profile for the press, ink, and paper combination with a set of TVI (tone value increase) curves that matched the ISO 12647-2 standard. Following the certification run, a verification run was conducted to ensure that the developed profile and TVI curves worked appropriately using a standard dataset such as FOGRA39. Since AdobeRGB is a larger color space than the printer color space, this profile provided the gamut mapping needed for colors outside of the printer gamut. With print sets made on the offset press for each of 17 institutions—plus two extra for the two institutions that each provided two files along with visually adjusted prints made for 11 of the institutions—30 reproductions were made for each piece of target artwork.

## Methodology

The print reproduction experiment was conducted in the same D50 booth in the Display and Perception lab as was used in the lighting experiment. The correlated color temperature of this booth is 4911°K, as measured with a PhotoResearch 650. The spectral power curve for this light source is shown in Figure 3-6. A total of 24 observers participated in this experiment.

The psychophysical experiment again followed a rank order protocol. In this experiment, however, there were too many stimuli for the observers to view them all at once. Consequently, the experiment began by laying out eight reproductions (or more for the two smaller images) of each piece of the artwork for the observers to view relative to the original artwork. The prints used were selected to roughly represent the range of reproduction quality of the available prints. The observers were then asked to sort these prints into piles of the better reproductions of the original, the less impressive reproductions, and those prints that were somewhere in-between. When this was accomplished, the remaining prints were handed to the observers one by one to be placed in the appropriate pile. When all 30 prints were sorted into the three piles, the prints within each pile were then ranked, beginning with the pile representing the worst reproductions of the original. The top ranked prints from this pile were added to the pile of the prints that were identified as being somewhere between the best and the worst. This pile of prints was then ranked from worst to best representations of the original. If one of the two prints remaining from the ‘worst’ prints pile was not selected as the worst of the ‘in-between’ pile, then the selected print was evaluated relative to the top of the ‘worst’ pile until it was found to be the better representation of the original. This process was repeated when the pile of the better reproductions of the original was ranked. In this way, a ranking of the worst reproduction to the best reproduction of each original was generated for each of the six originals by each of the 24 observers. The original artwork was present throughout this process. Once each ranking was complete, the observer was questioned as to whether he or she considered the print identified as the best reproduction to be an acceptable reproduction for his or her purposes, whether education, conservation, or publication (of a small poster, for example). If the answer was ‘yes’, the same question was then asked regarding the next print in the pile. This continued until the answer was ‘no’, thereby identifying the position in the ranking where the prints shift from being acceptable to unacceptable.

A similar experiment was conducted with images on a computer display. The digital files obtained from 15 of the 17 participating institutions were used to generate the soft copy images. One institution supplied files for two different cameras; both of these files were included. The images delivered were mostly encoded in either the sRGB or AdobeRGB color space, with a few in the eciRGB or ProPhotoRGB space. Given that the gamut of the Apple

### Section 3: Experiments

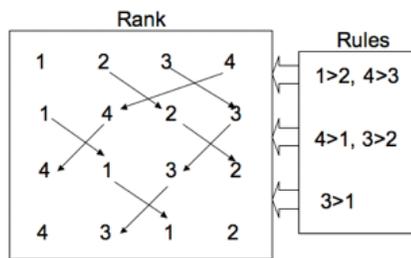
30" Cinema Display used in the experiments was smaller than that of the AdobeRGB space, images in either the eciRGB or ProPhotoRGB space were first converted to the AdobeRGB color space before being shown on the display. All of the images were resized to the same size so that two would fit side-by-side on the display, as shown in Figure 3-30.



Figure 3-30. The soft copy experimental set up with the original present

The soft copy experiment followed a modified paired comparison procedure. The generated images were shown to the observers in pairs, and the observers were asked to determine the better reproduction, whether the original or their preferred image (depending on whether the original was present or not). Images from 16 of the files delivered by participating cultural heritage institutions were used in this experiment. In a standard paired comparison experiment each stimulus would be compared to every other stimulus in the test. With 16 stimuli, this would have resulted in 120 comparisons for each of the six images, which would have been too many comparisons for each observer.

Consequently, in the present experiment, an algorithm was written so that the 16 images were first shown as eight pairs. The eight images that were selected as the better reproductions or preferred images then served as four pairs of images that were compared with each other, and those that were not initially selected served as the other four pairs of images that were compared with each other. This process continued until the best and the worst images were identified, with the images falling in-between subsequently being compared. In other words, images not selected in the first round of comparisons that are preferred in the second and third rounds may then be compared to the images that were selected in the first round but not in the second or third rounds. A schematic of this procedure is shown in Figure 3-31.



In this example, 1 is compared to 2 and 3 to 4, with 1 and 4 being selected as best. In the second row, 1 is compared to 4 and 2 to 3, with 4 and 3 being selected as best. Finally 1 is compared to 3 with 3 being selected giving a final order or 4-3-1-2 with 2 and 4 never being compared because their ranks are determined by the transitive relationships established by previous ranking decisions.

Figure 3-31. The adaptive form of paired comparison used in the soft copy ranking experiment

The experiment was conducted in the Perception and Display Lab in the Color Science building at RIT. To ensure accurate colorimetric reproduction, the display was characterized using an LMT 1210 colorimeter following the procedure outlined by Day, Taplin and Berns.<sup>30</sup> The display white point and luminance were adjusted to match with those of the light booth with a Halon perfect reflecting diffuser (PRD). Additionally, the luminance and chromaticity of the background of the light booth were measured using a PhotoResearch 650 spectroradiometer. The background of the software interface was adjusted to match these settings.

The colorimetric performance of the display was evaluated. The mean and maximum color differences were 1.4 and 2.2, respectively. Given that the white point of both the AdobeRGB and sRGB spaces is D65—the same as that of the display—no chromatic adaptation transform was performed. Display digital counts were generated from tristimulus values of test images using the display model. The original was shown in a D65 booth adjacent to the display (see Figure 3-30).

Once the testing was completed, the rankings provided by the observers were translated into  $z$ -scores following procedures outlined in Engeldrum<sup>31</sup> and based on Thurstone's Law of Comparative Judgments – Case V.<sup>32</sup> This transformation from observer rankings to  $z$ -scores was conducted to provide an interval scale rather than an ordinal one. An ordinal scale simply orders the stimuli but provides little information about the differences in quality between two stimuli, in this case the print reproductions. An interval scale provides the relative distance between two stimuli. In transforming from ranking to  $z$ -scores, the prints perceived to be of average quality would receive a  $z$ -score of 0. Prints perceived as being above average would have positive  $z$ -scores, and those prints perceived as being below average would receive negative  $z$ -scores.

## Print Results

The results of the psychophysical experimentation conducted to evaluate the perceived reproduction quality from each of the workflows used are shown in Figures 3-32 through 3-38 and are summarized in Table 3-4. The  $z$ -scores determined from the mean rankings of all observers averaged over the six pieces of artwork for each institution are shown in Figure 3-32. (One institution provided files for two different cameras, and another for two different color spaces: AdobeRGB and eciRGB). The blue columns in Figure 3-32 represent the prints made following the ISO 12467 protocol, while the peach columns represent the prints made with minor on-press adjustments to match the provided guide prints from certain institutions. It is interesting to note that there were no statistically significant differences between the prints made following the standards print workflow ('numbers') and those prints made

30 - Day, E.A., Taplin, L.A., & Berns, R.S. (2004, October). Colorimetric characterization of a computer-controlled liquid crystal display. *Color Research and Application*, 29(5), 365-373.

31 - Engeldrum, P.G. (2000). *Psychometric scaling: A toolkit for imaging systems development*. Winchester, Massachusetts: Imcotek Press.

32 - Thurstone, L.L. (1927). A law of comparative judgment. *Psychological Review*, 34(4), 273-286.

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with visual adjustments. It is important to remember that the visual adjustments made to these prints were limited in scope; larger adjustments would have required a change in printing plates.

Examination of the plots in Figures 3-33 through 3-38 reveals that the reproduction quality of the print was improved by the visual adjustments made on press in a few instances. For *Still Life*, the visual rendition for workflow W4 was substantially better than the numbers version, although the visual version for workflow W5 was actually worse than the numbers version. For *Bridge*, the visual renditions for the W1, W13, and W14 workflows were better than the numbers versions. For *Mountain*, the print with visual adjustments for the W8 workflow was significantly better than the number' version. *Photograph* was the piece that was most affected by the visual adjustments, though more were negatively affected than positively (see Figure 3-38). The visual renditions were considered better than the numbers versions for the W12 and W16 workflows, but were considered worse than the numbers versions for the W4, W5, and W8 workflows. This may be due to the fact that when the visual adjustments were made, they were made to the entire press sheet—all six prints were simultaneously affected. It is possible that visual adjustments to make better matches for several other images on a given press sheet resulted in pushing *Photograph* further from being a match.

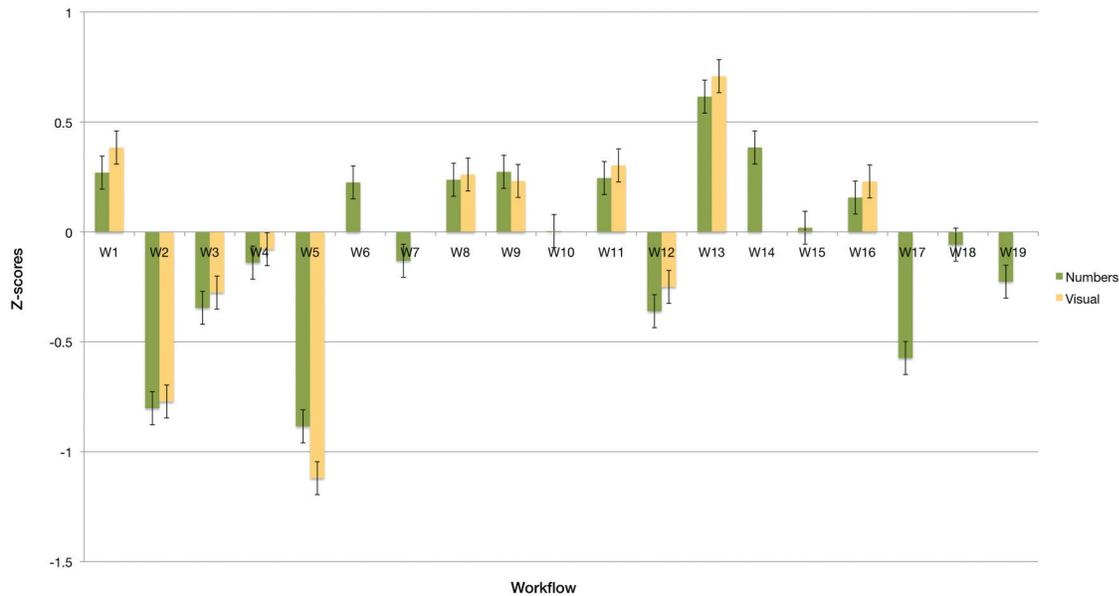


Figure 3-32. Z-scores for each of the workflows averaged over the six pieces of artwork<sup>33</sup>

33 - The green columns represent the prints made following the ISO 12467 specification (to the 'numbers') and the yellow columns represent the prints made by making on-press visual adjustments to guide prints. Figures 3-33 through 3-38 use this same format.

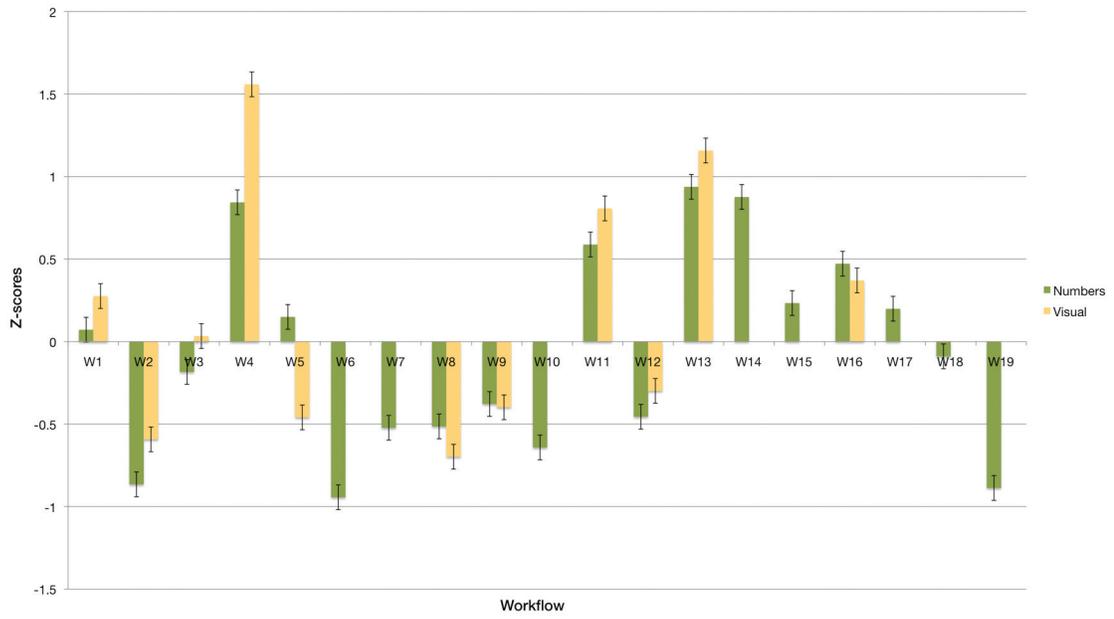


Figure 3-33. Z-scores of each workflow for 'Still Life'

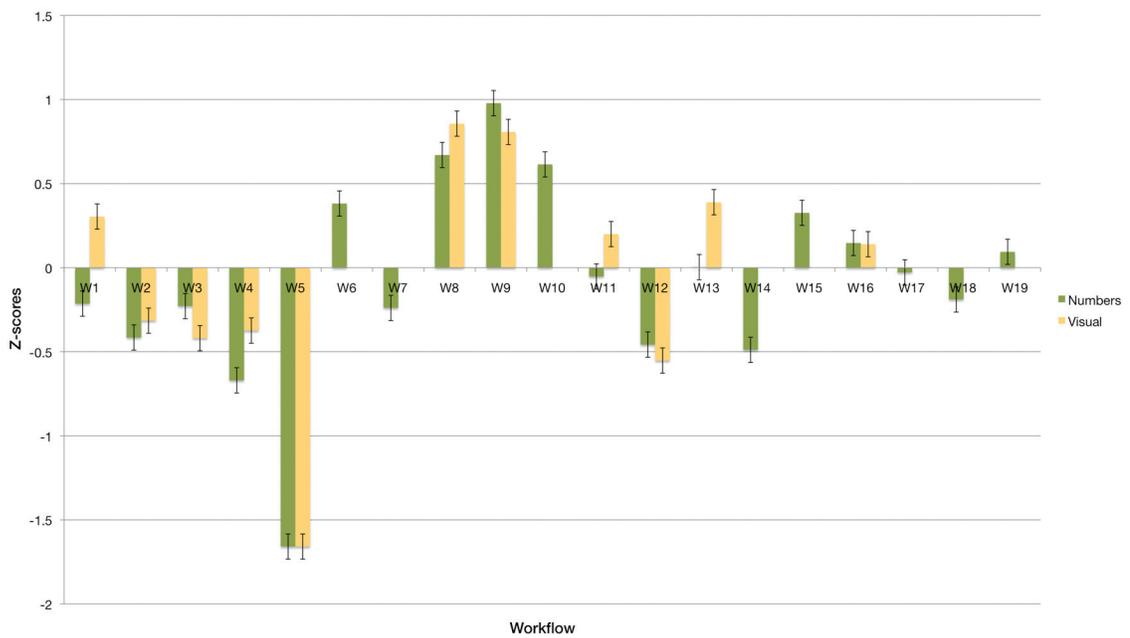


Figure 3-34. Z-scores of each workflow for 'Bridge'

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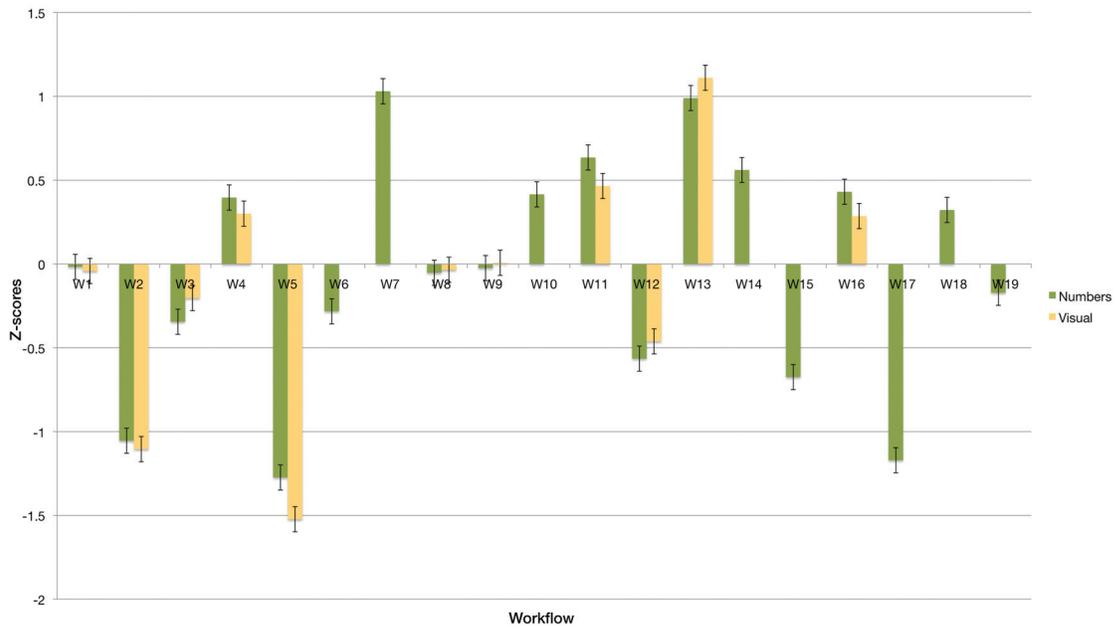


Figure 3-35. Z-scores of each workflow for 'Daisies'

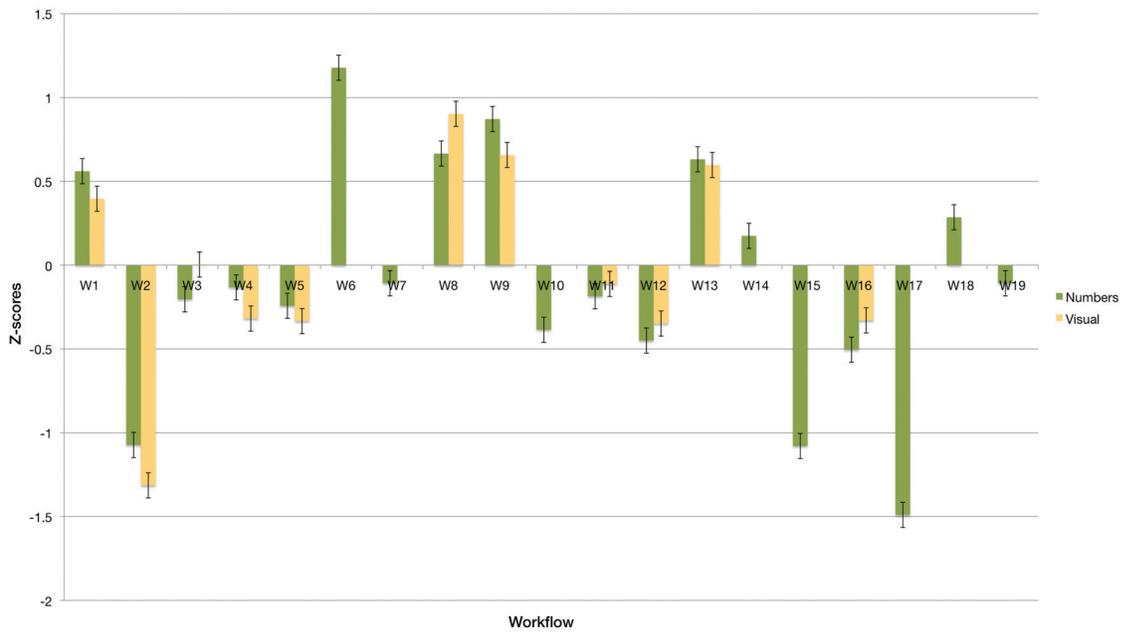


Figure 3-36. Z-scores of each workflow for 'Firelight'

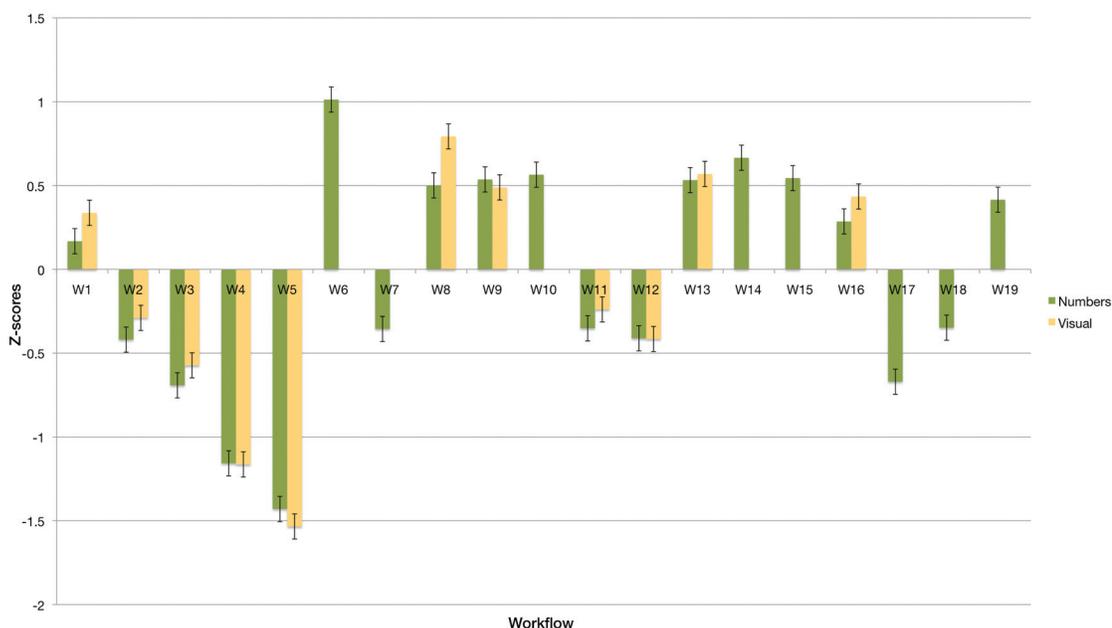


Figure 3-37. Z-scores of each workflow for 'Mountain'

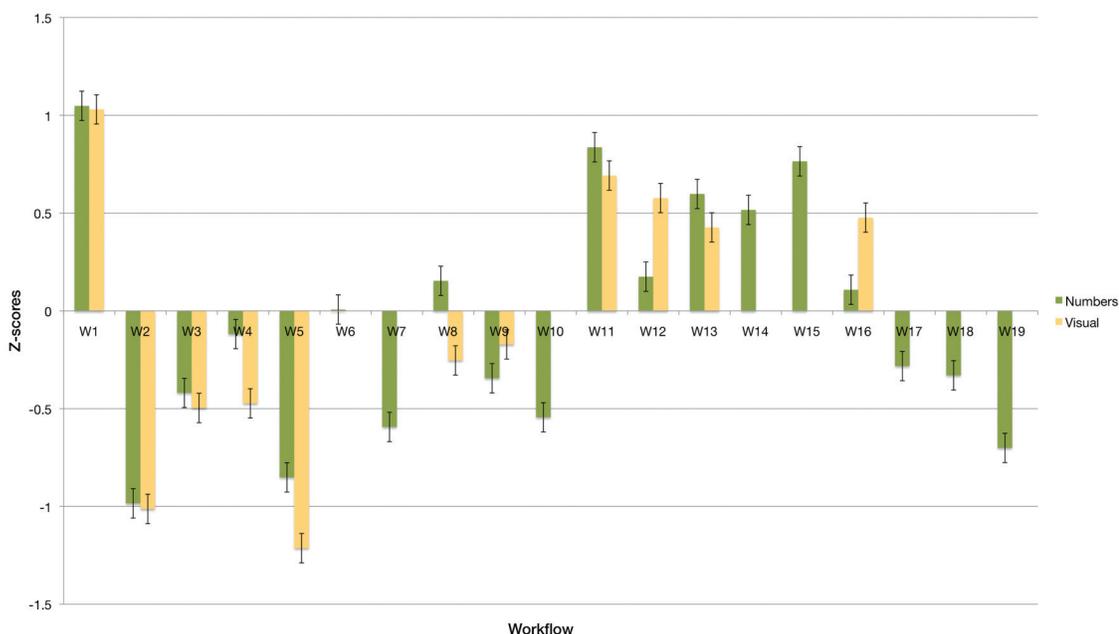


Figure 3-38. Z-scores of each workflow for 'Photograph'

Looking again at Figure 3-32, it is evident that the prints generated from the files provided by institution 13 were perceived as the best match to the original artwork on average, while the prints made from the files provided using workflows W2, W5, and W17 were generally considered to be furthest from a perceptual match. The results plotted in Figures 3-33 through 3-38—which show the  $z$ -scores calculated for each original—indicate that prints from different workflows were considered to be the best matches. In other words, there was no one workflow that was consistently found to be the best. For *Still Life*, the 'visual' rendition of the W4 workflow was, on average, considered the best match to the original. The numbers version of the W4 workflow and the renditions printed from the files from W13, W14, and W11 were also considered to be relatively good matches to the original. For

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*Bridge*, the W8, W9, and W10 renditions were considered the best. For *Daisies*, the prints made from the W7 and W13 files were considered the best matches, while the prints made from the W6 files were the most highly rated for both the *Firelight* and *Mountain* paintings. For *Photograph*, the print made from the W1 file was generally considered the best. When considered over the six different pieces of artwork, prints made from 10 different workflows were ranked as being the best match to the original.

Observers were generally more consistent in their ranking of the print renditions that they felt least represented the target artwork. The print made from the file for either W2 or W5—and for *Daisies* and *Photograph*, both of these prints—was considered to be among the furthest from the original for every piece of artwork included in the study. Other prints that were identified as being relatively poor matches to the originals were the W6 and W19 files for *Still Life*, W17 for *Daisies*, W17 and W15 for *Firelight*, and W4 for *Mountain*.

It is interesting to note that the files for W6 and W4 produced prints that were ranked as both the best and the worst matches for different pieces of artwork. The W6 prints were ranked as the best match for *Firelight* and *Mountain* and among the best for *Bridge* (see Figure 3-34), while it was among the worst for *Still Life*. For *Photograph* (see Figure 3-38), the performance of the W6 print was about average and for *Daisies* it was a little below average (see Figure 3-35). A review of the W6 results as summarized in Table 3-4 shows that the performance for these prints is consistently above average for the highly chromatic paintings (*Bridge*, *Firelight*, and *Mountain*). In contrast, the W6 prints for more achromatic images were generally ranked below average (*Still Life*, *Daisies*, and *Photograph*). Plotting the *z*-scores averaged over the achromatic and chromatic prints for each of the workflows helps to clarify this difference between perceptual reproduction quality for achromatic and chromatic images (see Figure 3-39). Other institutions exhibited a similar performance: W8 and W9 had better performance for the more chromatic prints, while W4 and W11 had strikingly better performance for the achromatic prints. The strong performance by the W6 workflow for the chromatic paintings was particularly notable because this institution did little in terms of post-process color corrections. The institution represented by W14 was also able to achieve dependably good quality, only ranking below average once for *Bridge* (see Table 3-4). It is a promising result that these institutions were able to achieve such good reproduction quality using relatively straight-forward, consistent approaches without extensive visual adjustments to the individual image files.

Table 3-4. Summarized results for each piece of artwork by each of the participating institutions<sup>34</sup>

Workflow	Mean	Still Life	Bridge	Daisies	Firelight	Mountain	Photograph
W1	Better	Better	Average	Average	Better	Better	Better
W2	Worse	Worse	Worse	Worse	Worse	Worse	Worse
W3	Worse	Average	Worse	Better	Average	Worse	Worse
W4	Average	Better	Worse	Worse	Worse	Worse	Worse
W5	Worse	Average	Worse	Worse	Worse	Worse	Worse
<b>W6</b>	<b>Better</b>	<b>Worse</b>	<b>Better</b>	<b>Worse</b>	<b>Better</b>	<b>Better</b>	<b>Average</b>
W7	Average	Worse	Worse	Better	Average	Worse	Worse
<b>W8</b>	<b>Better</b>	<b>Worse</b>	<b>Better</b>	<b>Average</b>	<b>Better</b>	<b>Better</b>	<b>Average</b>
<b>W9</b>	<b>Better</b>	<b>Worse</b>	<b>Better</b>	<b>Average</b>	<b>Better</b>	<b>Better</b>	<b>Worse</b>
W10	Average	Worse	Better	Better	Worse	Better	Worse
<b>W11</b>	<b>Better</b>	<b>Better</b>	<b>Average</b>	<b>Better</b>	<b>Average</b>	<b>Worse</b>	<b>Better</b>
W12	Worse	Worse	Worse	Worse	Worse	Worse	Better
<b>W13</b>	<b>Better</b>	<b>Better</b>	<b>Better</b>	<b>Better</b>	<b>Better</b>	<b>Better</b>	<b>Better</b>
<b>W14</b>	<b>Better</b>	<b>Better</b>	<b>Worse</b>	<b>Better</b>	<b>Better</b>	<b>Better</b>	<b>Better</b>
W15	Average	Better	Better	Worse	Worse	Better	Better
W16	Better	Better	Better	Better	Worse	Better	Better
W17	Worse	Better	Average	Worse	Worse	Worse	Worse
W18	Average	Average	Worse	Better	Better	Worse	Worse
W19	Worse	Worse	Average	Worse	Average	Better	Worse

As might be expected, the results for the acceptability ratings for the prints in this experiment as shown in Figures 3-39 and 3-40 generally support the ranking results. Figure 3-40 shows the percentage of the observers who found each print in the experiment to be an acceptable reproduction of the original for their specific needs; for example, a conservator would be considering the needs for conservation purposes. For curators, photographers, and imaging scientists, acceptability was defined in terms of posters, exhibition catalogues, and similar museum shop consumer items. Figure 3-41 shows the mean percentage of observers who found the artwork acceptable (green columns), the achromatic artwork acceptable (yellow columns), and the chromatic artwork acceptable (purple columns). In these figures, it can be seen that the prints for workflow W13 attain the highest level of acceptability, on average, with about one-third of observers who found these prints acceptable. W13 prints performed at a level of 25% acceptability or better for every image except *Bridge*. Workflow 14 also had difficulty with *Bridge* but attained an acceptability rating of 20% or better for every other original except *Firelight*. Additionally, the prints for workflows W1, W15, and W16 generally performed well, stumbling only on the *Firelight* and *Daisies* paintings.

34 - A positive z-score was designated 'Better', a negative z-score was designated 'Worse' and a z-score of about '0' was designated 'Average'.

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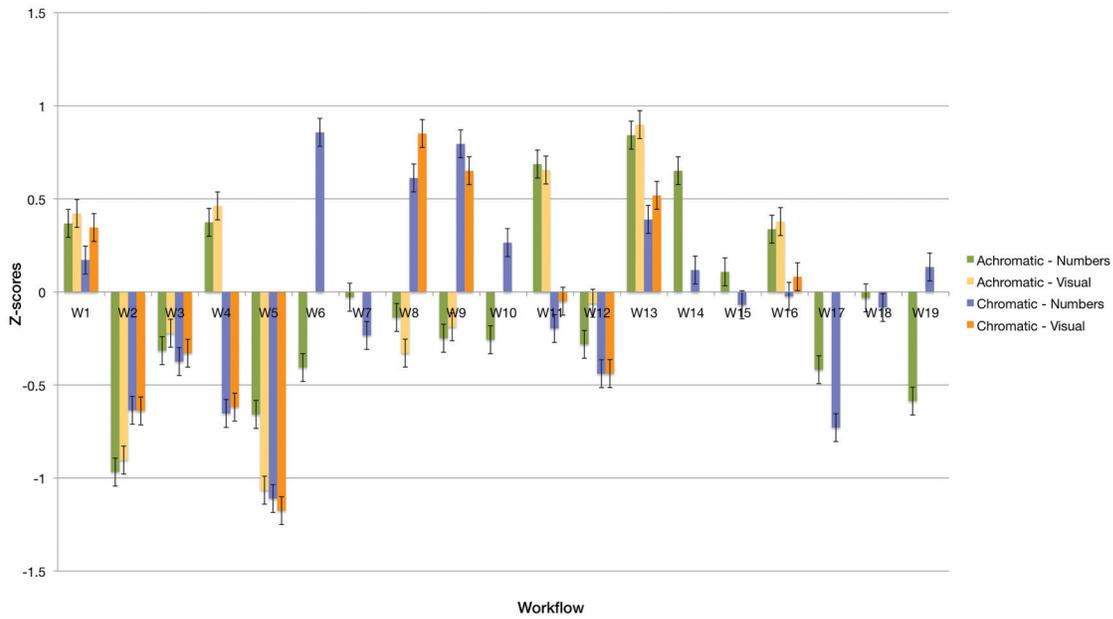


Figure 3-39. Z-scores for each of the workflows averaged over the achromatic and chromatic pieces of artwork<sup>35</sup>

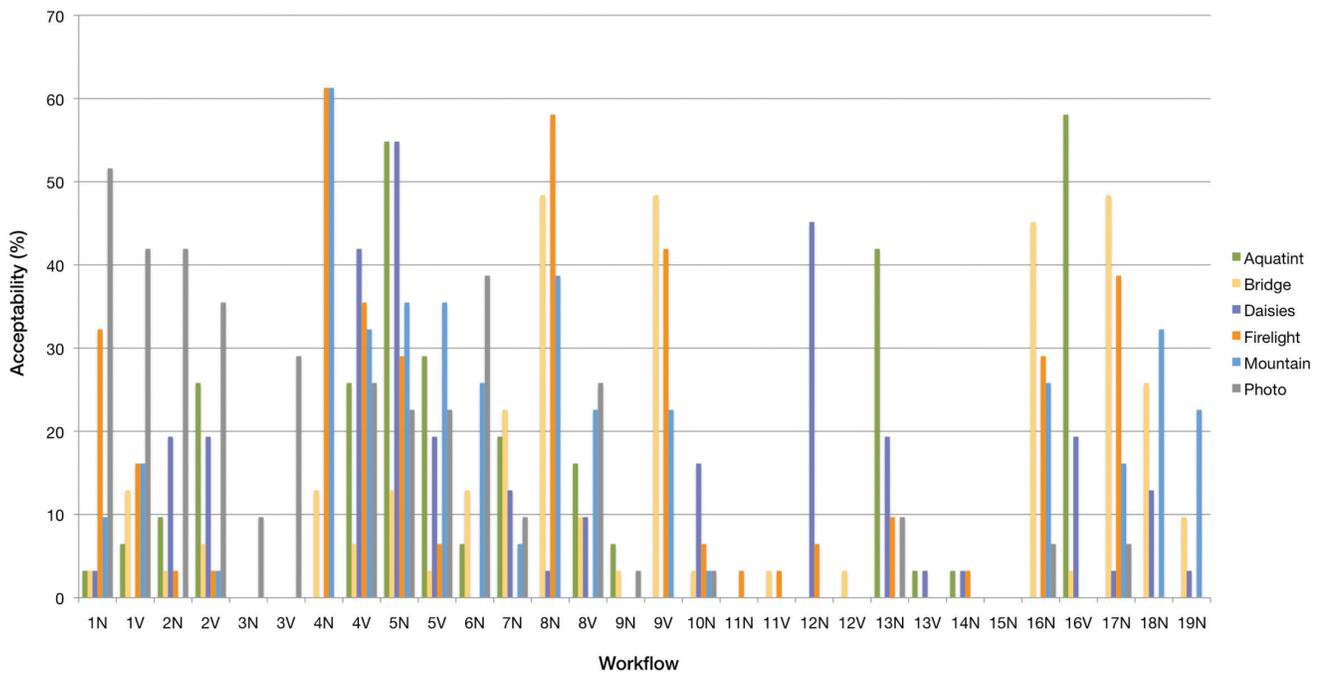


Figure 3-40. Percentage of observers who found a particular print to be an acceptable reproduction of the original artwork

<sup>35</sup> - The green (achromatic) and purple (chromatic) columns represent the prints made following the ISO 12467 specification (to the 'numbers') and the yellow (achromatic) and orange (chromatic) columns represent the prints made by making on-press visual adjustments to guide prints.

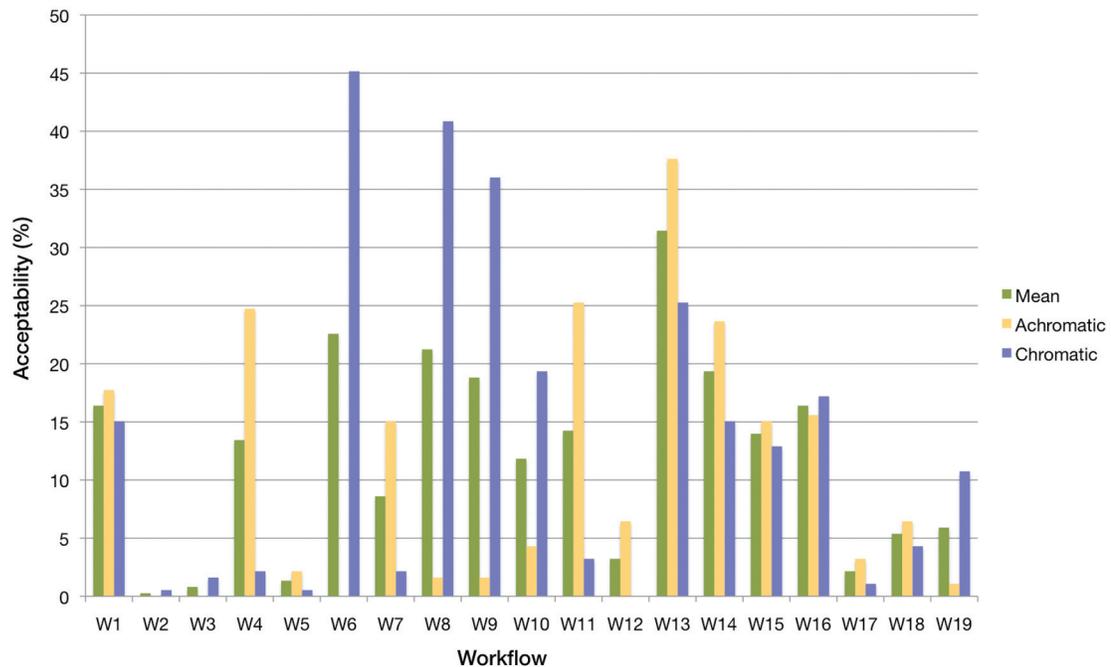


Figure 3-41. Average percentage of observers who found the prints for a given workflow to be acceptable reproductions for the six pieces of artwork included in the experiment

Another result clearly evident in Figure 3-40 is that Workflow 6 achieved the highest acceptability ratings in the experiment, with both the *Firelight* and *Mountain* paintings receiving acceptability ratings of over 60%. This is a remarkable achievement considering the minimal level of post-processing performed by this institution. These results are also in stark contrast to the performance of the more achromatic prints for W6, as none of these prints were ever found to be acceptable (see Figure 3-41). Note that workflows W8 and W9 had similar results, while workflows W4 and W11 had the opposite results; about one quarter of the observers found the prints of the more achromatic images to be acceptable while the more chromatic prints were rarely designated acceptable.

The objective targets were also imaged by the participating institutions. One of these, the Universal Test Target (UTT) supplied by Image Engineering, was designed to provide information regarding the quality of the image at the capture stage. (A thumbnail of the UTT is shown in Figure 3-44.) The results from the analysis of the capture files of this target are shown in Figures 3-42 through 3-48. (This analysis was conducted by Image Engineering.) The analysis provided information regarding tone reproduction, color, noise, resolution, and other image characteristics. Examples of the information provided for tone and color reproduction are shown in Figures 3-42 and 3-43.

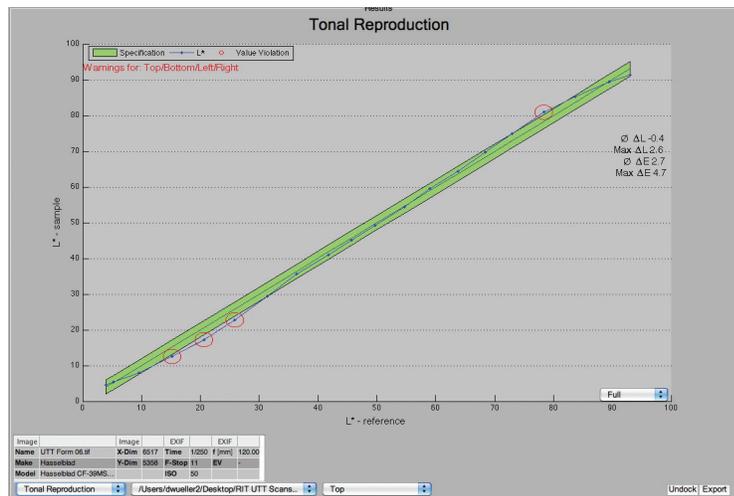


Figure 3-42. Tone reproduction results for one of the participating institutions as measured on the Universal Test Target from Image Engineering<sup>36</sup>

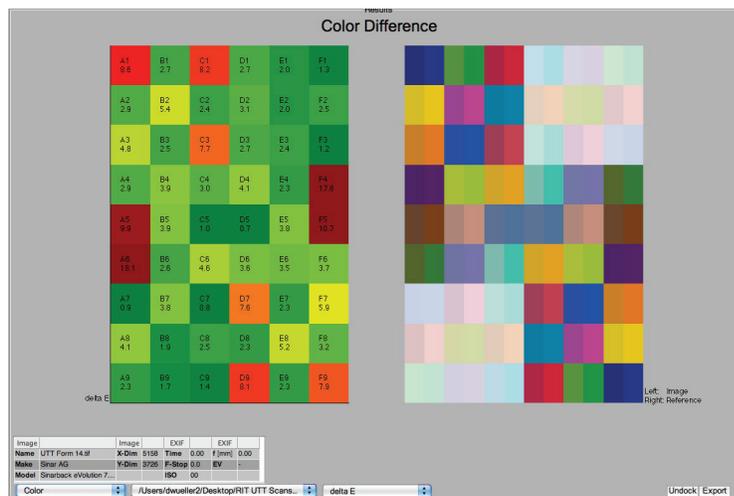


Figure 3-43. Color reproduction results for one of the participating institutions as measured on the Universal Test Target from Image Engineering<sup>37</sup>

Figure 3-44 shows the analysis results for image resolution measured at capture as a function of the mean  $z$ -score value for the 19 workflows averaged over the six pieces of artwork. The  $R^2$  value displayed on this chart is a measure of the linearity between the measured resolution and the mean  $z$ -score values, which were a measure of reproduction quality in this experiment. In other words, this value is a measure of how well the measured resolution predicts reproduction quality. If the measured resolution was a perfect predictor of the  $z$ -score value, then the  $R^2$  value would be 1.0. If, however, measured resolution does not predict  $z$ -score value at all, then the  $R^2$  value would be 0.0. The latter was essentially the result for the measured resolution versus  $z$ -score relationship. Therefore, measured resolution is essentially unrelated to the perceived reproduction quality of the prints. Figure 3-45 is a plot of the deviation from the aim white balance relative to the mean  $z$ -score value. Once again, this measure was not correlated with perceived reproduction quality.

36 - The measured values are plotted relative to the aim values. The green band represents the zone of acceptable tone values. This zone was found to be more aggressive than was needed for this study.

37 - The left graph shows the  $\Delta E_{ab}$  values calculated for the 54 patches measured. Green indicates acceptable values and red indicates unacceptable values. The right graph shows the aim (right) and measured (left) colors for each of the 54 patches.

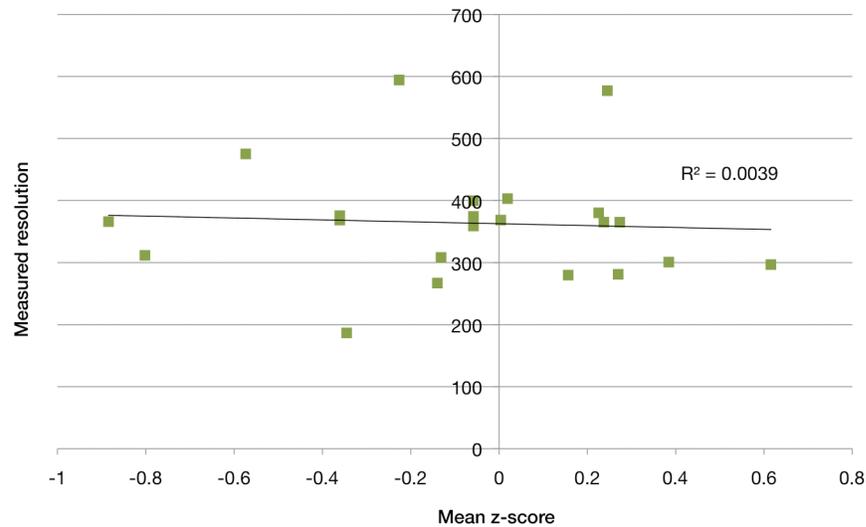


Figure 3-44. Measured resolution as determined from measurements of the UTT images supplied by the participating institutions as a function of the mean z-score value for each of the 19 workflows

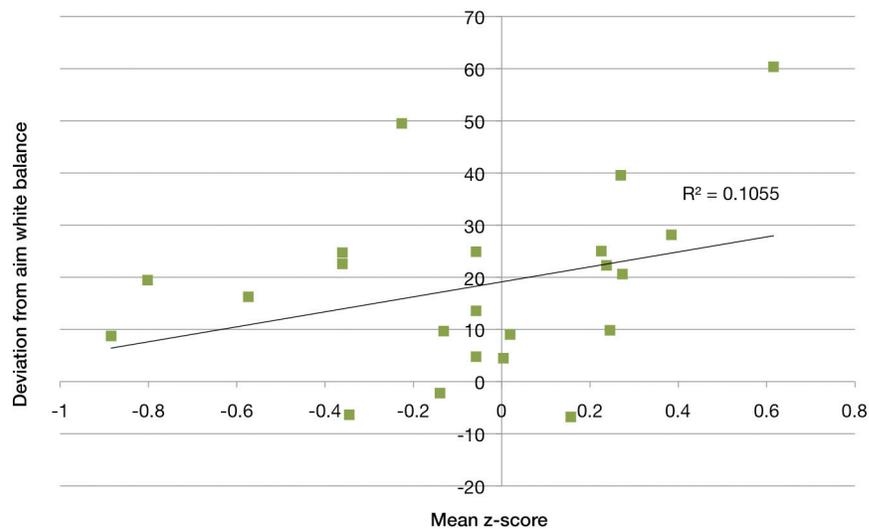


Figure 3-45. Deviation from aim white balance as determined from measurements of the UTT as a function of the mean z-score value

Figure 3-46 shows the deviation from the aim tone reproduction curve plotted relative to the mean  $z$ -score values. In this case, when three outliers<sup>38</sup> were removed from the analysis, the  $R^2$  value was 0.685. This indicates that aim tone reproduction is a reasonable indicator of perceived print reproduction quality for all but the three outliers.

<sup>38</sup> - The three outliers represented workflows in which extensive post-processing of the artwork images was performed.

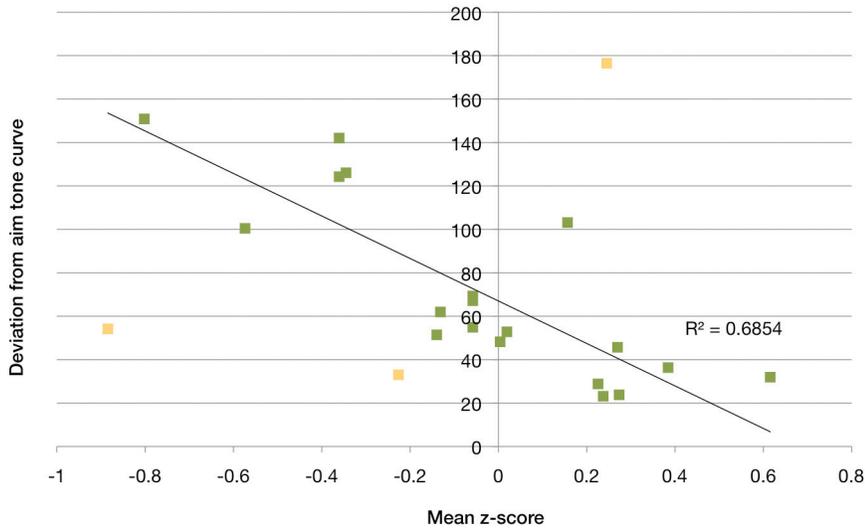


Figure 3-46. Deviation from the aim tone reproduction curve as determined from measurements of the UTT as a function of the mean z-score value

The positive result for the evaluation of tone reproduction as a function of  $z$ -score values suggests that the tone and, therefore, possibly the color of the prints may have been a significant factor in observers' assessment of reproduction quality. To investigate this further, the  $\Delta E_{76}$  information from the UTT captures was plotted relative to the mean  $z$ -score values (see Figure 3-47). The  $\Delta E_{76}$  value is a measure of the difference in color as measured at capture and of the aim color on the target. The  $\Delta E_{76}$  values ranged from approximately 4 to 17 with an average of 8.5. The  $R^2$  value of 0.7 indicates that color difference is also a fair indicator of perceived reproduction quality.

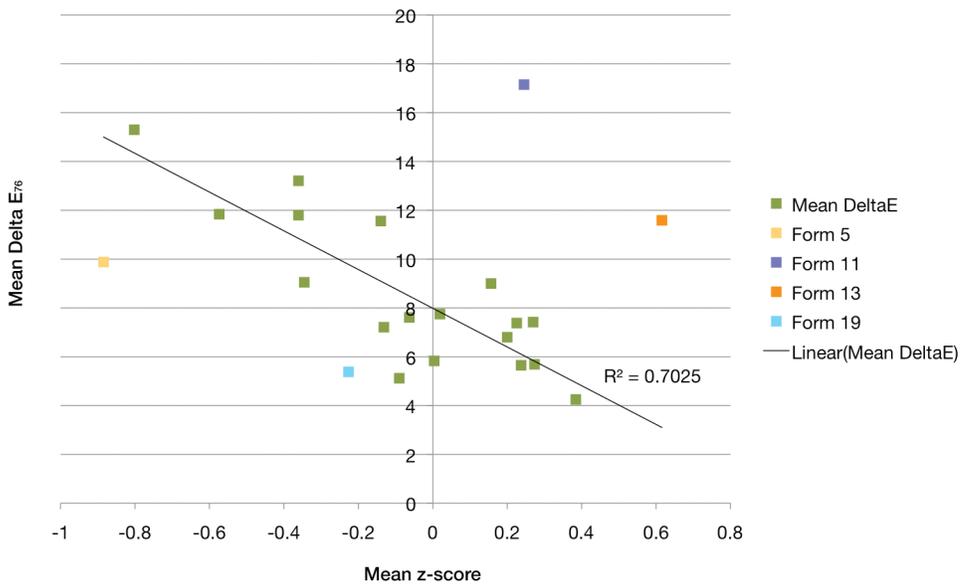


Figure 3-47. Mean  $\Delta E_{76}$  as determined from measurements of the UTT as a function of the mean  $z$ -score value for each of the 19 workflows

There are three components to the  $\Delta E_{76}$  value: lightness, hue, and chroma, which is a measure of the grayness of the color. Of these, lightness (also designated  $L^*$ ) is most closely related to tone. Consequently, the  $\Delta L^*$  values, which are a measure of the lightness differences between the captured colors and the target colors, were evaluated

relative to the  $z$ -score values (see Figure 3-48). The  $R^2$  value of 0.8 indicates that  $\Delta L^*$  values were a remarkably good indicator of perceived reproduction quality (with four outliers removed). This is a key finding from the experimentation. If this finding proves to be repeatable, it will be very important to the industry, as the ability to evaluate the quality of a printed reproduction through a measurement obtained in the capture stage would be invaluable.

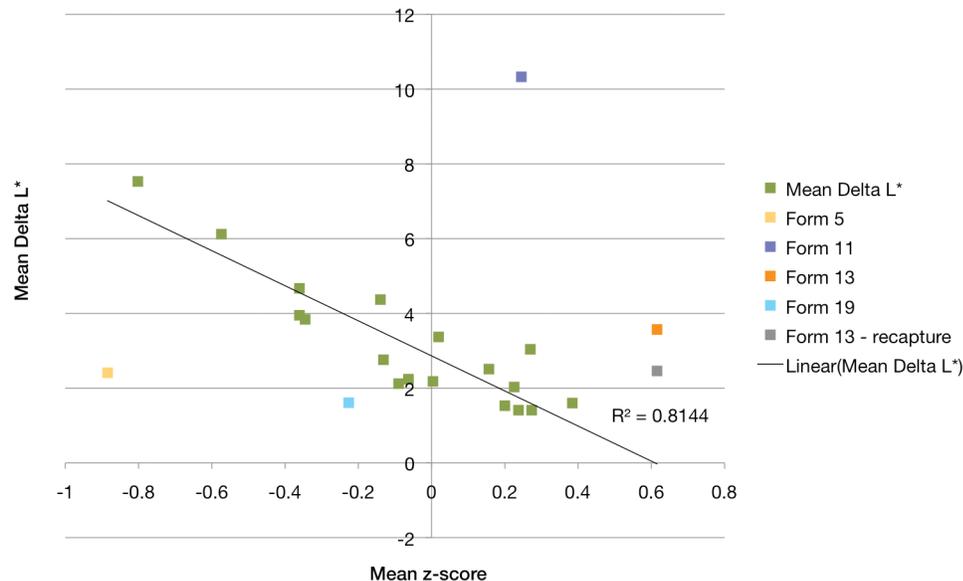


Figure 3-48. Mean  $\Delta L^*$  as determined from measurements of the UTT as a function of the mean  $z$ -score value for the 19 workflows

Further investigation into the data shown in Figure 3-48 revealed that the institution associated with W5 captured the artwork with a different workflow that it used for the capture of the targets. Additionally, the institutions associated with W11, W13, and W19 (among others), made color adjustments to the artwork images that were not made to the images of the targets. The data suggests that, if the institution associated with W5 had captured the artwork using the same workflow as it had for the targets, and if the institution associated with W19 had not made the additional color adjustments to the artwork images, the target prints generated for these two institutions may have received much better rankings. Contrarily, if the institutions associated with workflows W11 and W13 had not made the additional color adjustments to the targets, it is likely that the resulting prints would not have been as well regarded.<sup>39</sup>

Having identified  $\Delta L^*$  at capture as a reasonable indicator of perceived reproduction quality, it was of interest to understand if there was a measure from the actual prints that would also be useful in predicting perceived reproduction quality. The first step taken to evaluate this was the measurement of  $\Delta E_{00}$  values between the printed Macbeth ColorChecker patches and the original target. The results indicated that the  $\Delta E_{00}$  values of the prints were not nearly as good at predicting the perceived reproduction quality as the values measured at capture, even with five workflows removed from consideration (see Figure 3-49). This surprising result may be due to the patches on the UTT better representing the colors in the artwork than those of the ColorChecker, although both targets were developed for photographic evaluation.

<sup>39</sup> - In part to check this assumption, the institution associated with W13 performed an additional capture of the UTT, putting it through the same workflow as the artwork. The analysis of this new capture of the UTT target resulted in a  $\Delta L^*$  value of 2.46, which falls closer to the trend line in Figure 3-48. Though still not as low as the linear relationship would predict, it is now below the  $\Delta L^*$  limit of 3. Measurements below this limit generally indicated an above average reproduction.

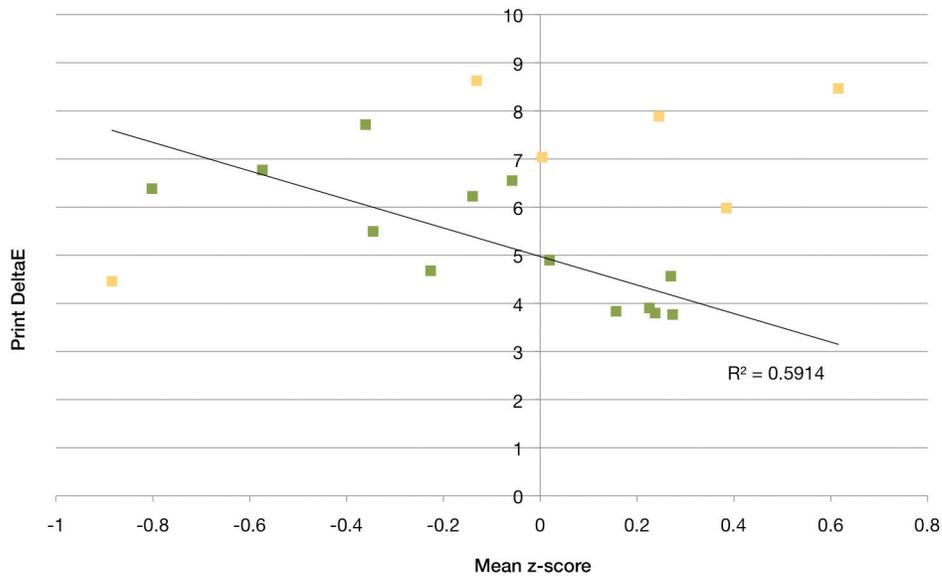


Figure 3-49. Color difference values ( $\Delta E_{00}$ ) as measured between printed and original Macbeth ColorChecker patches as a function of mean z-score value

It is interesting to note that previous testing<sup>40</sup> resulted in a mean  $\Delta E_{00}$  color difference of  $8.4 \pm 2.0$ , as measured on a Macbeth ColorChecker. The average  $\Delta E_{00}$  value in this experiment was  $5.8 \pm 1.6$ , indicating possible improvement since the time when the prior project was conducted. The workflows achieving the lowest  $\Delta E_{00}$  values (the smallest visual differences in color) in each of the two projects were roughly equivalent (see Table 3-5). However, the middle and highest  $\Delta E_{00}$  values (average and largest differences) were higher in 2005 than 2010 (see Figure 3-50 and Table 3-5), indicating that, while the best workflows were not necessarily getting better, the worst were substantially improved.

Table 3-5. Color differences as measured on the Macbeth ColorChecker in 2005 and in 2010

$\Delta E_{00}$ value	2005	2010
Lowest value	4.2	3.8
Median value	8.3	6.0
Highest value	13.7	8.6

40 - Berns, R.S., Frey, F.S., Rosen, M.R., Smoyer, E.P.M., & Taplin, L.A. (2005, April). *Direct digital capture of cultural heritage: Benchmarking American museum practices and defining future needs – Project report* (Technical report). Rochester, NY: Munsell Color Science Laboratory. Retrieved from [http://www.cis.rit.edu/museumSurvey/documents/Benchmark\\_Report\\_April.pdf](http://www.cis.rit.edu/museumSurvey/documents/Benchmark_Report_April.pdf)

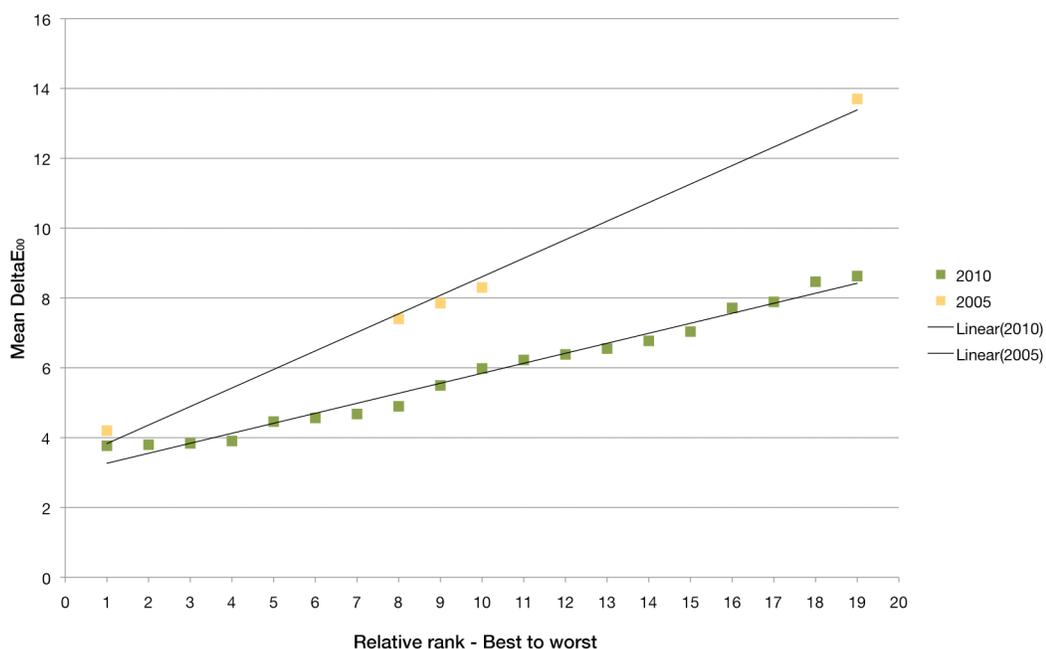


Figure 3-50. Color differences as measured on the Macbeth ColorChecker in 2005 and in 2010

The second step taken to evaluate whether there were measurements that could be made on the actual prints that would be useful in predicting perceived reproduction quality was to measure the  $\Delta E_{00}$  values between the colors on the original artwork and the associated colors in the print reproductions. To accomplish this, paper templates were created to maintain accurate locations for the Eye One spectrophotometer during color measurement. Between four and six locations on each of the originals were selected for analysis (see Figure 3-51). The resulting color difference measurements, averaged over all the pieces of the artwork, were plotted relative to  $z$ -scores (see Figure 3-52). The results show a strong relationship between color differences as represented by the  $\Delta E_{00}$  values and perceptual assessment of the reproduction quality as represented by the  $z$ -scores. This indicates that color and tone are critical factors in the perception of the reproduction quality of printed images.



Figure 3-51. Measurements of the specified areas of on the individual pieces of artwork

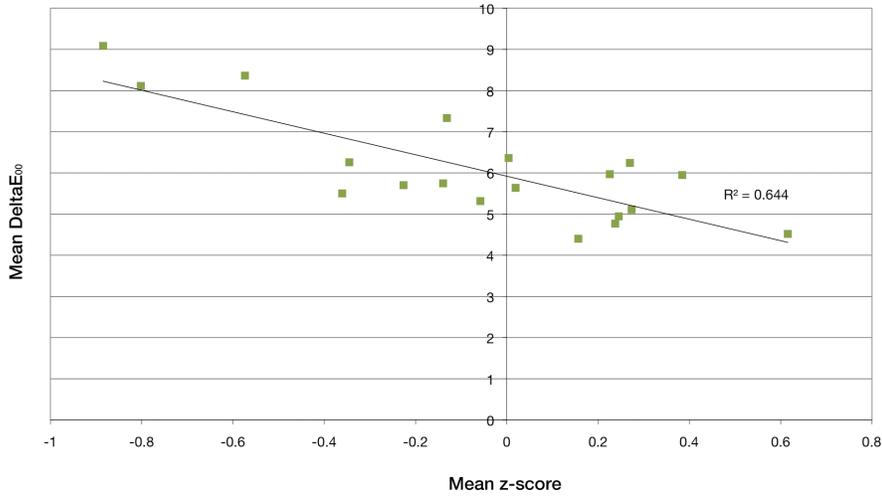


Figure 3-52. Color difference values ( $\Delta E_{00}$ ) as measured between the prints and the original averaged over the six pieces of artwork as a function of mean z-score value

Aspects of the workflows used by the participating institutions were examined to identify factors important to producing perceptually high-quality reproductions. Camera type and color space did not appear to be among the factors that were most important. The institutions associated with workflows 5, 14, and 15 all used the same general make and model camera, yet the results for these workflows were wide ranging (see Figure 3-32 and Table 3-4). W5 was one of the workflows with the most trouble, W15 was average, and W14 was one of the better performers. One institution also provided files in two different color spaces. The files were treated identically in all other aspects, and they had generally small differences in performance. Figure 3-53 shows the results for the two color spaces. The eciRGB space version was ranked higher for *Bridge*, while the AdobeRGB version of *Photograph* was ranked higher. Otherwise, the differences were not statistically significant. One other institution also used the eciRGB color space, and one other used ProPhotoRGB. These institutions were neither among the best or the worst of the participants. Both the best and the worst institutions delivered their image files in the AdobeRGB color space.

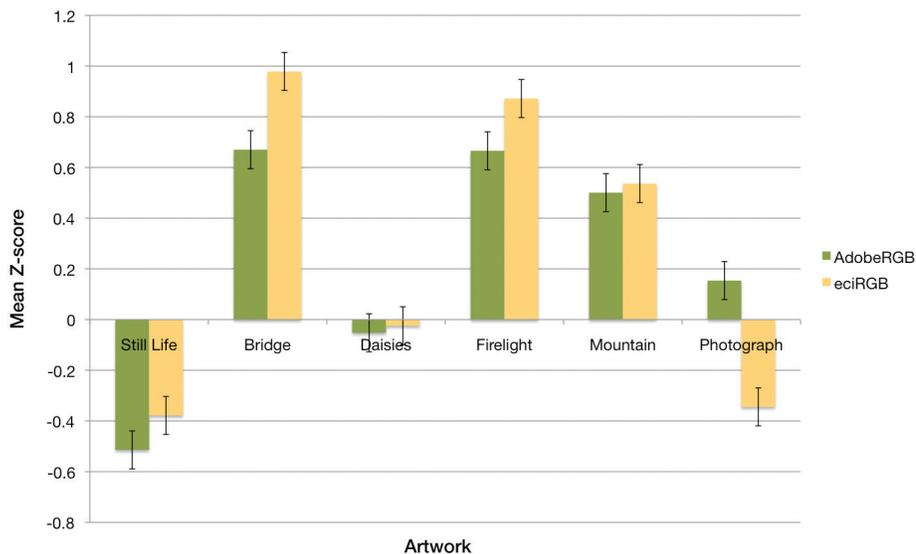


Figure 3-53. Mean z-scores for files using AdobeRGB and eciRGB color spaces from a single institution with an otherwise consistent workflow

## Soft Copy Results

The ranking results for the individual pieces of artwork are shown in Figure 3-54. Since the originals were present in this experiment and observers were asked to choose the better representation of the originals, colorimetric accuracy was used to predict and model the ranking results. To quantify the color accuracy, the color difference ( $\Delta E_{00}$ ) measurements under CIE Illuminant D65 on the hard copy prints were used as an indicator of color accuracy. Simple linear regression was performed for each image. The z-scores converted from the ranking data were used as the response, and mean color difference at selected locations on the hard copy was the predictor. An example of this analysis is shown in Figure 3-55.

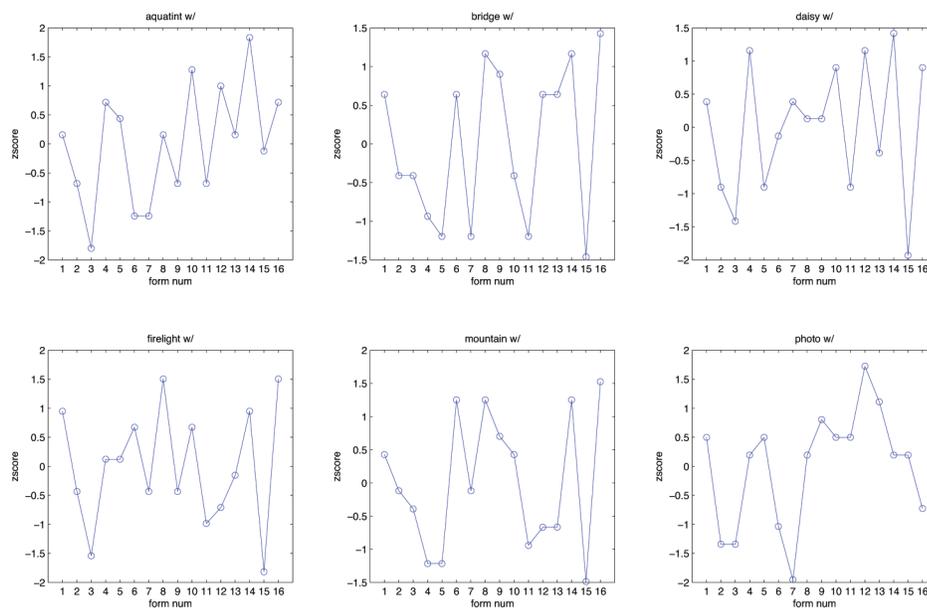


Figure 3-54. Soft copy z-score results with the original present for each piece of artwork<sup>41</sup>

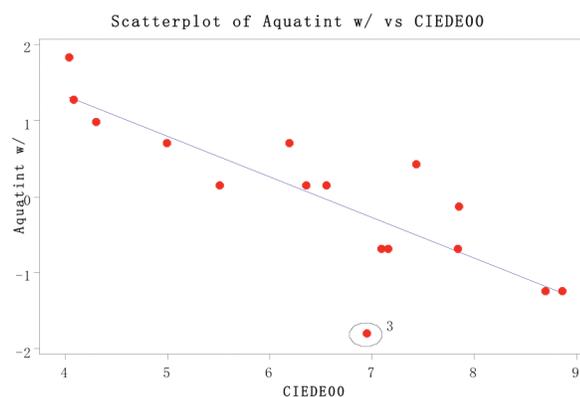


Figure 3-55. Results for 'Still Life' (aquatint) with the original plotted against the color difference

In Figure 3-55, the y-axis is the z-score of the ranking data for *Still Life*. The higher the z-score, the better the image was ranked. The x-axis is the mean color difference. The regression line fitted most data points well, indicating that

41 - The form numbers for the soft copy experiment do not match those of the hard-copy experiment because only 16 of the 18 workflows were represented.

## Section 3: Experiments

the color difference on the corresponding hard copy served as a reasonably good predictor of perceptual quality. (The  $p$ -value for the color difference predictor was almost zero, and the *adjusted*  $R^2$  value was 66.3%.) The negative slope of the regression line meant that the higher the color difference, the worse the reproduction was ranked.

The Form 3 soft copy reproduction seemed to be an outlier in Figure 3-54. It was ranked as the worst while its color difference was not among the highest. However, the Form 3 image was much lighter than the remaining reproductions of *Still Life*. To verify this difference, the lightness histograms of the Form 3 reproduction and the mean of the remaining reproductions were compared (see Figure 3-56).

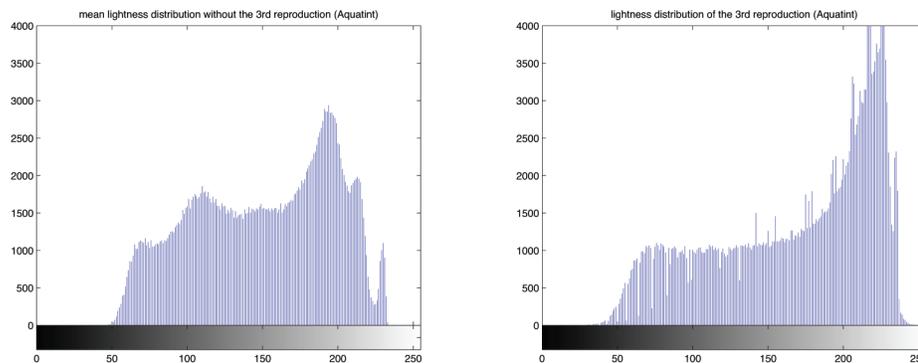


Figure 3-56. Lightness distributions for 'Still Life' (aquatint) reproductions

The lightness distribution of the Form 3 reproduction was much more skewed to the right, which was in agreement with its much lighter appearance. The lightness difference between the hard copy reproduction and the original ( $\Delta L^*$ ) was therefore included in order to improve the model. For *Still Life*, more variance could be explained through the addition of  $\Delta L^*$  to the model, as the *adjusted*  $R^2$  value increased from 66.3% to 84.8%. Both color difference and  $\Delta L^*$  were found to be significant predictors, with a  $p$ -value of 0.001 for  $\Delta L^*$ .

The color difference predictor was found to be highly significant in predicting the experimental results for all six of the images. This indicates that the major criterion used by observers to rank the images when the original was present was colorimetric accuracy.

### Soft Copy Results Versus Hard Copy Results

A comparison of the perceived quality scaling results for the images displayed on-screen (soft copy) relative to those for the prints (hard copy) indicates that there is a high degree of correlation between these modalities (see Figure 3-57). The images for three workflows show a relative improvement when considered in soft copy format. For two of these workflows, this may be because the prints were relatively low in contrast and therefore not as visually appealing, but the on-screen images may have appeared to be closer to the original. For one workflow, a file prepared specifically for web viewing was provided. The workflow used for this file appears to have been more successful than the workflow used for print output. The images for the fourth workflow fell from being ranked as the highest in print to above average (tied for fourth) when viewed on-screen. This may be due to the fact the files provided were optimized for print viewing.

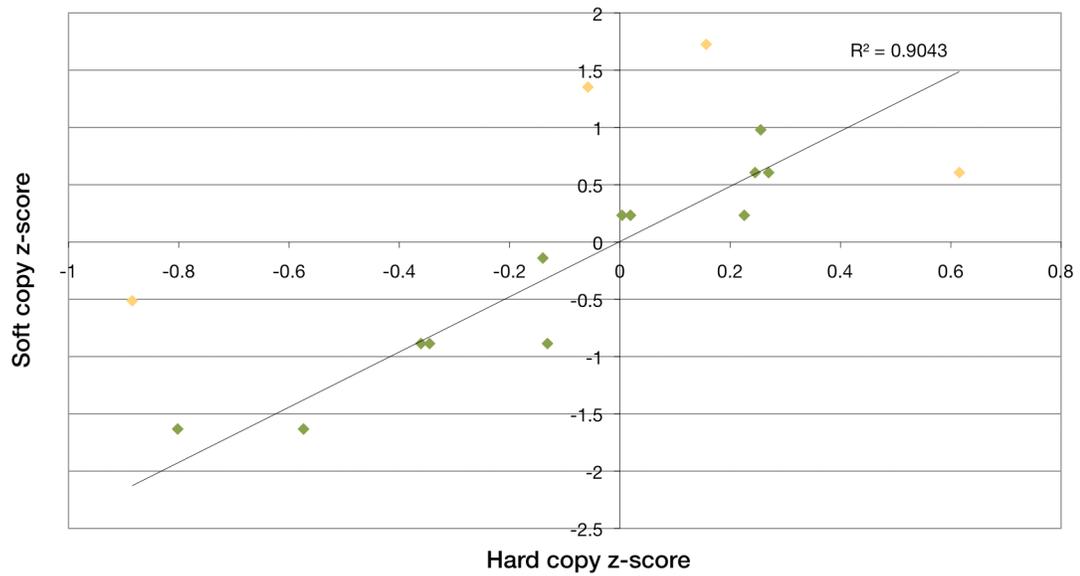


Figure 3-57. Z-scores for the soft copy (screen) images relative to the printed (hard copy) reproductions in the workflow experimentation with the original artwork present

Table 3-6. Rankings for the soft copy (screen) images and hard copy (print) images in the workflow experimentation with the original artwork present<sup>42</sup>

Soft copy	Hard copy
16	13
18	
8, 9	
1, 11, 13	1, 6, 8, 9, 11, 16
6, 10, 15	10, 15, 18
4	
5	4, 7
3, 7, 12	3, 12
2	17
17	2, 5

42 - The best reproductions are listed at the top in green, the worst at the bottom in red. The soft copy workflows were re-numbered to match those of the hard-copy experiment.

## EXPERIMENT IV: THE IMPACT OF WORKFLOW ON THE PERCEIVED QUALITY OF FINE ART IMAGES WITHOUT THE ORIGINAL PRESENT

The most common experience that people will have with printed reproductions is without the original artwork available for direct comparison. People may be buying printed materials in the museum shop, looking at exhibition catalogues in their homes, or tacking up small posters in their offices. It is of interest, then, to understand the difference in how people rank print reproductions without the original present. The next experiment conducted in this project examined this question. This experiment was conducted using the same procedure and the same stimuli that were used in the workflow experiment, with one exception: now the observers were being asked to identify the most preferred image rather than the best reproduction of the original. A total of 14 observers participated in this experiment, including 10 that had participated in the workflow experiment and, therefore, were well acquainted with the original artwork. The other four observers, however, had only limited knowledge of the originals.

### Hard Copy Results

The results for the print portion of the experiment, shown in Figures 3-58 through 3-64, indicate that the presence of the original had limited impact on the ranking results for most of the prints. The results averaged over all of the artwork were highly correlated for most of the workflows (see Figure 3-58).

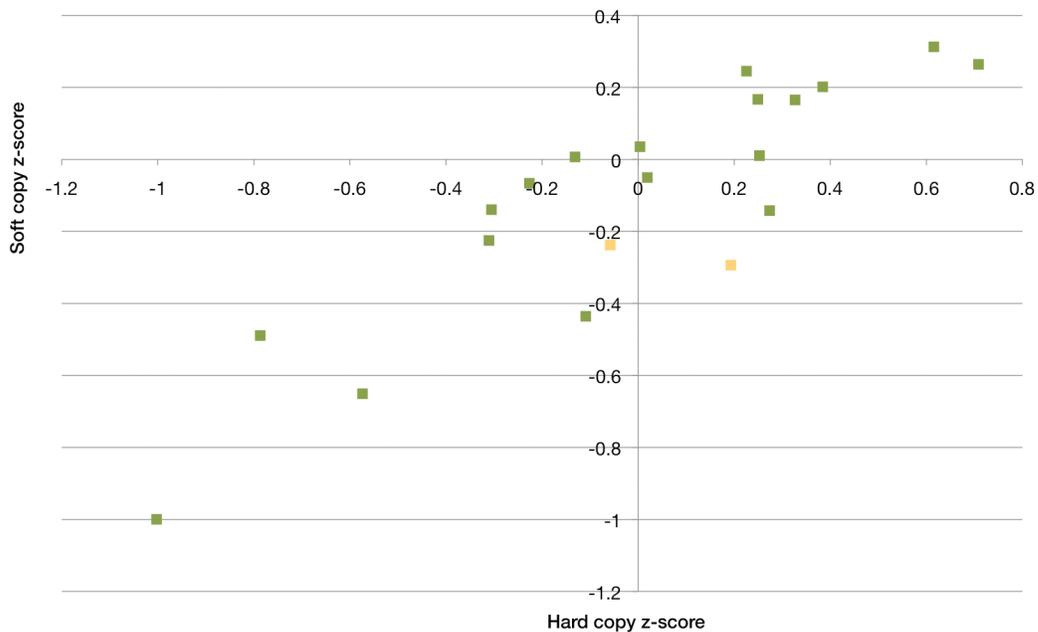


Figure 3-58. Mean z-score value for each of the printed images ranked without the original present averaged for all artwork plotted as a function of the mean z-score value for the prints when ranked as a reproduction of the original artwork

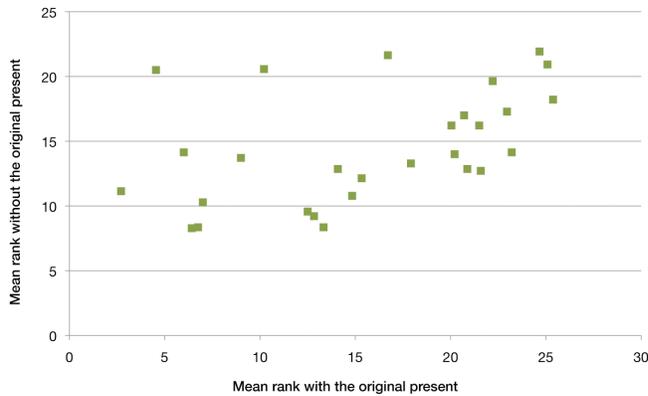


Figure 3-59. Mean ranking of the prints for ‘Still Life’ without the original present relative to the rankings for the same prints when ranked as reproductions of the original

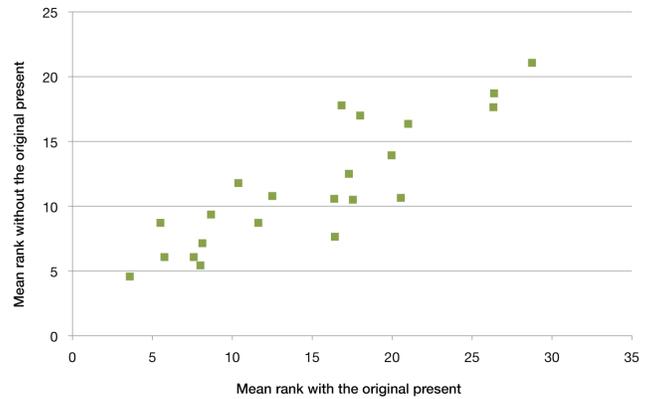


Figure 3-62. Mean ranking of the prints for ‘Firelight’ without the original present relative to the rankings for the same prints when ranked as reproductions of the original

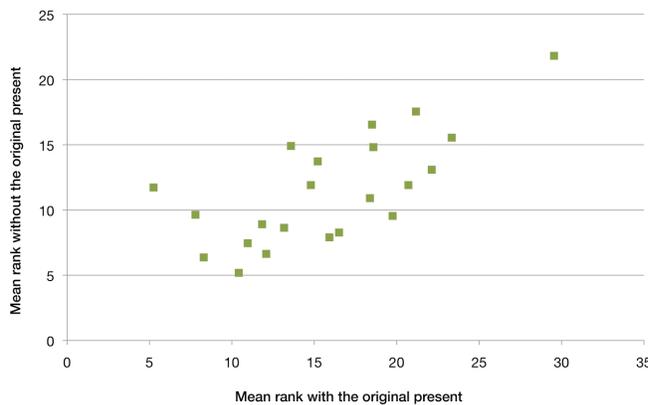


Figure 3-60. Mean ranking of the prints for ‘Bridge’ without the original present relative to the rankings for the same prints when ranked as reproductions of the original

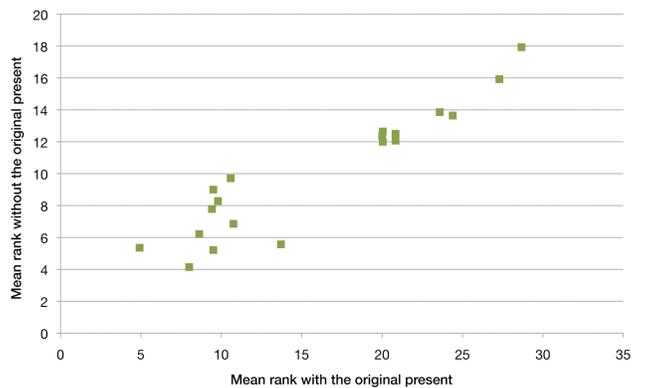


Figure 3-63. Mean ranking of the prints for ‘Mountain’ without the original present relative to the rankings for the same prints when ranked as reproductions of the original

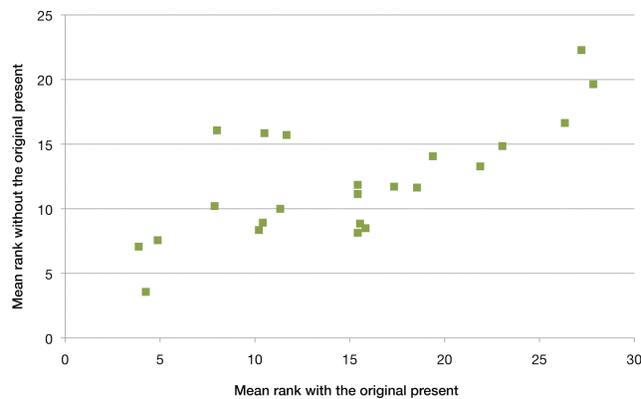


Figure 3-61. Mean ranking of the prints for ‘Daisies’ without the original present relative to the rankings for the same prints when ranked as reproductions of the original

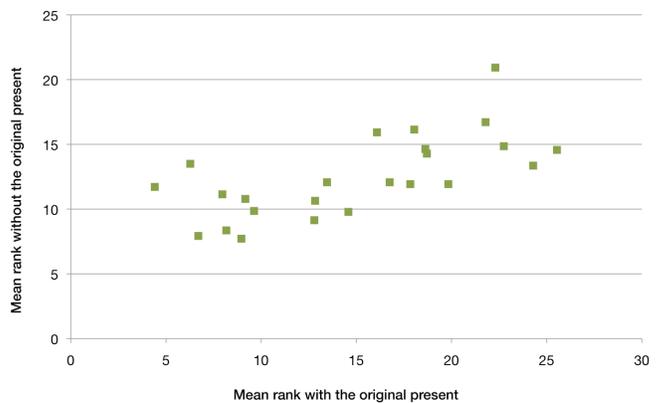


Figure 3-64. Mean ranking of the prints for ‘Photograph’ without the original present relative to the rankings for the same prints when ranked as reproductions of the original

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The results for the individual pieces of artwork revealed three factors that seemed to drive the few changes in how prints were ranked when comparing to the original relative to evaluating on the print's own merits. One of these factors was contrast. Prints that were relatively low contrast but close in overall hue to the originals ranked about average when the originals were present, but fell out of favor when the prints were evaluated on their own. Another factor was texture. Observers tended to rank prints depicting some degree of the texture of the original paintings—whether the impasto or the canvas itself—more highly when the paintings were present than when the originals were absent. This can be seen especially for the *Bridge*, *Daisies*, and *Firelight* paintings (see Figures 3-60, 3-61, and 3-62 respectively).

The third factor was neutrality. The original *Still Life* aquatint had a slight sepia or brownish hue when viewed under the D50 experimental lighting conditions. Prints that matched this hue were ranked relatively well when the original was present. However, without the original in view, many observers exhibited a preference for prints having an overall hue that was closer to neutral, perhaps because they had little memory of the general hue of the original. This same effect was evident, though to a lesser degree, for *Photograph*. Observers may have had more of an idea of how a historic photograph should look than they had for the aquatint. The correlation between the rankings with and without the original present was lowest for these two originals (see Figures 3-59 and 3-64).

The relationship between the rankings with and without the originals being present was strongest for the *Mountain* and *Firelight* paintings (see Figures 3-63 and 3-62). Indeed, the correlation for these paintings was surprisingly high, given the change in task, and may possibly be due to the level of intra-observer repeatability. (This would be something that would be interesting to check in another experiment.) The high correlation may be the result of these paintings containing a significant level of 'memory' colors—colors for which humans have a specific impression of appearance—and may indicate that the artist painted with a relatively 'natural' palette. It may also indicate that some degree of preference is involved even when evaluating the prints for reproduction quality.

### Soft Copy Results

The results for the display (soft copy) portion of the experiment are shown in Figure 3-65 for all of the artwork and in Figure 3-66 for each individual piece. These results indicate that the presence of the original had a much more dramatic impact on the ranking results for several of the images. The performance for eight of the workflows improved without the original present while the rankings for four of the images were considerably worse. In fact, the rendition that was ranked the best with the original present was ranked the worst when it was not present. Though the colors were close enough in appearance to warrant high rankings when the original was present, these same colors were unappealing when the decision criterion shifted to preference. The images for this workflow, along with the images for the workflow that was ranked second with the original present but a little below average when it was not, appeared low in contrast.

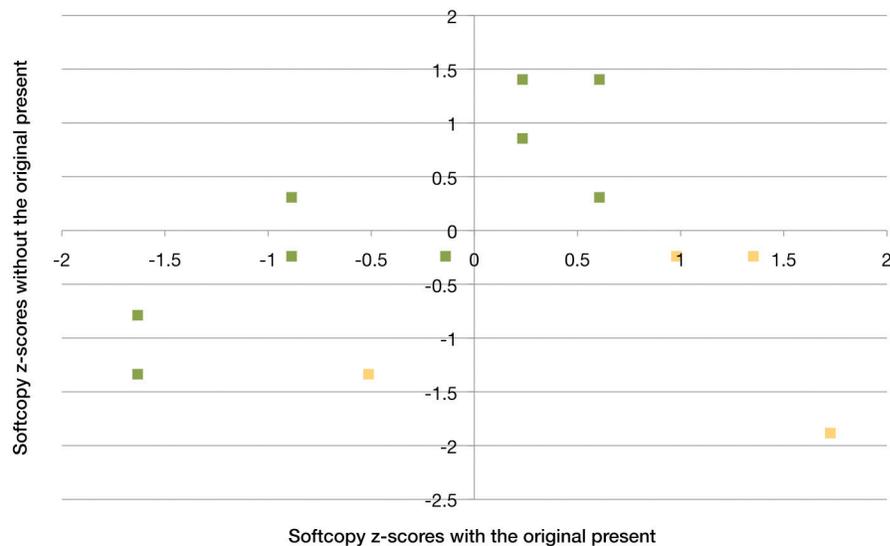
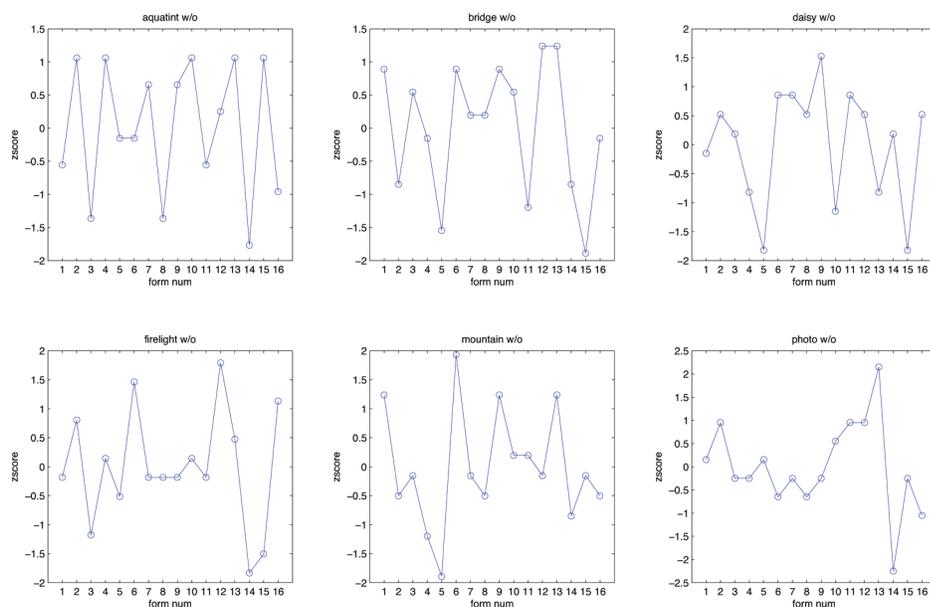


Figure 3-65. Soft copy z-score results with and without the original present

Figure 3-66. Soft copy z-score results without the original present for each piece of artwork<sup>43</sup>

Measurement of the tone reproduction curve made using the UTT for these workflows showed that the  $L^*$  values for the black patches of the tone curve were considerably lighter than the aim (see Figures 3-67 and 3-68). For comparison, the tone curve measurements for one of the institutions considered the best without the original present is shown in Figure 3-69. The tone reproduction curves for the remaining workflows indicated either higher contrast than or close to the aim curve, with the exception of one that was too light overall and one that was too dark overall. There was also one workflow, Form 2, which generally did not receive high rankings when the original was present but was well ranked for the *Still Life*, *Daisies*, *Firelight*, and *Photograph* images when the original was not available for comparison. This workflow was one of those that had a tone reproduction curve

43 - The form numbers for the soft copy experiment do not match those of the hard-copy experiment because only 16 of the 18 workflows were represented.

## Section 3: Experiments

indicating higher contrast than the aim (see Figure 3-70). The effect of contrast was not as prevalent in the print portion of the experiment. Observers did not consider prints from these two workflows to be among the best matches to the original, but neither did they consider them among the worst in terms of preference.

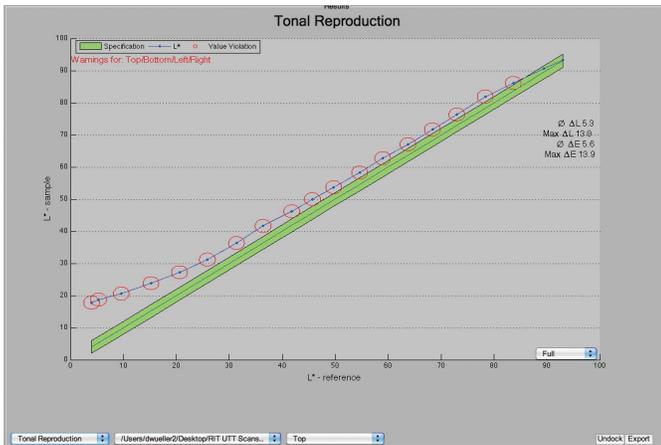


Figure 3-67. Tone reproduction curve for the UTt for the workflow that went from top-ranked for color reproduction to the lowest ranked for preference

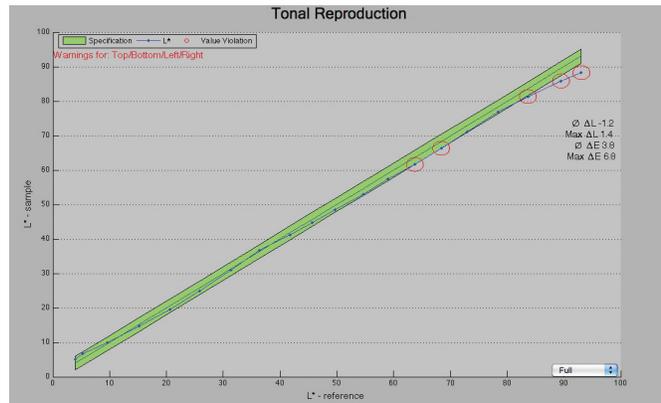


Figure 3-69. Tone reproduction curve for the UTt for the workflow that was ranked a little above average for color reproduction and among the best for preference

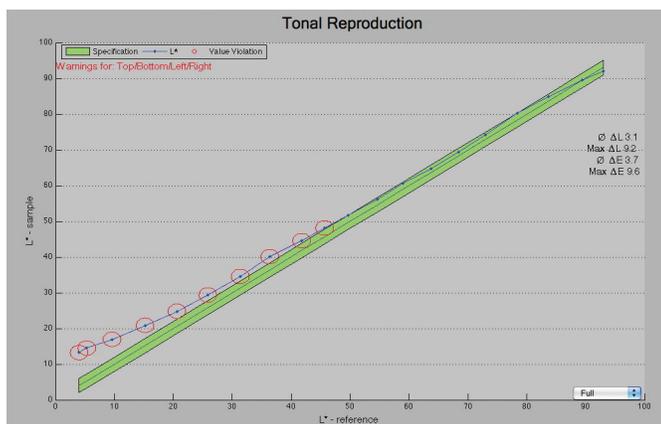


Figure 3-68. Tone reproduction curve for the UTt for the workflow that went from second-best for color reproduction to a little below average for preference

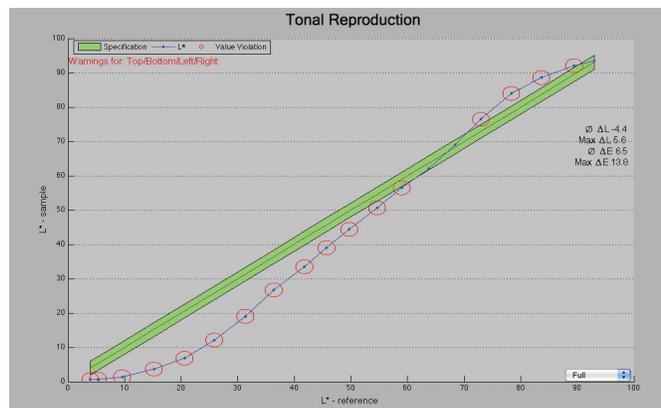


Figure 3-70. Tone reproduction curve for the UTt for the workflow that was ranked poorly for color reproduction but was among the more preferred images for several pieces of artwork

## Hard Copy Versus Soft Copy Results

When the original was not present there was, once again, fairly good agreement between the z-scores for the images when viewed as soft copy relative to when they were viewed as hard-copy for most of the workflows (see Figure 3-71 and Table 3-7). The renditions for five of the workflows, however, were ranked much lower for the soft copy mode. There was no consistency among these renditions: one was high-contrast, one was low-contrast, two were relatively dark, and the other had a fair amount of texture in its rendition of *Bridge*. The low-contrast image was the highest-ranked image in the soft copy experiment when the original was present and the lowest ranked image when the original was not present. Neither of these rankings correlated well with the print results: this workflow was ranked slightly above average when the original was present and slightly below average when it was not present.

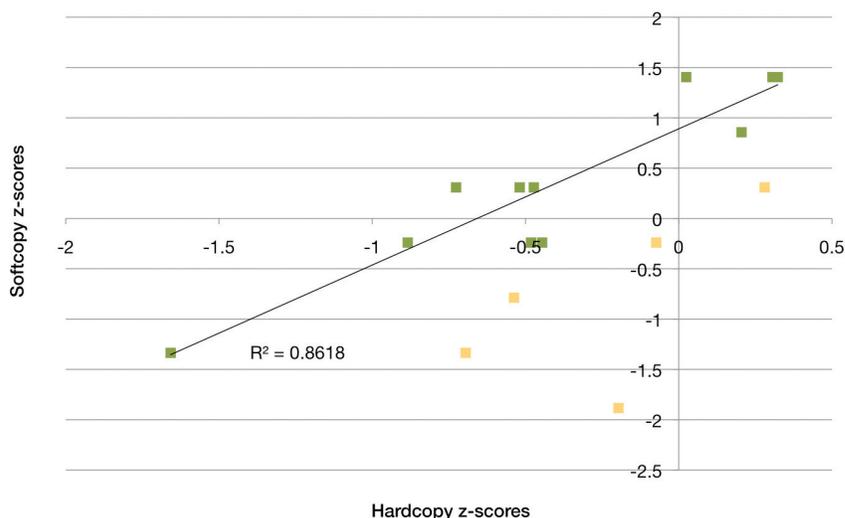


Figure 3-71. Z-scores for the soft copy (screen) and hard copy (print) images in the workflow experimentation without the original artwork present

Table 3-7. Rankings for the images in the soft copy (screen) and hard copy (print) images in the workflow experimentation without the original artwork present<sup>44</sup>

Soft copy	Hard copy
	13
6, 13, 15	1, 6
10	8, 9
1, 3, 7, 11	7, 10, 15
	11, 12
4, 8, 9, 12, 18	3, 16, 18
2	2, 17, 4
16, 5, 17	5

<sup>44</sup> - The best reproductions are listed top in green, the worst at the bottom in red. The soft copy workflows were re-numbered to match those of the hard-copy experiment.

## Conclusion

The results of the experiments performed in this study indicate that there were few significant differences in the rankings for the printed renditions when viewed with and without the original present. The biggest changes in the rankings were for the more monochromatic images. The originals of these images were not neutral, but, when the originals were not present, people preferred the more neutral renditions.

There was a greater degree of difference with and without the original for the soft copy mode. The two workflows most often selected as providing the best representations of the originals were considered the worst, on average, when the original was not present. Understanding which workflows provide both acceptable representations of the originals as well as pleasing images will be important to understand for those who are striving to provide images of fine art. It is also of interest to understand which workflows provide reasonable images when viewed both on-screen and in print. The differences between the rankings for the images when viewed in the hard copy and soft copy modes were minimal for most workflows whether or not the original was present.

## EXPERIMENT V: THE IMPACT OF WORKFLOW ON PERCEIVED QUALITY OF FINE ART IMAGES WHEN VIEWED ON THE WEB

For this experiment, a web application that included a graphic user interface and a back-end database was implemented to allow a test of fine art reproductions in an uncontrolled environment. Observers from around the world were invited to take part in the experimentation, with limited constraints on viewing conditions as long as reasonable Internet speed and a web browser were available. The software was built in Java<sup>®</sup> using Eclipse<sup>®</sup>. Tomcat<sup>®</sup> was used for the web server with a MySQL<sup>®</sup> database. iWeb<sup>®</sup> was used to design the user interface.

The main interface of the web-based application is shown in Figure 3-72. During the experiment, observers were asked to select their preferred image by clicking in the area of the image that most influenced their decisions.

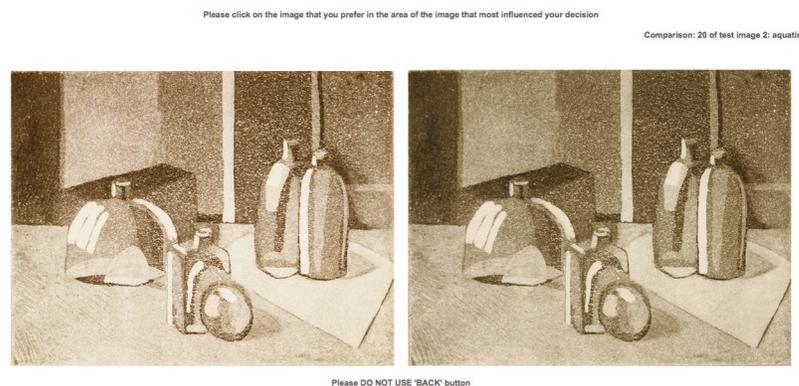


Figure 3-72. Graphic user interface for web-based ranking experiment

Eighty-eight observers, ranging in age from 20 to 65, participated in the experiment. There were approximately an equal number of male and female participants. The size of the displays used by observers ranged widely, from 13 inches to 30 inches. In addition, about two-thirds of participants used the Macintosh<sup>®</sup> operating system while the rest used the Microsoft Windows<sup>®</sup> platform. The vast majority of observers took part in the experiment through either the Firefox<sup>®</sup> or Safari<sup>®</sup> web browsers, with a few using Internet Explorer<sup>®</sup> or Google Chrome<sup>®</sup>.

Two of the sixteen images in the first two soft copy experiments came from the same institution but were captured by two different cameras. The performance for these images was quite similar. Therefore, in this experiment, one of these two images was replaced by a reproduction that was not included in the first two soft copy experiments but that had performed well in the hard copy portion of Experiment III. It was of interest to evaluate how well this image was perceived in a soft copy environment. (When comparisons were made to the previously conducted soft copy experiments, the replaced image and the replacement image were both excluded.)

In order to examine how observers' display settings affected the ranking results, observers were requested to answer questions prior to the ranking experiment regarding their display contrast and color management. A snapshot of the user interface for determining display contrast is shown in Figure 3-73. Observers were asked to identify the number of shades visible in two grayscale. The first (top) grayscale was used to test the smoothness of changes in the gray tone from black to white, and the second (bottom) grayscale was intended to test the performance of the display in showing just-noticeable-differences (JND) in highlight, mid-tone and dark neutral colors. The number of perceptible shades was indicative of the image contrast of the display.

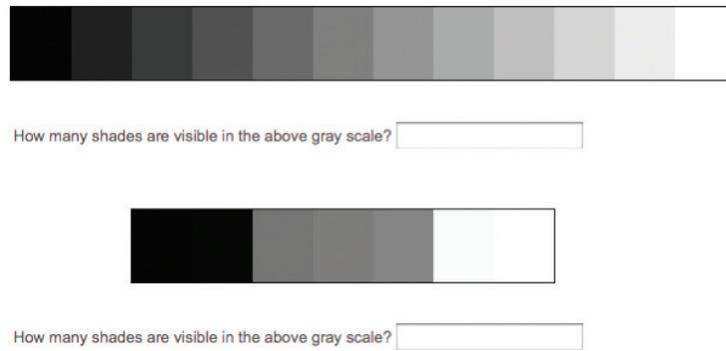


Figure 3-73. Grayscale test for the web-based ranking experiment

The first (top) grayscale was a continuum of shades of neutral color, gradually changing from black to white. The second (bottom) grayscale was composed of two black, three gray, and two whitish shades. The shades in the second grayscale were designed to have just-noticeable-differences within each set of black, gray and whitish colors. The number of shades that were identified by observers would be indicative of the gamma configuration (and thus the contrast) of the display. On an ideal display, twelve shades would be seen in the first grayscale with seven shades in the second grayscale.

A vast majority of observers were able to distinguish all twelve shades in the top grayscale, based on the ranking data from the first 60 observers. However, observers were not always able to see the differences in the second grayscale. The distribution of the number of identifiable shades in the second grayscale is shown in Figure 3-74. About half of the observers were unable to distinguish all seven shades in the JND-grayscale, indicating a too-low or too-high contrast resulting from an improper setting of gamma on the display.

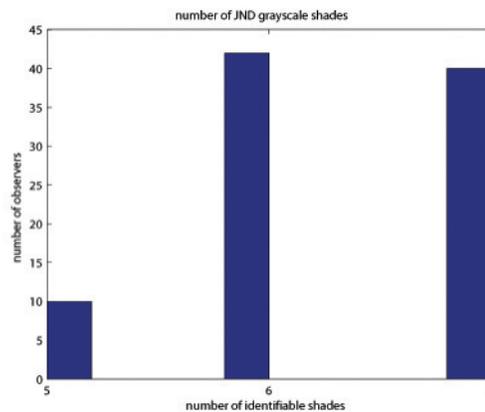


Figure 3-74. Number of shades identifiable by observers in the second grayscale

The ranking data from observers who could not identify all seven shades in the JND-grayscale were compared with those from observers who identified all seven shades (see Figure 3-75). In this figure, Group 1 (the blue bars) was composed of observers who were not able to see all seven shades in the JND-grayscale, and those in Group 2 (the red bars) were observers who identified all seven shades. Given the ordinal nature of the ranking data, Spearman  $\rho$  correlations<sup>45</sup> were calculated between the two groups. For all six images, the correlation coefficients were close to 1, indicating a high correlation (see Figure 3-76). (All of the  $p$ -values were close to 0.) From this analysis, it was

45 - Miller, I., & Miller, M. (2004). *John E. Freund's mathematical statistics* (7<sup>th</sup> ed.). Upper Saddle River, NJ: Pearson Education.

concluded that the ranking data were not significantly different despite the differences in the achievable contrast on observers' displays. In other words, the perceived image quality—when evaluated on the basis of preference—was not significantly affected by the contrast settings of the display. Therefore, a characterized display might not be necessary to learn how images are appreciated by observers when the originals are not present.

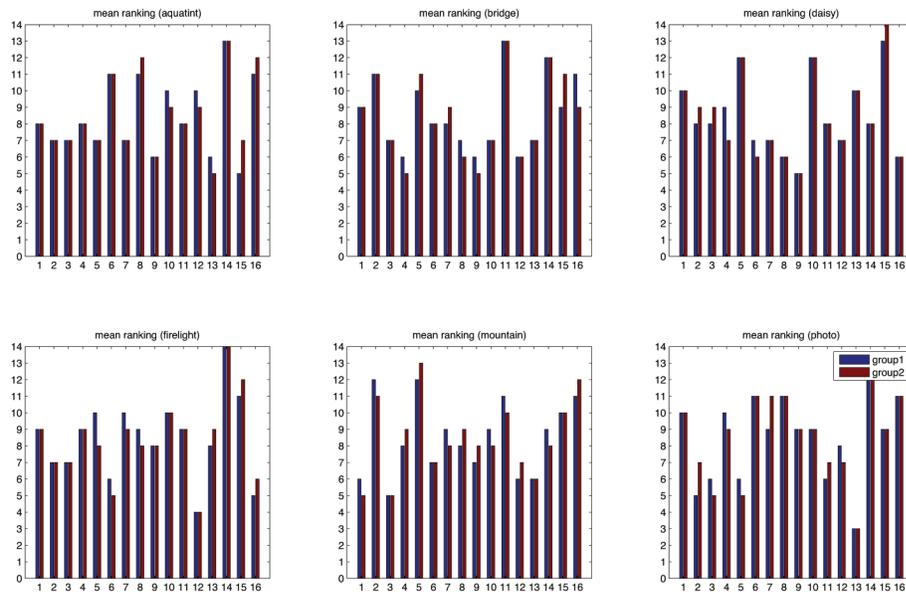


Figure 3-75. Mean ranking of the six images of the observer groups based on display contrast settings<sup>46</sup>

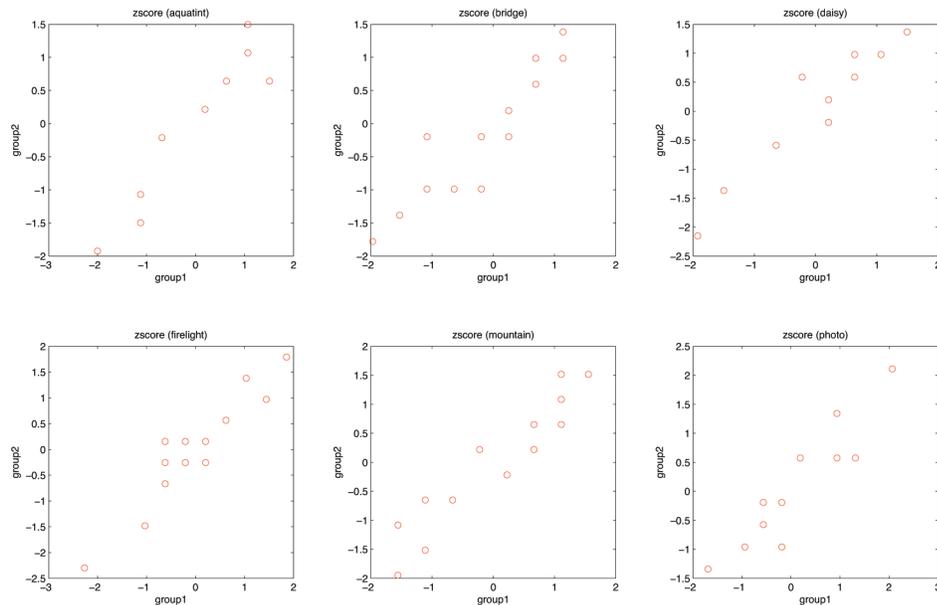


Figure 3-76. Z-scores of the observer groups based on display contrast settings

In addition to the question regarding display contrast, observers' web browser color management modules were also of interest. A web browser with effective color management settings can identify ICC profiles (versions 2 and

46 - Group 1 (the blue bars) was composed of observers who were not able to see all seven shades in the JND-grayscale, and those in Group 2 (the red bars) were observers who identified all seven shades.

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4) when they are embedded in an image, and thus are able to display images in the intended colors.<sup>47</sup> Therefore, a question was asked to determine whether the browser being used could successfully identify embedded profiles (see Figures 3-77 and 3-78). Two images were provided that were tagged with sRGB and AdobeRGB ICC profiles, respectively. If differences in color were able to be detected between the two images, then color management must have been supported by the web browser. Since the images provided by the sixteen institutions were not tagged with the same ICC profiles, color management support would be beneficial to the evaluation of perceived image quality in the web-based ranking experiment. At least one web browser did not employ effective color management.



The colors in these two images  
 look very similar.     look different.

Figure 3-77. Color management test for the web-based ranking experiment with color management active



The colors in these two images  
 look very similar.     look different.

Figure 3-78. Color management test for the web-based ranking experiment with no color management

Thirty-eight observers used Firefox and 48 used Safari. These two browsers are properly color-managed,<sup>48</sup> as the two *Mountain* images appeared different (see Figure 3-77). Out of 95 total observers, only nine used browsers that might not support color management. Since the observers using color-managed browsers outnumbered those who did not by a large margin, statistical analysis on the influence of web browsers was not possible. (Effects of this difference may be better estimated with a similar number of observers from each group when all the other variables are kept the same.) However, given that perceived image quality based on preference is generally invariant to observers' viewing conditions (lighting and display settings), it was not very likely that the presence of a color management module would be an influential factor.

## Results

The ranking results for the soft copy experiments conducted in the lab were compared with those for the web study. Given the ordinal nature of the ranking data, the Spearman *rho* correlation coefficients<sup>49</sup> were calculated across the three experiments for each image. For all six images, the Spearman *rho* correlations between the web-based ranking results and those obtained in the lab environment without the original present were highly significant. As an example, the *z*-scores converted from the ranking data in all three experiments for *Firelight* are shown in Figure 3-79.

47 - International Color Consortium. (n.d.). *Is your system ICC version 4 ready?* Retrieved from <http://www.color.org/version4html.xalter>

48 - This assumes that observers used the latest browser version available, as we did not test all versions.

49 - Miller, I., & Miller, M. (2004). *John E. Freund's mathematical statistics* (7<sup>th</sup> ed.). Upper Saddle River, NJ: Pearson Education.

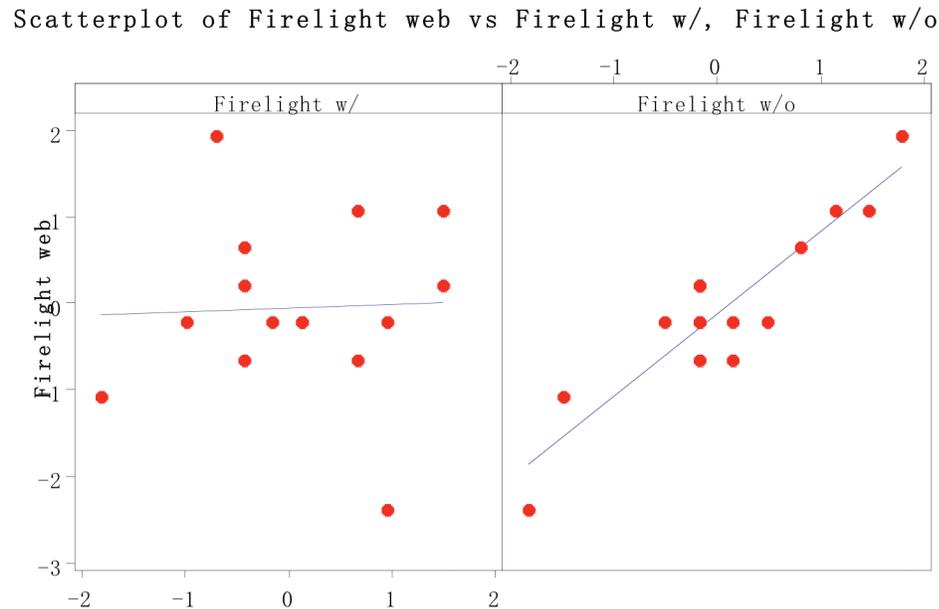


Figure 3-79. Z-scores for ‘Firelight’ rankings from the web-based experiment versus the soft copy results with and without the original present

In Figure 3-79, almost all of the data points aligned along the regression line in the plot on the right, indicating a high correlation between the rankings of images in the web-based experiment and those obtained without the original present in the lab environment. However, in the plot on the left, the data points were scattered, indicating a lack of correlation between the ranking results in the web experiment and those obtained with the original present in the lab environment. The Spearman *rho* correlation coefficients between web-based results and those with the original were almost always insignificant at a 0.05 confidence level with the exception of *Photograph*. For *Photograph*, the *p*-value for the correlation coefficient of 0.06 was near the borderline of 0.05.

A significantly high correlation was found between the ranking results in the web-based experiment and the results from the soft copy experiment without the original present. Given the high correlation and the absence of the originals in both experiments, a similar criterion—image preference—must be shared by observers when the images were evaluated. Moreover, the preference judgments by observers were less likely to be affected by display settings, lighting conditions, and so forth, given the wide range of displays used by observers who participated in the web-based experiment. One direct application of this result would be the ability to conduct evaluations of image quality based on preference online when a characterized display or a controlled environment was not readily available. Similar results could be expected when having observers perform the test through the Internet. However, a relatively large number of observers would be needed to eliminate the biases introduced by various testing conditions.

In the web-based experiment, the regions of interest were identified by having participants click not only on the preferred image, but also on the area of the image that most influenced their decision. Figure 3-80 shows participants’ clicks (as indicated by the red dots) on the renditions of the images that were ranked as the best. Since the top-ranked reproductions received more clicks than the remaining reproductions, it was of interest to understand which part of the image contributed most to this ranking.

### Section 3: Experiments

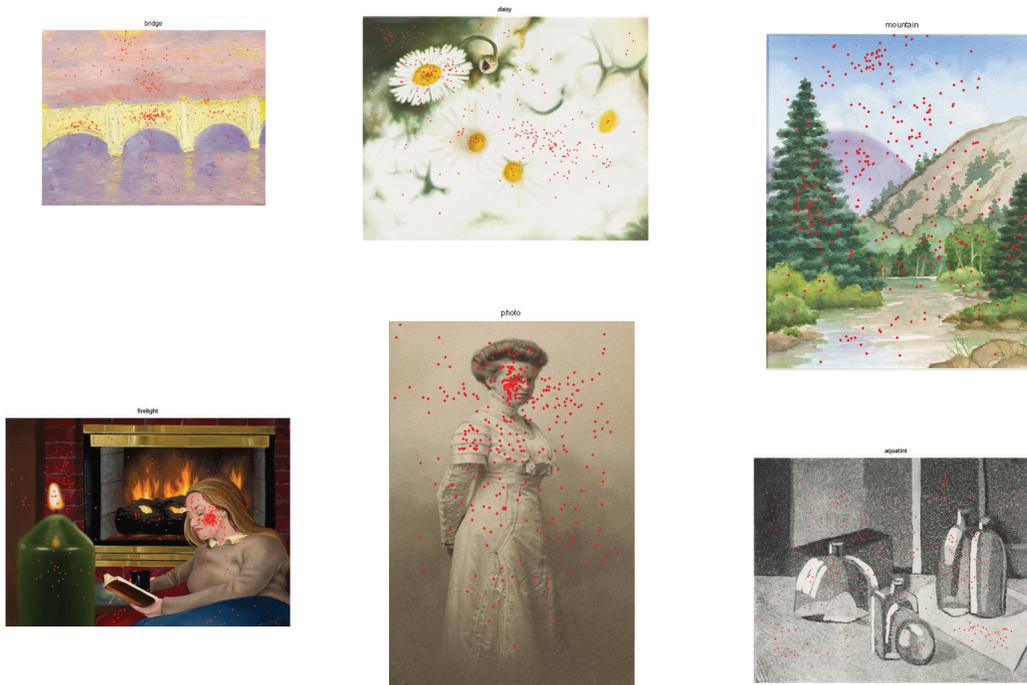


Figure 3-80. Participant clicks overlaid on the 'Bridge,' 'Daisies,' 'Mountain,' 'Firelight,' 'Photograph,' and 'Still Life' images

The results of this investigation were interesting: participants' clicks were not randomly distributed. Instead, they were object-oriented. Observers appeared to be overwhelmingly drawn to the objects in the images, such as the bridge in *Bridge*. This was true regardless of the occupation of the observer. However, photographers<sup>50</sup> tended to look at different objects than participants having other occupations. Figure 3-81 shows the participant clicks for those who identified themselves as photographers (red dots) and those who identified themselves as having occupations other than photographer (green dots). Clicks by photographers were mainly around the center of the painting (on the whitish petals). Clicks by other observers were found more on the top left greenish area. Other observers also tended to click on yellowish areas more than photographers.

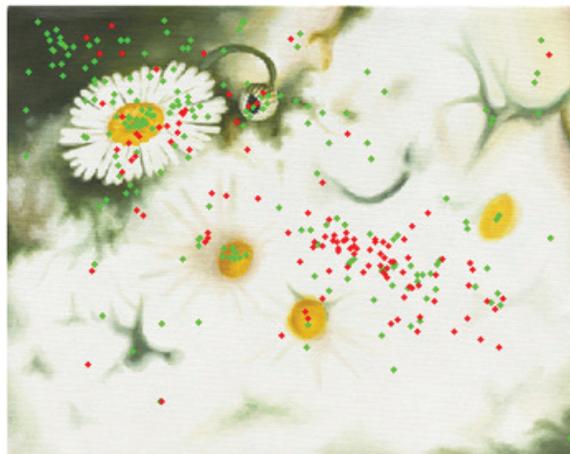


Figure 3-81. Participant clicks differentiated by occupation on the 'Daisies' image<sup>51</sup>

50 - This was the only occupation with enough participants to analyze as a group.

51 - The red dots indicate clicks by photographers, while the green dots indicate clicks by all other occupations.

The central regions of the objects received many more clicks than the boundaries of the objects. However, if the edges of objects shared similar colors with the areas that were clicked by observers, accurate color reproductions of the edges would be of similar importance. To investigate observers' interest in the edges of objects, both the areas clicked by observers and the pixels that were of similar colors to those clicked by observers were examined (see Figure 3-82). The red dots in this figure represent either locations that were clicked by observers or pixels of similar colors to those clicked by observers. The horizontal boundary between the sky and the bridge and that between the bridge and the water could be identified easily, as these were not covered by red dots. The patterns of red dots in Figures 3-80 and 3-82 indicate that the ranking decisions made by observers were more likely to be influenced by the color reproduction of objects, and most especially the central region of the objects. The object boundaries were of much less importance when preference judgments were being made. Since the color and texture of the objects were usually more coherent in the center, it was much easier for observers to click near the center. Much more effort would have been needed to click on a thin edge of an object.

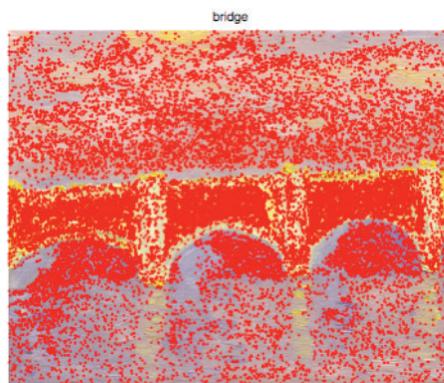


Figure 3-82. Color-of-interest pixels overlaid on the 'Bridge' image<sup>52</sup>

Similar results were found for the other images, except for *Photograph* and *Firelight*, both of which had human faces present. The clicks on these images were highly concentrated on the faces. Simply overlapping the mouse clicks on the image might cause an underestimation of the number of clicks in very crowded areas. Therefore, an intensity map was plotted to more accurately reflect the distribution of the clicks. The intensity maps for *Photograph* and *Firelight* are shown in Figure 3-83. The color bar represents the intensity of clicks on the images. The warmer the color, the more clicks were made by observers in that region.

<sup>52</sup> - The red dots in this figure represent either locations that were clicked by observers or pixels of similar colors to those clicked by observers.

## Section 3: Experiments



Figure 3-83. Intensity maps of image region clicks for the 'Firelight,' 'Photograph,' and 'Still Life' images

In Figure 3-83, the intensity map for *Firelight* shows that participant clicks were highly clustered on the lady's cheek. The number of clicks on this area was about three or four times that of the other regions in the painting. This strong interest indicates that the pleasing reproduction of skin tones was a key driver for rankings of the soft copy reproductions. A similar concentration of participant clicks was found on the face of the lady in *Photograph*. In contrast, the intensity map for *Still Life* indicates a more distributed response.

### Conclusion

A strong correlation was found between the ranking results in the web-based experiment and those from the soft copy experiment without the original present, indicating a lack of impact of testing conditions on preference judgments of images. The participant clicks in the web-based experiment were object-based, and heavily skewed towards the center of objects. The boundaries of objects in the images received the least attention.

## EXPERIMENT VI: DIGITAL VERSUS OFFSET PRINT REPRODUCTION QUALITY

### Methodology

The files from eight of the participating institutions that contributed to the broader project were used in the digital versus offset experiment (see Table 3-8). These were primarily the institutions from the workflow study that more frequently conduct print runs of their collected works. A few files from smaller institutions were also retained for comparison purposes.

Digital prints were obtained from the HP Indigo 5500 in the Printing Applications Laboratory at RIT. Two print runs were conducted. In one of the runs, the RGB files were sent directly to the printer, allowing the embedded printer algorithms to perform the transformation to CMYK. In the results, these prints are referred to as DigRGB. In the second run, the CMYK files from the offset lithographic run—transformed according to the ISO 12647 protocol—were used. In the results, these prints are referred to as DigCMYK. The institution code numbers in this experiment do not align with those from the workflow experiment. Three prints were made for the institution that provided files in multiple encodings: one each for AdobeRGB, eciRGB, and ProPhotoRGB.

Print sets were made on the offset press for each of the eight institutions, with one extra for the institution that provided two files. This resulted in a total of nine offset prints. Two digital prints were produced for each institution, with two extra for the institution that provided files in multiple color encodings. This yielded 20 digital prints. Therefore, a total of 29 reproductions were made for each piece of artwork.

Table 3-8. Cultural heritage institutions that participated in the offset versus digital experiment

Participating Institutions
Art Institute of Chicago
The Getty Center
Harvard College Library
The Metropolitan Museum of Art
MoMA - The Museum of Modern Art
The National Gallery, London
The National Gallery of Art, Washington
Yale University Art Gallery

### Results

The experiments yielded comparative ranking results for the prints made using offset and digital printing (see Figures 3-84 through 3-91). The results averaged over all of the artwork showed that the digital prints made using the transformation algorithms embedded in the printer (DigRGB) performed worse than the prints made using offset lithography (see Figure 3-84). This was true for all of the workflows<sup>53</sup> except G. The difference in workflow G was that it produced a slightly greenish offset lithographic print, whereas the transformation from RGB to CMYK as executed by the digital printer algorithms tended to produce slightly reddish prints. For workflow G,

<sup>53</sup> - B3 did not have an offset print, but generally had similar performance to B1.

this resulted in a print that was perceived to be statistically better than the offset print. With the remainder of the workflows, the DigRGB prints were considered too red or too warm.

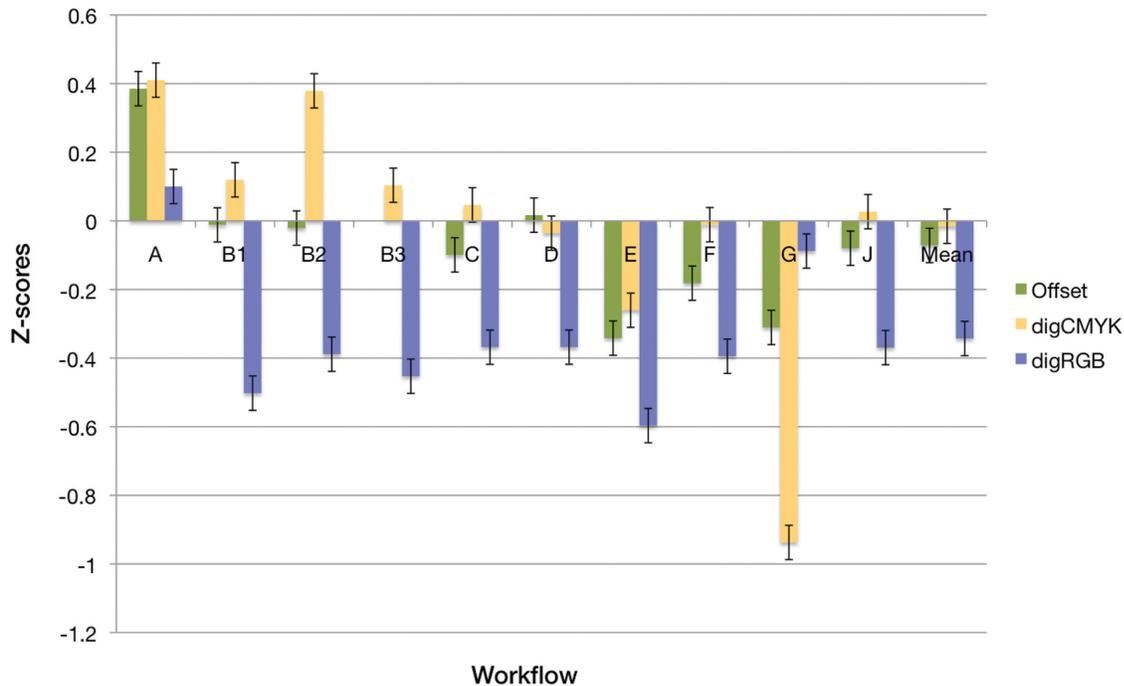


Figure 3-84. Z-scores generated from the ranking of the prints by workflow<sup>54</sup>

When the transformation from RGB to CMYK was executed following the ISO 12647 standard procedure (digCMYK), the opposite results generally occurred. The digCMYK prints were ranked comparably to, or slightly better than, the prints made using offset lithography for most of the workflows. Again, workflow G was ranked differently from the other workflows, which is due to the digCMYK prints being slightly greener in appearance than the offset prints. Since workflow G produced greener offset prints than other workflows, the digCMYK prints for this workflow were considered rather ghastly in appearance, generally receiving the worst ranking overall. The digCMYK prints for Institutions A and B2 and the offset lithographic prints for Institution A were considered to be the best, when averaged over all six pieces of artwork. It is important to note that there was no *Still Life* aquatint print for workflow B2. The other prints for Institution B (B1 and B3) did not rank particularly well for the aquatint. Therefore, if a print of this piece had been included, its overall average might not compare quite as well. An analysis of the average for the three workflows without the aquatint shows that the results for B2 were still above those for B1 and B3, but by a lesser margin (see Figure 3-85).

54 - The digital print runs were conducted by letting the printer perform the transformation from RGB to CMYK (DigRGB) and by transforming the digital files according to the ISO 12647 standard protocol (digCMYK).

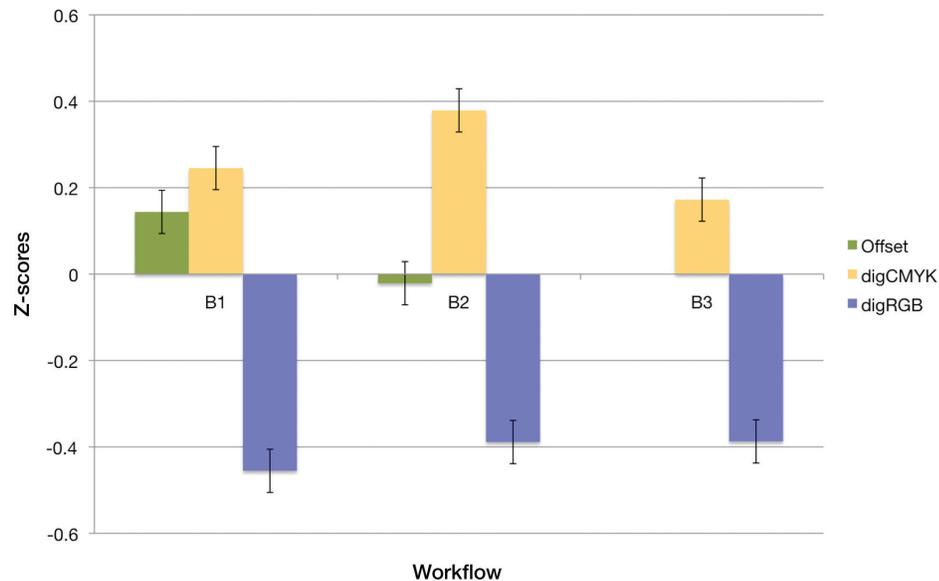


Figure 3-85. Ranking results expressed in terms of z-score values for the three workflows from Institution B with the results for ‘Still Life’ (aquatint) excluded<sup>55</sup>

An analysis of the results for the individual pieces of artwork showed some image-dependent differences in performance. The *Daisies* painting was the one piece of artwork for which the digCMYK version of workflow G was ranked about average (see Figure 3-88). In this case, the slight green cast did not detract as much as it did for the other paintings and more neutral pieces. For both *Still Life* and *Daisies*, workflow J performed better than with the other images, while workflows C, B1, B2, and B3 had more difficulty than with the other images (see Figures 3-86 and 3-88). These pieces of art were less chromatic than the remaining images, with the exception of *Photograph* (see Figure 3-91). For *Photograph*, the prints made using offset lithography generally did better, although the digCMYK prints for workflows B1 and B2 were ranked highest, on average. For the more chromatic pieces—*Bridge*, *Firelight*, and *Mountain*—workflows C, B1, B2, and B3 performed much better than the others. The digital versions for Institution E also performed very well for *Bridge* (see Figure 3-87). However, the prints for Institution D—which did quite well overall—did not rank well for this painting. Institution E had the most difficulty with the *Firelight* painting (see Figure 3-89). This was also the piece of artwork for which Institution A was not among the highest ranked for at least one of the workflows. The digCMYK version of the *Mountain* painting for Institution A and the offset and digCMYK versions for Institution C were ranked statistically higher than the other prints (see Figure 3-90). A summary of the best and worst workflows for each individual piece of artwork and for the body of work as a whole is shown in Table 3-9.

<sup>55</sup> - No offset print was provided for workflow B3.

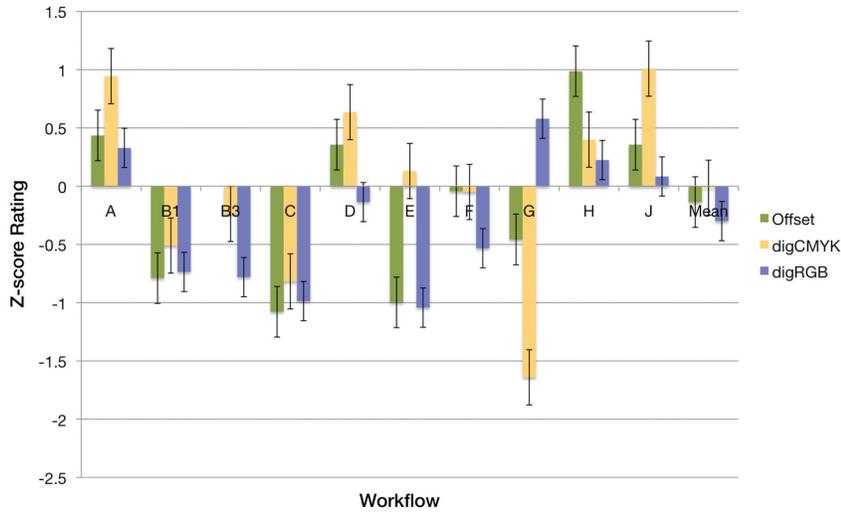


Figure 3-86. Ranking results for the 'Still Life' aquatint

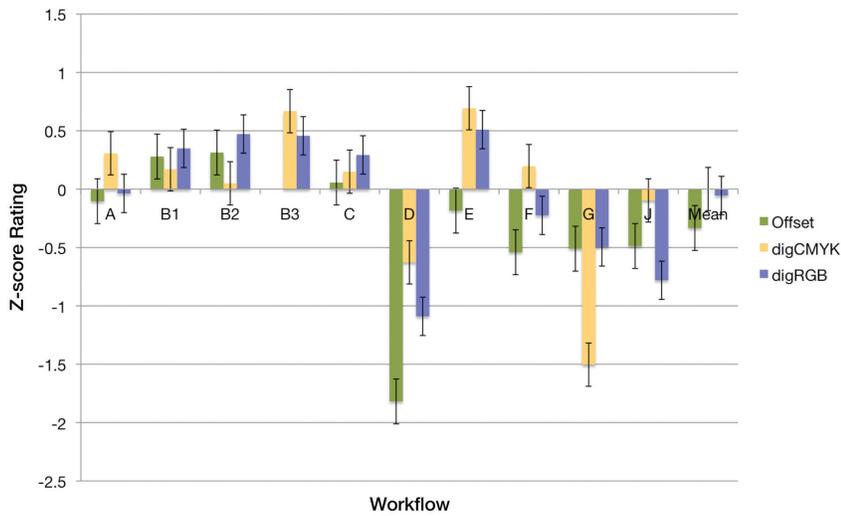


Figure 3-87. Ranking results for the 'Bridge' oil painting

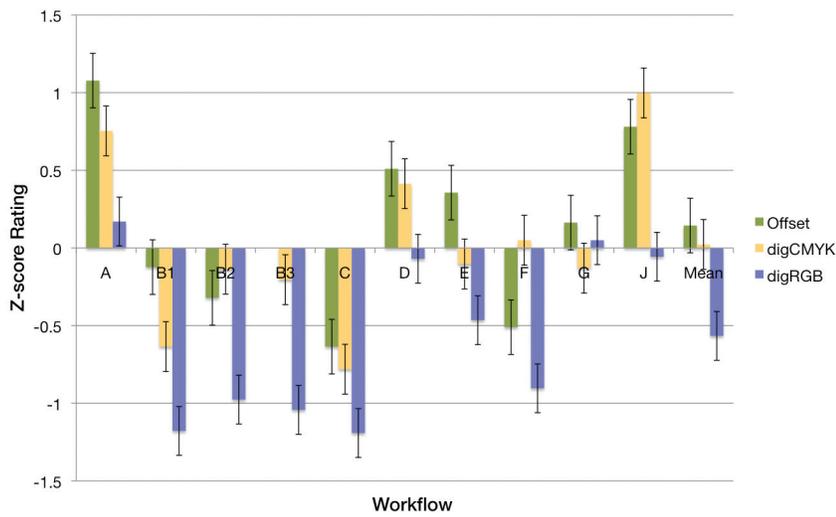


Figure 3-88. Ranking results for the 'Daisies' oil painting

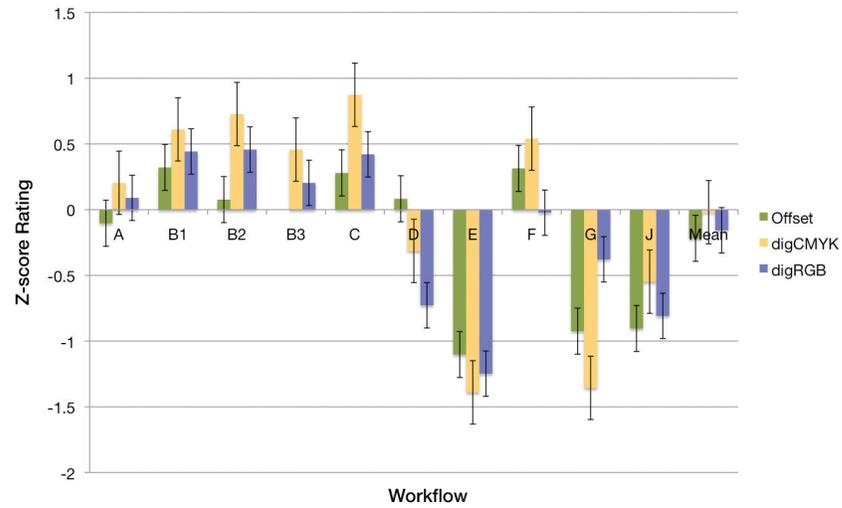


Figure 3-89. Ranking results for the 'Firelight' acrylic painting

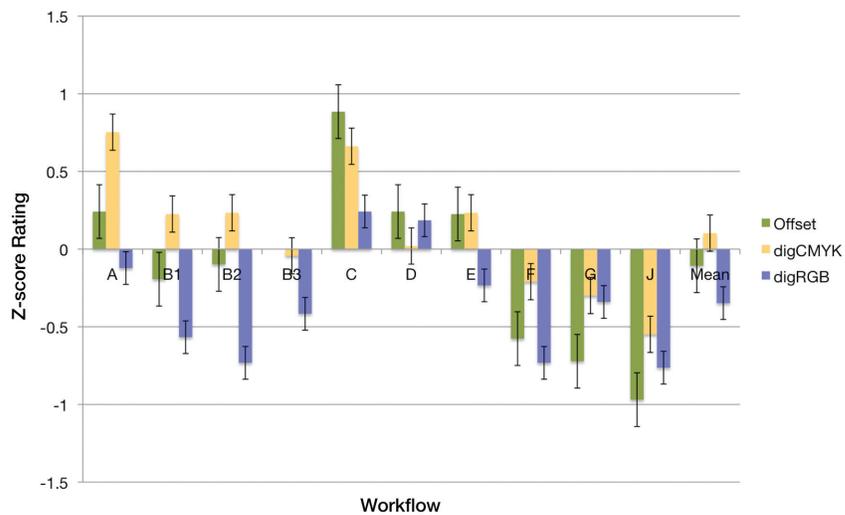


Figure 3-90. Ranking results for the 'Mountain' watercolor painting

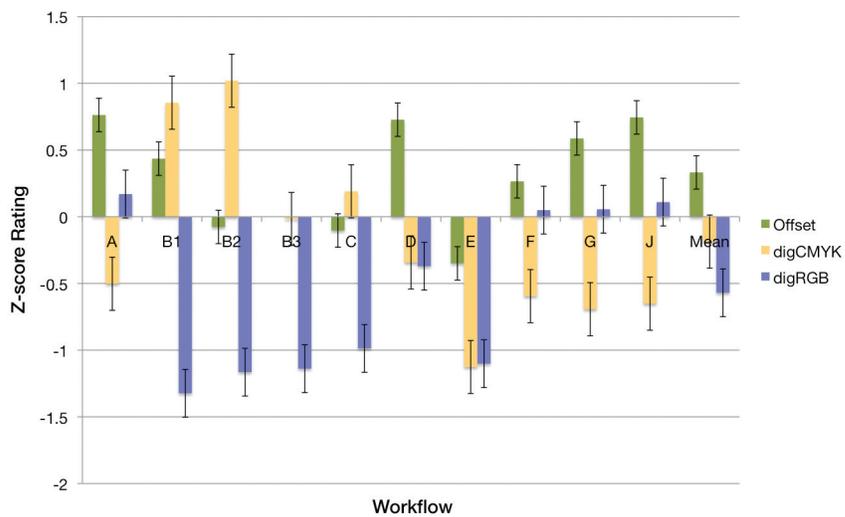


Figure 3-91. Ranking results for the 'Photograph' platinotype print

Table 3-9. Best and worst ranked prints by workflow

Artwork	Best	Worst
Aquatint	Form H offset; Forms J and A DigCMYK	Form G DigCMYK
Bridge	Forms E and B3 digital	Form D offset; Form G DigCMYK
Daisies	Form A offset; Form J DigCMYK	Forms F, C, B1, B2, B3 DigRGB
Firelight	Forms F, C, B1, B2, B3 DigCMYK	Form E all; Form C DigCMYK
Mountain	Form C offset and DigCMYK; Form A DigCMYK	Form J offset and DigRGB; Form G offset; Forms F and B2 DigRGB
Photo	Forms B2 and B3 DigCMYK	Forms B1,B2,B3, E, and C DigRGB; Form E DigCMYK
Overall	Form A offset and DigCMYK; Forms B3, C, and B1 DigCMYK	Form G DigCMYK (Also: Forms B1, B2, B3, D, E, F, J DigRGB)

## Conclusion

In summary, the electrophotographic digital press generally produced prints that were perceived as comparable in quality to or slightly better than those printed using offset lithography if the conversion from RGB to CMYK was done prior to printing. This result was image-dependent, with the offset prints ranked higher than the digital prints for the platinotype photographic print. This result also varied across institution, with the DigRGB prints for Institution G generally being ranked as better reproductions than offset or DigCMYK; the DigCMYK prints being ranked best, on average, for workflows B2, B3, and E; and offset and DigCMYK being ranked comparably for the remaining institutions.

## KEY EXPERIMENTAL FINDINGS

The key conclusions from each of the experiments conducted as part of the Current Practices in Fine Art Reproduction project are summarized in Table 3-10 below. Some of the important points to note are:

1. Lighting conditions may have a strong impact on image appearance.
2. Reasonable reproductions may be achieved without extensive manual color manipulations.
3. The use of a target to ensure proper capture setup is recommended.
4. Web-based testing may be a reasonable approach for evaluating on-screen reproduction preference.
5. Acceptable reproductions are achievable with a digital workflow.

Table 3-10. Key findings of the experiments

Title	Key Findings
The Impact of Lighting on Perceived Quality of Fine Art Reproductions	Prints made to match under one lighting condition may look ‘just wrong’ under another.
	Prints that are viewed under lighting conditions other than those specified in the workflow are more likely to be considered unacceptable reproductions.
Evaluating CATs as Predictors of Observer Adjustments in Soft Copy Fine Art Reproduction	Adjustments were image-dependent.
	The Fairchild92 chromatic adaptation transform performed the best of the models tested, but the use of a color appearance model may be needed.
The Impact of Workflow on Perceived Reproduction Quality of Fine Art Images	Reasonable printed and electronically displayed results may be achieved without extensive visual color adjustments.
	Use of a target at capture to ensure proper setup is recommended.
The Impact of Workflow on Perceived Quality of Fine Art Images without the Original Present	The presence of the original did not have as significant of an effect for prints as it did for electronically displayed images.
	Observers did not like lower contrast images when they were electronically displayed.
The Impact of Workflow on Perceived Quality of Fine Art Images being Viewed on the Web	There was a limited impact of testing conditions on the preference judgments for these images.
	The ranking results for the experiments conducted in the lab without the original and via the web were highly correlated, indicating that, when the original is not included, a web-based test may be a reasonable approach.
The Perceived Image Quality Of Printed Fine Art Reproductions	For the capture files used, the digital press produced perceptual results comparable to or better than offset lithography when the RGB to CMYK transformation followed standard protocol prior to printing. This result was image-dependent.



# SECTION 4: INTERVIEWS

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In addition to the experiments described in Section 3 of this report, a number of interviews were conducted. The interviews took place in three different settings:

1. Interviews were set up during site visits at various institutions. The researchers talked with people in the photo studio, conservators, curators, and members from the publication department.
2. Phone interviews were conducted with the institutions the researchers were unable to visit.
3. Observers that participated in the experiments were asked a number of questions as part of the experiment.

The researchers talked to people with a variety of backgrounds and roles in the fine art reproduction cycle, including:

- Photographers
- Managers of imaging studios
- Staff performing post-processing and printing of guide prints
- Staff responsible for DAM
- Publication staff
- Conservators
- Prepress specialists
- Printers
- Graphic designers
- Art historians
- Librarians
- Paper manufacturers
- Standards expert
- Imaging scientists
- Color scientists

Questionnaires were prepared for: a) people working in the photo studio (including post-processing), b) people working in the publication department, and c) observers for the experimentation. Some of the questions were excluded depending on the specific role of the interviewee in the reproduction process. The full lists of questions for the photo studio, publication department, and observers are included in Appendix D.

The majority of the interviews were taped, and most of these were transcribed. The researchers used this information to find common challenges, new ideas and approaches, and to help interpret the experimental results and put together the guidelines. In addition, the interviews helped to put together a survey that will be administered as a follow-up to this project. Following are summaries of questions asked to some of the stakeholders and the most interesting answers.

## PHOTO STUDIO

Important topics in the discussions with photo studio personnel included:

- How an image “travels” from the photo studio into the bookstore; who is involved (curator, photographer, graphic designer, etc.).

## Section 4: Interviews

- Who touches the images within the studio - are the same people processing the images for printing and display?
- Are technical guidelines used internally or with external partners such as designers or image contributors from outside the institution?
- Are guide prints used and, if so, how are they made?

## Comments

- “Would hire an image scientist rather than a photographer. Want someone who understands the process and someone interested in the objective; photographers now frustrated with the process – want to make subjective adjustments...”
- Post-production takes longer than capture – paintings often not close to the workstation.
- Take proof prints to the gallery (may be doing this before gallery opens with portable D50 lights).
- Expectations higher with digital, but standards are higher as well.
- Design department had to learn how to deal with the files they get; documentation was created to help the designers understand the files they receive from the photographers.
- Imaging department would like to be kept in the loop during the publication process.
- Would like more training regarding curator preferences.
- The images go through so many hands—there are so many chances for mistakes.
- Conservation not always done before imaging.
- Conservation personnel can explain well what they need.
- Permanence of the record, need something that is objective (accuracy of greater importance than preference).

## PUBLICATIONS DEPARTMENT

Important topics in the discussions with publication department personnel included:

- Are ISO standards being used?
- Communication channels with image generators and users – specifically, feedback to the photographers after a book has been printed and feedback from customers regarding what they like about the publications.
- Plans for using print-on-demand for books.
- Who is selecting the paper for publications?

## Comments

- Files from outside the museum vary a lot.
- Compare in gallery using D50 lights.
- If you have a digital asset you can make money from it.
- Going digital is very expensive, but having a digital asset is very valuable.
- Work with a group of select printers.
- Variance between curators.
- Worried about the next generation – no training for future employees; it takes a long time to develop knowledge needed to do this job well.

## OBSERVERS

Important topics in the discussions with observers included:

- Lighting conditions used when making image quality assessments.
- Proofing of artwork, including attitudes on soft-proofing.
- Observer experience with image quality assessment within the context of their everyday work activities.

The most interesting comments from the observers generally fell under four categories:

### Lighting

- People can be instructed to use standard lighting for critical viewing, but they do not always truly understand and follow through.
- Photography instructor commented that students do not use light booths:
  - » “We teach the students to use light booths for critical viewing, but they don’t do it.”
- Comparisons being made in the gallery.
- One publications person commented that the color corrections person that she works with does not have access to a light booth!

### Use of Soft-proofing

- Most who commented on the use of soft-proofing said that they believed it is not advanced enough for color-critical work, but that it was an appropriate tool for everything else.
- One person commented that he felt soft-proofing provided a match close enough for the general audience.
- Monitor to print is still a big transition.

## Section 4: Interviews

- One curator commented that what looks great in the database can look “crazy” in print.
- One observer with a strong print background commented that getting soft copy right is “harder than people think.”

### Economics As a Driver

- Would like to be handed a way to make reproductions consistently.
- Often have to accept ‘just good enough.’
- Soft-proofing is a useful tool to consider in reducing costs.
- One person in a publications position with limited funding said that they “hope and pray that we are doing a decent job.”

### Contrast in Fine Art Reproduction

- One observer described an incident where they printed a book digitally and the first rendition looked horrible – it needed to have the contrast boosted to provide a reasonable piece.
- Another observer related a story of a poster reproduction that looked ‘flat’ in the museum shop – greater contrast would have resulted in a better product.
- A publications person in a major museum commented that adding contrast to the capture file is part of their standard procedure.

### Additional Comments

- Educator – We tell our students most of what you do is not photography; it is print making.
- Conservator – We want a faithful reproduction; do not want to make it ‘better.’
- Art historian/educator – Many students will never see the originals.

## KEY INTERVIEW FINDINGS

- Define imaging goals and talk to your users in order to help set expectations.
- Acceptability concerning the quality of the images produced varies for the different stakeholders. This fact is often not clearly understood within an institution. As a result, some parties will be unhappy with the images they are getting since they are not what they expected. It is important to understand and clearly communicate expectations.
- Document workflows in detail.
  - » No undocumented processing should be performed along the image interchange cycle.
  - » Generally, the more often a file is touched, the worse the results.

- Digital Asset Management (DAM) systems that contain different versions of a file can lead to the wrong images being used further downstream in the process. Images should be clearly labeled, and unwanted files deleted or moved.
- Close the communication loop in the image interchange cycle. Too many disconnects can occur in the image interchange cycle. Every effort should be taken to ensure that the key stakeholders are in direct communication.



# SECTION 5: RECOMMENDED GUIDELINES

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Based on the key findings from the experiments and the interviews, the following set of guidelines was developed. As mentioned previously, each of the institutions provided information about the workflows they currently use. One objective of the experimentation was to identify workflows that provided acceptable representations of the originals as well as pleasing images on screen and in print. Additionally, it was important that these workflows did not incorporate a significant degree of image-specific post-processing so that they would be repeatable and as independent of the individuals doing the capture and processing as possible. A few workflows did fulfill these requirements.

Existing guidelines such as the UPDIG (Universal Photographic Digital Imaging Guidelines)<sup>1</sup> and, more specifically, the UPDIG Digital Image Submission Guidelines *Fine Art Reproduction—What Museums Need*<sup>2</sup> are also an excellent source of detailed information when setting up workflows.

It should also be mentioned here that our guidelines have a different purpose than the guidelines currently developed by the Federal Agencies Digitization Guidelines Initiative<sup>3</sup> or the Metamorfoze Preservation Imaging Guidelines<sup>4,5</sup>. Our guidelines are meant to be used in combination with guidelines such as these. Additionally, they are meant to be used by professionals in their fields—such as photographers, digital imaging specialists, etc.—that are familiar with state-of-the-art technology and working procedures.

The guidelines that follow deal with the capture and processing of artwork covering the image interchange cycle, from capture to end-use. What was not covered are metadata creation and preservation of digital files. These two areas were outside of the scope of this project. However, many resources exist on these topics.

## MAIN PRINCIPLES

- Camera make, lighting, and file format did not impact our ranking results. This indicates that all institutions are using equipment uniformly capable of achieving the objectives.<sup>6</sup>
- Define imaging goals and talk to end-users whenever possible. This will help set expectations. Acceptability varies for different stakeholders; this is a fact that has to be communicated clearly in an institution. Failing to do so will very likely result in unhappy constituents.
- Document workflows covering the whole image interchange cycle in detail. Examples of the documentation of the capture and processing steps can be seen in Appendix C.
- No undocumented processing should be performed along the image interchange cycle.
  - » The more often a file is touched, the greater the possibility that the quality of the images will suffer.
- Proper calibration of equipment is indispensable.

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1 - <http://www.updig.org/index.html>

2 - [http://www.updig.org/guidelines/ir\\_fine\\_art.html](http://www.updig.org/guidelines/ir_fine_art.html)

3 - <http://www.digitizationguidelines.gov/>

4 - <http://www.metamorfoze.nl/en/methodiek/conversion.html>

5 - In the near future, it is planned to combine the information from these two guidelines into a document published by ISO.

6 - Some of the common techniques that institutions use to light the object include double polarization (to reduce specular reflections) and adding a UV block filter over lights to prevent fluorescence of the object (which can erroneously elevate the blue response in the camera).

- The use of targets to ensure a proper capture setup is recommended.
  - » Getting the tone scale right at capture is very important and should therefore be one of the main goals. Using a target-based setup will help to reach this goal. Targets can also help to facilitate trouble-shooting of workflows.
  - » Feedback from the associated software is valuable for workflow assessment, though this may require education on use and relevance.
- Following standardized workflows, ISO printing standards, and ISO viewing standards reduces the need for manual post-processing.
  - » Adjusting the tone scale of the images after capture may be helpful as a simple, specified step in post-processing.
- Lighting conditions may have a strong impact on the appearance of a reproduction. Reproductions made under one lighting condition may be a poor representation of the original under another. Files created for a D50 workflow that are modified as a result of evaluation under gallery lighting may produce disappointing results. This suggests that proofing protocols may need to be revisited.

## STEPS TO ACHIEVE THESE OUTCOMES

### ICC Color Management

- ICC profile-based color management should be used.
- Color space:
  - » Transformation to CMYK should be done by the print provider.
  - » In our experimentation, there was no significant difference between AdobeRGB (1998), eciRGB, and ProPhotoRGB color spaces on the relative rankings of the resulting prints. As a result, it is probably best to work in the color space most familiar to your print provider.
  - » sRGB<sup>7</sup> may be used for images to be displayed on the web.
- File formats should be uncompressed TIFF for print and JPEG for web.
- Work with a print provider that works to standards and uses an ICC-managed workflow.
  - » ISO 12647-2 - *Graphic technology -- Process control for the production of half-tone colour separations, proof and production prints -- Part 2: Offset lithographic processes*, which provides specified process control aims and tolerances for offset lithography, provided good results in our experimentation.
  - » Two other commonly used standard workflows are GRACoL and G7.
- Guide prints did not prove especially useful in our experimentation, and can lead to greater printing costs due to unnecessary additional runs. In their survey of printing standards utilization, Chung and

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<sup>7</sup> - For artwork with a limited gamut, such as works on paper, sRGB may be a more appropriate color space. However, verification that the colors of the piece are entirely within the sRGB gamut must be performed.

Jensen (2011) also found evidence that customer-supplied proofs were of limited use for print providers.<sup>8</sup> However, guide prints provide a quick visual ‘reality check’ when the printing takes place. While their use as proofs or match prints warrants more investigation, guide prints can provide a sense of how the intended final image should appear, and are also a convenient vehicle for the discussion of any desired changes. Certified proofing systems should be used and every proof should be verified.

## Monitor Calibration

- Monitor calibration should be performed on a regular basis by the same person when possible. The aim is to achieve a visual match between the white point of the display and that of the viewing booth. The settings suggested by UPDIG provided a useful starting point. Based on the recommendations of personnel from the participating institutions, updates have been made to account for changes in the displays typically being used in visual evaluation:
  - » Gamma: 2.2
  - » White Point: 5000K - 5800K<sup>9</sup>
  - » Brightness: around 120 cd/m<sup>2</sup><sup>10</sup>
- ISO 3664:2009 *Viewing Conditions – Graphic technology and photography* provides details on viewing conditions for comparing an original with a reproduction.
- ISO 12647-7 - *Graphic technology -- Process control for the production of half-tone colour separations, proof and production prints -- Part 7: Proofing processes working directly from digital data* provides guidelines for proofing.

## Sharpening

- Sharpening may be needed to compensate for the loss of detail introduced by various stages of the image reproduction workflow including capture, resizing, screening, and printing.
- Capture sharpening may be done by the camera or in Photoshop depending on the comfort level of imaging personnel with the various approaches. The need for capture sharpening can be significantly reduced by maximizing system MTF through camera setup. The majority of the participating institutions did not sharpen at capture.
- Approaches to producing sharp images in our experiment included:
  - » RAW files processed with sharpening set to zero, maximize system MTF with appropriate aperture setting.
  - » Match lens optics to system MTF.<sup>11</sup>
  - » Unsharp masking.

8 - Chung and Jensen (2011) found that nearly half of the 90 printers surveyed felt that there was not a good match between the customer-supplied proof and the contract proof, and that nearly 9 out of 10 respondents believed that they could produce a hard copy proof that was more representative of the desired end product than the customer-supplied proof.

9 - Please note that, if visual matching to an original or proof is not being conducted, a white point of 6500K may be more effective.

10 - Typically on-screen images are viewed in dim surround. If the viewing conditions are brighter, a higher brightness may be needed.

11 - Lenhardt, K. (n.d.). *The image quality of lenses for digital photography*. Retrieved from [http://www.schneiderkreuznach.com/knowhow/opt\\_quali\\_e.htm](http://www.schneiderkreuznach.com/knowhow/opt_quali_e.htm); *Optics for digital photography*. Retrieved from [http://www.schneiderkreuznach.com/knowhow/digfoto\\_e.htm](http://www.schneiderkreuznach.com/knowhow/digfoto_e.htm)

## Section 5: Recommended Guidelines

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- If capture sharpening is done using Photoshop, the image must be viewed as *Actual Pixels* on the display. If it is not, the effects of the sharpening will not appear as they would on the print (or displayed image).
- All other sharpening should be performed at printing so that it is done with respect to the specific image size and the printer characteristics. Sharpening that may need to be applied is dependent on the particular printer, press, paper, and linescreen. It is therefore not possible for the cultural heritage institution to know how best to sharpen to compensate for specific printing conditions. Communicate with your print provider to ensure they know that they are expected to sharpen to compensate for loss of detail.
- Sharpening generally should not be done to enhance the image, only to return to the initial image appearance.
- Output sharpening is dependent on the characteristics of the printer, the screening, and the print media (ink and paper). Sharpening should therefore be done by the print provider. It is imperative to communicate with the print provider so they know what is expected of them.<sup>12</sup>

### Camera Setup

- Specifics on the camera setup and lighting configuration will not be provided here. These settings vary with the artwork being imaged and should be determined by the photographer. However, the following steps are recommended:
- Flat fielding – Some cameras have flat-fielding procedures incorporated. Implementation of on-board flat-fielding procedures is recommended. Procedures described by successful institutions included:
  - » Flat fielding is handled by the camera software. A “black reference” capture is incorporated into the capture process. The black reference is captured when the software is launched, when the shutter speed is changed, and periodically to account for temperature change. We also produce “scene reference” files that are applied to flat copy work. The scene reference is produced using the camera software by photographing a plain white reference that fills the entire capture area. Care is taken with exposure and to eliminate dust.
  - » Lens correction routines conducted within the camera system that are, according to the manufacturer, correct for chromatic aberration, distortion and vignetting for individual lenses.
  - » The camera system was flat-fielded using a clean, white reference.
- Use targets to verify capture.
  - » Targets should be used at capture to verify camera setup. Using targets such as Image Engineering’s Universal Test Target or Image Science Associates’ Golden Thread target along with the accompanying verification software helps to build a consistent workflow. Print reproductions from institutions that had tone curves and Delta L\* (difference in the lightness of two colors) values closest to the aim values provided by the targets consistently ranked above average in visual quality.

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<sup>12</sup> - Researchers’ discussion with Ken Fleisher.

- » Targets are not needed in the image files for color management. However, they may be useful for files that will be used by a variety of people to identify and document unexpected changes.
  - Color corrections made to the artwork may have a different impact on the Color Checker due to metamerism.
  - If no color corrections are made, a target may be added, but is not necessary if the print provider uses a color-managed workflow as recommended.
  - When a target is included, its purpose and proper use must be clearly communicated to all who may subsequently use the file.
- Personnel from one of our participating institutions recommends using a UV/IR cut filter on the lens to remove components of the light that the camera is sensitive but the human eye is not. Without such a filter, over-exposure in the red channel in the presence of IR can occur. It is reported that adding the filter “improved captures significantly particularly for works on paper.”<sup>13</sup>
- Document camera settings.
  - » See Appendix C for an example of what might be included.

## Tone Scale

- The print reproductions from the institutions that most accurately captured the tone curve and  $\Delta L^*$  values of the color patches were generally ranked the highest for visual quality. These institutions followed different procedures for adjusting the tone scale of captured images with acceptable results. These generally included:
  - » Using the Kodak Q13 tone scale, adjusting the A, M, and B patches to specified settings.
  - » Using the neutral patches on the Macbeth ColorChecker 24 and making adjustments to specified settings.
  - » Adjusting the curves in the RAW files prior to exporting to TIF, typically to linear between specified levels.
- Clearly document adjustments made (see Appendix C for a sample documentation sheet).

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13 - Myers, R. (2000). *Color accurate digital photography of artworks*. Retrieved from [http://www.rmimaging.com/information/color\\_accurate\\_photography.pdf](http://www.rmimaging.com/information/color_accurate_photography.pdf)

## Special Considerations for Web Images

- When the original was not present for images viewed on computer displays, people ranked the lower contrast images among the worst. For a web audience when the original is not present, some boost to the contrast level may be needed. It is recommended that, at a minimum, the contrast of the original (as measured using test targets at capture) be maintained.
- Tools to check display settings:
  - » ICC tool to determine proper use of profiles.<sup>14</sup>
  - » Tone scale to determine if display gamma is too steep. (See Figure 3-73.)
  - » Images with differing profiles to determine whether color management is being used. (See Figures 3-77 and 3-78.)
- Sharpening for the web, e.g., using Photoshop CS5, unsharp mask (Settings: Amount between: 110%-125%; Radius: 0.3 pixels; Threshold: 0 levels).
- Experimentation indicated that the viewing conditions including the white point of the display did not have a significant impact on ranking results when the original was not present.

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14 - <http://www.color.org/version4html.xalter>

## SECTION 6: SYMPOSIUM

Rochester Institute of Technology (RIT) hosted the Current Practices in Fine Art Reproduction Symposium from June 16-18, 2010. Stephen Chapman of Harvard University and Steven Puglia of the National Archives and Records Administration moderated the program. One hundred and twenty-five people from around the world attended the symposium. The final agenda is shown in Table 6-1.

Table 6-1. Symposium agenda

WEDNESDAY, JUNE 16	
9:00 am – 9:15 am	Welcome - Jim Reilly, RIT
9:15 am – 10:00 am	Overview of the Project - Franziska Frey, RIT
10:00 am – 10:15 am	Impressions from a Recent Exhibit: When Bad Things Happen to Good Digital Images - Barbara Bridgers-Johnson, The Metropolitan Museum of Art
10:45 am – 12:00 pm	Image Quality in Fine Art Reproduction - Susan Farnand, RIT
1:15 pm – 1:40 pm	Seeing America: The Publication - Marjorie Searl, Memorial Art Gallery
1:40 pm – 2:00 pm	Standards and Targets - Evan Andersen, Customer Service Representative, GSB
2:00 pm – 3:00 pm	Print on Demand for Fine Art Books - Frank Cost, RIT
3:30 pm – 5:00 pm	Panel: Target-Based Workflows - Moderator: Steven Puglia, National Archives and Records Administration; Panelists: Kenneth Fleisher, National Gallery of Art; Don Williams, Image Science Associates; Dietmar Wüller, Image Engineering
5:00 pm – 5:30 pm	Highlights of the Cary Graphic Arts Collection - David Pankow, RIT
6:00 pm – 8:00 pm	Reception & Tour of Cary Graphic Arts Collection
THURSDAY, JUNE 17	
9:00 am – 9:20 am	Soft Copy Image Evaluation - Jun Jiang, RIT; Susan Farnand, RIT
9:20 am – 9:45 am	Natural Language Color Editing - Karen Braun, Xerox Corporation
9:45 am – 10:15 am	Towards Solutions for Archival Color Imaging - Robert Buckley, Rob Buckley Consulting
10:45 am – 11:15 am	Interviews and Survey - Franziska Frey, RIT
11:15 am – 12:15 pm	Toward Rich Digital Representations of Fine Art - James Ferwerda, RIT
1:30 pm – 3:00 pm	Practitioners Panel - Moderator: Stephen Chapman, Harvard University; Panelists: Erik Landsberg, Museum of Modern Art; Alan Newman, National Gallery of Art; Stanley Smith, J. Paul Getty Museum
3:00 pm – 3:20 pm	The Evolving Digital Photographic Workflow - Patricia Russotti, RIT
3:20 pm – 3:30 pm	Overview of Tours & Exhibits - Franziska Frey, RIT
4:00 pm – 6:00 pm	Exhibits & Tours
FRIDAY, JUNE 18	
9:00 am – 9:45 am	Building & Using Digitized Photographic Collections - Paul Conway, University of Michigan
9:45 am – 10:00 am	Fine Art Postcard Quality Evaluation - Susan Farnand, RIT
10:30 am – 12:00 pm	Publication Panel - Moderator: Frank Cost, RIT; Panelists: Shalimar Fojas White, ARTstor; Tony Harris, Monroe Litho; Dan Kushel, Buffalo State College; Tom Rieger, Rieger Imaging; Marc Sapir, MoMA
12:00 pm – 12:15 pm	Wrap-Up - Franziska Frey & Susan Farnand, RIT
12:15 pm – 12:30 pm	Conference Closure

The complete symposium program book, images from the conference and recordings from the panel discussions can be found at <http://artimaging.rit.edu>. The program consisted of formal presentations regarding the benchmarking project, additional presentations to expand on some of the topics related to the project, three panel discussions, an exhibit and lab tours at RIT, and ample time for discussions and networking. The abstracts of the invited talks are included in the next section, followed by information on the panel discussions.

## INVITED TALKS

### Impressions from a Recent Exhibit: When Bad Things Happen to Good Digital Images

Barbara Bridgers-Johnson, General Manager for Imaging, The Metropolitan Museum of Art

In September 2009, the Rijksmuseum and the city of Amsterdam made the uniquely generous gesture of sending Johannes Vermeer's revered painting, *The Milkmaid*, for a brief month and a half long visit to The Metropolitan Museum of Art. This special loan helped to commemorate the four hundredth anniversary of Henry Hudson's voyage from Amsterdam to Manhattan. The painting held pride of place in a small, intimate special exhibition surrounded by the Metropolitan's five Vermeers and several other seventeenth century Dutch master works from the Museum's European Paintings collection.

The painting of *The Milkmaid* was featured in all of the attendant advertising for the exhibition. The young woman's iconic image was replicated in publications ranging from New York magazine to the New York Times, and throughout the Museum's printed materials for visitors. The image was reproduced on kiosk posters lining the plaza in front of the Museum and directional stanchion posters throughout the building. A huge mural hanging at the entrance of the exhibit assured visitors that they had indeed arrived at the desired location, and a variety of reproductions strategically located within the exhibition continually allowed one's eye to return to and reference the beautiful original. Finally, at the exit of the exhibition, numerous publications, prints and posters were displayed—many of which reflected the painting a final time.

The imaging program at the Rijksmuseum is standards-based and founded on sound and methodical principles, and the digital file behind all the reproductions emerging around town, and within the Museum, was authoritative and accurate to the painting. Why was it then, that between the entrance and the exit of the exhibit itself, the variety of outputs looked so different? The variations were the result of the file passing through multiple hands and a variety of publication processes and reproduction devices. When the curator of the exhibition called for a wall grid of the thirty-six known paintings by the artist, and provided a disk of images gathered from institutions all over the world in order to facilitate this gallery feature, it was time to admit the obvious—bad things happen to good digital images. This small jewel of an exhibition, and the wonderful painting at the heart of it, proved a definitive object lesson in the many obstacles we all face in our efforts to see our digital images successfully reproduced.

### Seeing America: The Publication

Marjorie Searl, Chief Curator, Memorial Art Gallery of the University of Rochester

In 2006, the Memorial Art Gallery of the University of Rochester published the first-ever catalog of its collection of American painting and sculpture. The book, containing seventy-six essays by fifty-two authors, and over two hundred images, was a massive undertaking for a mid-sized museum without a publication department or an in-house photography staff. The challenges were significant, but the resulting publication has proven to be a great institutional asset.

The lessons learned by one museum in its efforts to create a publication worthy of the quality of the art contained in its collections during a period of time in which film was being replaced by the digital image were discussed.

They noted that the physical presence was a significant benefit for this complex and high-quality publication. For instance, in the process of laminating the cover, the color changed drastically. Because the curator was present, the press run could be halted and corrections made. This co-location allowed them to make corrections as the process went along. Adjustments were made on press and final approval was required for every press sheet. This was both a blessing and a curse. While it allowed them to achieve the publication they desired, it was an expensive process. Future publications may not have the luxury of making three rounds of corrections for each image. Certainly, if there were a standard procedure that allowed them to get close on their first attempt, significant time and money could be saved.

The designer also stated that she spent as much time doing corrections as she did laying out the book. She estimated that she touched each page five times. She commented that if she were to be involved again, she would wait for all content before beginning the layout. Finally, the colorist working for the printer took the proofs to the gallery to compare them to the originals, even though he realized that gallery lighting was far from that of the light booth. Given the results of our experiment, this is likely not the best approach.

## Standards and Targets

Evan Andersen, Customer Service Representative, GSB

A review of international standards of potential benefit to museums was conducted. Relevant to fine art reproduction are standards related to image capture, ink verification, process control of printing, proofing, measurement and viewing conditions, digital workflow and files formats, printing aims and characterization data, and ICC color management. All of these areas affect the outcome of a fine-art reproduction. A review of test targets and how they can be implemented in fine art reproduction was also conducted. The research concluded that the practice of standardization could be improved within museums. It was also found that there was a large range of understanding and use of test targets. Utilizing present standards and available test targets is the best place to start in establishing best practices and procedures. Test targets have become much more sophisticated in what they can accomplish; they will very likely be an essential part in establishing future workflows in museums.

## Print on Demand for Fine Art Books

Frank Cost, Interim Dean, College of Imaging Arts & Sciences, RIT

Gloomy predictions regarding the future of print in the Internet age are highly exaggerated. Print is alive and thriving – and the Internet is fueling the industry. Online innovators are making it easier than ever to publish books and other printed materials – and the definition of publishing is expanding to include products never before imagined—there is the possibility of doing radical new things.

As the print on demand market for books is maturing, more and more libraries, archives and museums are looking into using this technology for part of the books they produce. The speaker will explore current market trends, technical roadblocks and opportunities in using print on demand for fine art books.

## Natural Language Color Editing

Karen Braun, Xerox Corporation

Color scientists and engineers use numerical specifications to accurately describe color. They use mathematical functions to describe transformations of those colors. However, from the time we are little children, we have a

natural and shared language for describing color. First we learn basic color names (red, blue, yellow, etc). Then we learn modifiers for those named (dark, light, colorful, etc). When viewing color images, we have developed a language for the changes that we'd like to see, and this is especially true for professionals working in imaging: "Make the blues more vivid." "The skin tones are too yellow."

Our experiments showed that people could very accurately describe color and color changes using natural language, even more accurately than describing the changes using numerical and mathematical specifications. One participant described a color he saw on his display to a second participant, and the second participant tried to create the color using sliders. The result was shown to the first participant, who then described the color difference between this and his original color, and the participants iterated thusly until participant 1 was happy with the match. The number of iterations was found to be smaller and the closeness of the match better when descriptions were made using natural language than when using mathematical specifications.

The results of these experiments gave us confidence that users would benefit from an adjustment interface that allowed them to describe colors in his own words. A color adjustment sentence can be thought of as including two main elements, the color to be adjusted and the adjustment itself. These elements can further be specified in language. The color can include a base color name or hue, such as "red," "green," "puce," "cornflower," and also modifiers such as "light red," "deep green," etc. The adjustment includes the type of adjustment, such as "lighter," "brighter," "redder," the direction such as "more" or "less," and the magnitude of that adjustment, such as "slightly," "extremely," "somewhat." Our interface includes a parser to understand user intent, and a translator to convert those words to color adjustments. In this presentation we will describe the interface and show some results of using it to modify colors.

### Towards Solutions for Archival Color Imaging

Robert Buckley, Founder, Rob Buckley Consulting

The CIE Technical Committee on Archival Colour Imaging (CIE TC8-09) was formed "to recommend a set of techniques for the accurate capture, encoding and long-term preservation of colour descriptions of digital images that are either born digital or the result of digitizing 2D static physical objects, including documents, maps, photographic materials and paintings." As has been noted elsewhere, the committee comprises color experts from industry and academia, as well as practitioners from the cultural heritage community, which includes libraries, museums and archives, with responsibility for the capture, long-term preservation, reproduction and distribution of images in digital and print format.

In 2009, a questionnaire was circulated among committee members, asking them, among other things, what areas in the capture, processing, archiving and preserving of digital images they found problematic and ambiguous. One concern expressed was how well would archiving color images in a color space for accurate display or printing later on work. So while the committee is focused on capture, encoding and long-term preservation, it is clear that the ultimate use of the archived material will influence the study. Some of the responses would be familiar to anyone involved with a color reproduction workflow, especially when one respondent noted not having a workflow that retains color accuracy over the wide variety of output media required by their users, in addition to the requirements of a safe storage repository. Quantifying color accuracy in the encoding was a recurring theme in responses to the questionnaire.

According to another response, color spaces are one of the most problematic and ambiguous areas, with a poor understanding of appropriate color spaces for master files as well as derivatives. One goal is to determine which color space to use for a particular project or content type. The committee is looking for techniques that will rely whenever possible on standards for describing color “that will stand the test of time” in the face of format obsolescence and with the aid of appropriate metadata. One question to be addressed is what metadata to embed in file in order to document facts about the color information that the file contains.

An early review of the results from the questionnaire confirmed that one encoding will not meet the needs of all use cases and content types. Rather than focus on one particular use case and content type combination, the committee is reviewing a range of encoding methods, including spectral and tristimulus based methods, and will discuss the applicability, practicality and risk of each in digitizing originals for use cases from the cultural heritage community. For example, practitioners want to know things such as “What is the disadvantage of using a larger color space than sRGB even if the majority of the content colors fall within sRGB if capture is done at a high number of bits/pixel?”

As a result of these inputs, the committee, in collaboration with the Still Imaging Group of the Federal Agencies Digitization Guidelines Initiative, is working on practical solutions, initially focused on existing RGB and other tristimulus-based methods, to encode digital image content in a manner that has a known accuracy, enables accurate representation of the object when displayed or reproduced, and is sustainable.

## Toward Rich Digital Representations of Fine Art

James Ferwerda, Associate Professor, Munsell Color Science Laboratory, Carlson Center for Imaging Science, RIT

Digitization has had an enormous impact on access to fine art collections. Art that was once sequestered behind closed doors can now be accessed worldwide through digital images. The positive impact of digital collections is widely acknowledged.

However there are important artifacts that cannot be represented with digital images alone. These include works where the three-dimensional forms and materials of the work are as important as the visual content. Examples include oil paintings, bas-relief sculptures and intaglio engravings, wood carvings, mosaics, and textiles.

We are developing next-generation digitization tools for creating rich digital representations of fine art using image-based modeling and rendering: a set of techniques for accurately capturing and visualizing the 3D shapes and material properties of objects from a set of digital images. Unlike existing 3D technologies such as Quicktime VR, the digital representations produced by image-based modeling and rendering are physically accurate digital surrogates that can be visualized, analyzed, and manipulated in ways that are not possible using images alone.

For example, using image-based modeling and rendering, it is possible to create a digital representation of an illuminated manuscript where an observer can tilt the page back and forth to see the glints off the gold leaf; hold the page up to a virtual light to see the translucency of the vellum; view the page under daylight or smoky candlelight; restore missing portions of the illuminations; and reverse or accelerate the aging process to see how the page would have looked 600 years ago or how it will look 600 years from now.

In this talk I will first describe the tools we are developing for capturing the complex geometries, textures, and materials that comprise different works of art. I will then discuss how we are creating mathematical models of the

art from this captured data and producing radiometrically accurate renderings using physically-based techniques. Finally I will describe some recent work to develop “tangible” display systems that allow these digital surrogates to be observed and manipulated as naturally as the original objects. The overall goal of this work is to create rich digital representations of fine art that can be used to enhance efforts in archiving, conservation, scholarship, and public access.

## **Building & Using Digitized Photographic Collections**

Paul Conway, Associate Professor, School of Information, University of Michigan

The creation of collections of digitized photographic archives is emerging as a ubiquitous component of cultural heritage programs of all types and sizes. Digital collections provide mechanisms for delivering digital surrogates of archival photographs. They might also be considered archival collections in their own right – representing the archival characteristics of original source materials, but also reflecting the decisions that archivists make throughout the digitization process. As archives, collections of digitized content are subject to the same tests of quality, integrity, and value as traditional archives built organically over time by organizations and individuals. The research issues associated with the creation and use of image digital libraries are profound and as yet largely unexplored. Particularly weak is our understanding of how digitization processes and decision making influence the use of digital surrogates in a variety of settings. Much remains to be learned about the actual uses of rich visual content in scholarly and non-scholarly contexts, on the usefulness and ultimate value of image digital libraries, and on the impact of digital image use at levels ranging from the personal to the societal. This presentation highlights key findings from a multi-faceted research project that explores the mechanisms at play in the digital collection building process that potentially influence the way that end users judge the archival values of the product. The paper creates a conceptual bridge to the use of digitized photographs in three distinctive scenarios: discovering something new in an image; constructing narrative stories from visual resources; and opening temporal and geospatial windows on historical landscapes. The presentation concludes with an outline of the implications of the research for digitization practice.

## PANEL DISCUSSIONS

Three panel discussions were organized. The panels were organized around three main topics: targets and their usage in the museum imaging workflow, an update from the practitioners on the input side and a look at the different forms of publishing.

### Panel: Target-Based Workflows

**Moderator:** Steven Puglia, Preservation and Imaging Specialist, National Archives and Records Administration

**Panelists:** Kenneth Fleisher, Photographer/Color Scientist, National Gallery of Art  
Don Williams, Founder, Image Science Associates  
Dietmar Wüller, Image Engineering

Organizations have been discussing using target-based workflows for objective correction of color and tone reproduction of digital images for many years. While there has been a lot of work and progress on both the development of targets and related software tools, a limited number of organizations have implemented target-based workflows and rely on this approach exclusively. The panelists will discuss the pros and cons, as well as address issues relating to using targets. There will be time for open discussion and answering questions.

### Summary of Discussion Points

- Targets are good for monitoring systems over time, checking lighting or resolution; for measuring rather than creating profiles.
- Dietmar Wüller suggests targets be adapted for specific materials.
- Ken Fleisher suggests that targets not be included in images because the danger posed by doing so outweighs the possible benefit in a color-managed workflow.
- Don Williams recommends that practitioners have an acceptance plan for expensive equipment.
- Paul Conway pled for teaching materials on how to properly use targets.

### Practitioners Panel

**Moderator:** Stephen Chapman, Open Collections Program Manager, Harvard University Library

**Panelists:** Erik Landsberg, Head of Collections Imaging, Museum of Modern Art  
Alan Newman, Chief, Division of Imaging and Visual Services, National Gallery of Art  
Stanley Smith, Head of Imaging Services, The J. Paul Getty Museum

Photographers from the J. Paul Getty Museum, the Museum of Modern Art, and the National Gallery of Art share their perspectives on techniques and challenges in producing, managing, and distributing digital images of works of art to serve the myriad needs of large institutions. Panelists will present an overview of the various tools and workflows used in the creation of images of works of art in each institution's collection. They will discuss the systems that enable a large and diverse community of users, particularly within the organization, to search and quickly obtain the images they need—in secure and controlled environments. Managing the quality and accuracy

## Section 6: Symposium

of image representations “downstream” from capture will be the key subtopic of this panel: how the creation and interchange of images results in “accurate” reproductions is a surprisingly complex dance among creators, technicians, equipment, software, environment, and subjective curatorial whim. Ultimately, all reproductions of art are interpretations, whose “quality” is determined by many variables including capture metrics, color management, media, viewing environment, scale, context, and the skill and discipline of the viewer. Given these variables, methods applied by institutions represented on this panel need to skew towards the creation of a rich master file that can live protected upstream, but spawn the best interpretations possible for any particular image use. Although we acknowledge the impossibility of controlling all variables present in art imaging and distribution, our challenge is to try to do so. With questions from the audience, the panel hopes to facilitate conversations on two broad topics: methods in producing image masters and device-specific deliverables; and protocols and techniques—in the studio and beyond—used to organize, preserve, describe, and distribute digital still images.

### **Summary of Discussion Points**

The discussion focused on rapid capture:

- Gets images of more pieces, including small objects and works on paper.
- Dedicated art handler needed – one institution commented that it was easier to train an art handler to run the camera than to have a photographer handling art, so, if only one person can be committed to this process, it is an art handler.
- Can be staffed by entry-level photographer (frustrating task for highly qualified photographer).
- Needs attention to detail.
- Focus is a bottleneck.
- May be possible to use these files for print-on-demand.
- Only spot check for quality – color and metadata.
- Use the regular workflow when there is an immediate need for publication, when greater attention to quality is needed, and for hard-to-handle objects.
- Should be a reliable workflow for most things if profiling is done well.

Other comments:

- Concern of file preservation – expectation is that file will outlast the technology (display capability).
- Significant move to mobile devices (probably truer today).
- 500 most popular pieces are probably also the 500 worst images because they were done first and it is difficult to arrange time to recapture them.
- Questions around image processing implementation in Digital Asset Management Systems (DAMs).
- Monitor set to D50 or D65?

- Best practices information needs to be brought into other communities, e.g., web developers.
- Guidelines for developing a product—putting it all together.

## Publication Panel

**Moderator:** Frank Cost, Interim Dean, College of Imaging Arts & Sciences, RIT

**Panelists:** Shalimar Fojas White, Collection Development Associate, ARTstor  
Tony Harris, Vice President of Sales & Marketing, Monroe Litho  
Dan Kushel, Professor, Art Conservation Department, Buffalo State College  
Tom Rieger, President, Rieger Imaging  
Marc Sapir, Production Director, Museum of Modern Art

Publishing fine art images can happen through a variety of channels and media. Our five panelists are all involved in publishing fine art—however, their work and interests span a wide range of types of “publications.” Each of the panelists will share their view of what they consider the focus of the publications they create: from digital collections viewed on-line, to conventionally and digitally published and printed fine art books, to museum displays and documentation for art conservation. The panelists will discuss differences and commonalities of these various expressions of fine art publications as it relates to audiences, user expectations and preferences, image quality and ever changing workflows, equipment and media choices.

## Summary of Discussion Points

- Acquire high, preserve uncompressed master, and derive from there.
- ARTstor has few standards beyond the size for the images they ingest.
- Philosophical question of making the image ‘better.’
- Museums as theme parks – less emphasis on historical accuracy.

## **SYMPOSIUM FEEDBACK**

Feedback was captured in a post-symposium survey that was sent to all participants. The feedback from participants and speakers was mostly very positive, with ratings between 4.2 and 4.7 out of 5. Some of the participants would have liked to hear directly from the institutions that fared best in our experimentation. However, this was not possible due to the need for anonymity. A few participants would have liked to see the final results of all experimentation. Since the number of participating institutions increased from an initial plan of four to six and then to seventeen, the timetable had to be changed accordingly. While most of the experimentation was completed prior to the symposium, some experimentation was still ongoing. Results of this experimentation were shared after the event. Additionally, the symposium was also conceived in a way that it would provide additional information to be incorporated into the interpretation of the results and the final findings of the project.

Comments included:

“This was a fabulous event! In fact, it was by far the best symposium that I’ve ever attended. The cross section of thoughts, ideas, organization and participants was spot on. It provided an open environment and gave us all a chance to talk about our mutual problems with as much clarity as possible. I can’t wait to see the results of momentum that has been created from this event! We are done talking and are ready to move forward.”

“Superb event, excellent speakers, outstanding group of participants. Congratulations to all who were part of the conception and organization of the symposium. It was one of the very best I’ve attended in many years.”

## IMAGES FROM THE EVENT



Jim Reilly, Director, Image Permanence Institute



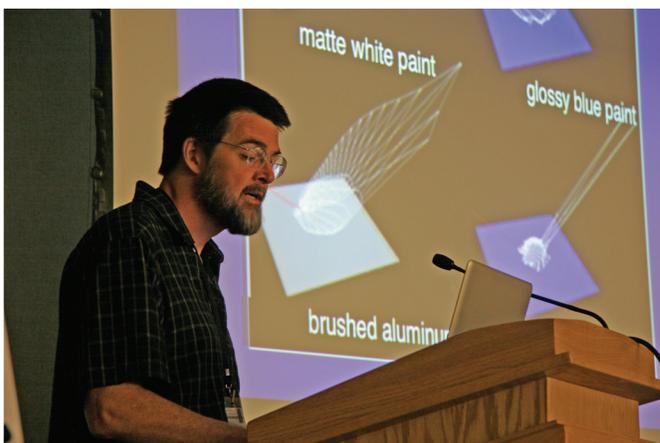
Attendees fill the auditorium



Images from the Metropolitan Museum of Art



Target-Based Workflows Panel  
(L to R: Dietmar Wuller, Don Williams, Kenneth Fleisher)



Jim Ferwerda, Associate Professor, Munsell Color Science Laboratory, RIT



Practitioners Panel (seated L to R: Erik Landsberg, Alan Newman, Stanley Smith)

Section 6: Symposium



Vendors & Exhibits



Munsell Color Science Laboratory - Color Experiment



Publication Panel (seated, L to R: Shalimar Fojas White, Tony Harris, Dan Kushel, Tom Rieger, Marc Sapir)



L to R: Franziska Frey, Steven Puglia, David Remington, Susan Farnand

## SECTION 7: KEY FINDINGS

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Digital photography workflows are now well established in cultural heritage institutions. This project studied the full art image interchange cycle from capture to user, involving more stakeholders and widening the scope of the previous benchmarking project. The following is a summary of the key findings of this project.

- One of the key objectives of this study was to find a method to connect objective, measurable image quality to subjective image quality as perceived by observers. In this experimentation,  $\Delta L^*$  values of the target used at capture were a remarkably good indicator of perceived reproduction quality. If this finding proves to be repeatable, it will be very important to the industry, as the ability to evaluate the quality of a printed reproduction through a measurement obtained in the capture stage would be invaluable. Hunt<sup>1</sup> lays out the scientific reasons for this result.
- Historically, the driving force behind many of the imaging projects in cultural heritage institutions has been publishing. While this is still the case in many institutions, two movements can be seen:
  - » ‘Publications’ traditionally meant printing books, posters and postcards with offset lithography. Increasingly, cross-media publishing to a variety of output media is a fact of life for publication departments. Future cross-media publishing workflows will benefit greatly from a use-neutral digital master to allow consistent image quality for the derivatives created for the various output media.
  - » “Capture now—process later” is beginning to take a hold in some institutions. This is a change from output-driven publishing.
- Camera make, lighting, and file format did not impact our ranking results.
  - » All the participating institutions are using equipment uniformly capable of doing this job.
  - » Industrial solutions for the benchmarking of camera systems do exist, and should be used if possible.
  - » This will help with purchasing decisions and setting up process control.
- Workflows still vary considerably, but some commonalities were found for workflows producing images that were generally ranked highly in all our experiments. These workflows were used as a basis for the development of the recommended guidelines.
- Workflows covering the entire image interchange cycle should be documented in detail.
  - » No undocumented processing should be performed along the image interchange cycle.
- The more often a file is touched, the greater the possibility that the quality of the images will suffer.
  - » The availability and use of workflow documentation in cultural heritage institutions has increased considerably since the previous study. However, it would be helpful to have more consistency in how workflows are documented.

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1 - Hunt, R. (1996). Why is black-and-white so important in color? In *Fourth Color Imaging Conference: Color Science and Engineering Systems, Technologies, and Applications* (pp. 54-57). Springfield, VA: The Society for Imaging Science and Technology.

## Section 7: Key Findings

- ICC profile-based color management should be used to achieve best results.
  - » It is important to choose print providers who work to standards and use an ICC managed workflow to reduce cycle time and improve repeatability of results.
  - » Transformation to CMYK should be done by the print provider.
  - » The print provider should be consulted on sharpening needed for a specific print output device.
  - » The overall achieved color quality among the testing institutions has improved since the previous study. The good news is that the while the best workflows did not necessarily get better, the worst ones improved considerably over the past five years.
- Proper calibration of equipment is indispensable.
  - » Most institutions have calibration procedures in place. Uncertainty remains regarding target specifications and calibration frequency.
  - » Calibration procedures have improved over the past five years.
- The use of targets to ensure a proper capture setup is recommended.
  - » Getting the tone scale right at capture is very important and should be one of the main goals. Using a target-based setup will help to reach this goal. Targets can also help facilitate troubleshooting of workflows.
- Following standardized workflows, ISO printing standards, and viewing standards reduces the need for manual post-processing.
  - » Adjusting the tone scale of the images after capture may be helpful as a simple, specified step in post-processing.
  - » Reasonable printed and electronically displayed results may be achieved without extensive visual color adjustments.
- Lighting conditions may have a strong impact on image appearance.
  - » Prints that are viewed under lighting conditions other than those specified in the workflow are more likely to be considered unacceptable reproductions. Files created for a D50 workflow that are modified as a result of evaluation under gallery lighting may produce disappointing results.
  - » Proofing protocols will have to be revisited.
- Acceptable reproductions are achievable using a digital press.
  - » This is an important finding for print-on-demand that will allow for smaller press runs, versioning, and variable data printing.
- Fine art reproduction adjustments by observers were image-dependent.
  - » Use of a color appearance model may be an important component in procedures developed to deal with this issue. Applications for this are described in Section 8: Future Work.

- The presence of the original did not influence the observers' rankings as significantly for prints as it did for electronically displayed images.
  - » Observers did not like lower contrast images when they were electronically displayed.
- Web images might need a slight boost in contrast, as well as some sharpening.
  - » These procedures should be established in collaboration with the curatorial departments.
- Web-based testing may be a reasonable approach for evaluating on-screen reproduction preference.
  - » The ranking results for the experiments conducted in the lab without the original and via the web were highly correlated, indicating that, when the original is not included, a web-based test may be a reasonable approach.
  - » Testing conditions had a limited impact on preference judgments for the images used in this project.
- Defining imaging goals and talking to users is indispensable to help set expectations.
- Acceptability concerning the quality of the images produced varies for the different stakeholders. This fact is often not clearly understood within an institution. As a result, some parties will be unhappy with the images they receive because they are not what was expected. It is important to understand and clearly communicate expectations.
- While Digital Asset Management (DAM) systems are a very helpful tool for managing the files created, they often contain different versions of one file. This can lead to the wrong images being used further downstream in the process. Images should be clearly labeled, and unwanted files deleted or moved.
- This project helped strengthen the community.
  - » Some institutions started collaborating to address workflow issues uncovered during the experimentation.
  - » The symposium helped strengthen relationships and led to the establishment of new ones. Events like this are very important for bringing the field together and setting the direction for future work.

## Section 7: Key Findings

- Closing the communication loop in the image interchange cycle is of utmost importance. Too many disconnects can occur in the image interchange cycle. Every effort should be taken to ensure that the key stakeholders are in direct communication. Figure 7-1 shows the different stakeholders involved in the art image interchange cycle. It is easy to understand how an information breakdown can happen with so many parties involved.

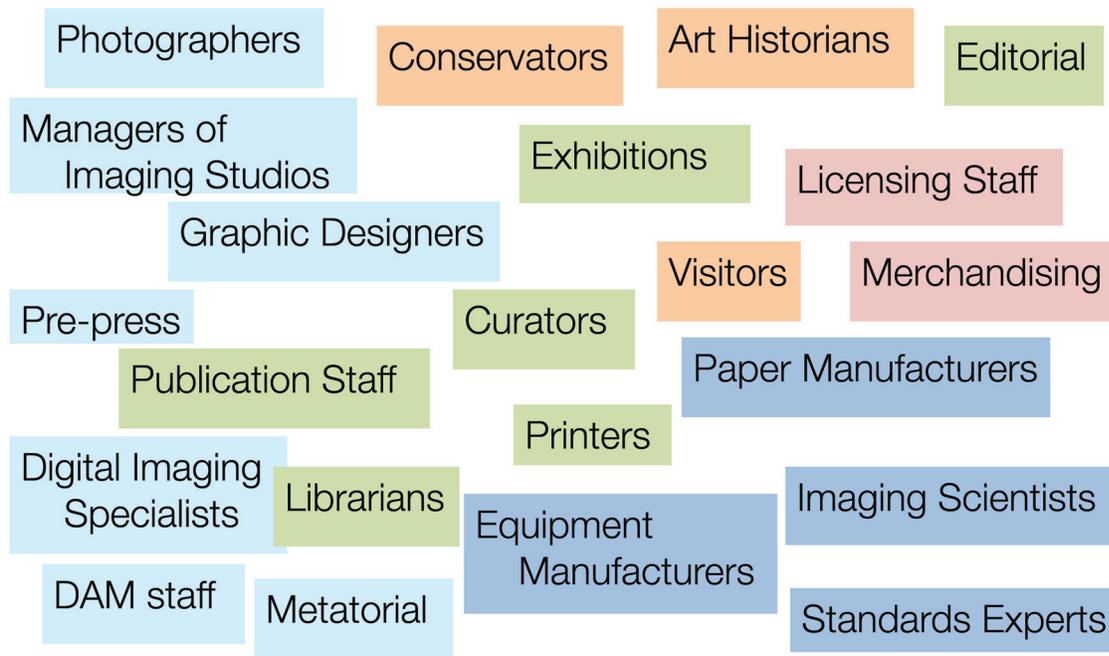


Figure 7-1. Parties involved in the art image interchange cycle

## SECTION 8: FUTURE WORK

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This project points to a number of paths forward for future research, services, training and related activities.

- Benchmark the image quality of new forms of reproductions on new generations of displays (e.g., iPad, mobile devices).
  - » The museum experience is increasingly interactive.
  - » It is important to study how the quality of the reproductions users see is affected by these game-changing technologies.
  - » The arrival of these new generation displays is comparable to the invention of color photography or color displays. After the introduction of these technologies, it took more than a generation to increase the image quality to an acceptable level. Studying the image quality of this new generation of displays could help ensure that the time to attain acceptable image quality would not be this long again.
- Study the effect of the size of the art object on the reproduction procedure needed to achieve an acceptable result.
  - » This is especially interesting in light of new forms of looking at reproductions on a variety of displays.
- Study the effects of rendering 3D objects under several lighting directions and types of illumination using computational photography.
  - » Increasing interactivity for museum visitors will include the use of 3D rendering techniques. Culture heritage institutions provide an ideal selection of objects with varying surface properties for rendering.
  - » 3D rendering techniques generally fall into two categories: model-based and data-driven methods. Data-driven methods can yield more accurate rendering effects as the rendered image is a re-sampling of the actual pictures taken at different lighting or viewing geometries.
- Benchmarking art image interchange cycles for 3D originals.
  - » The current study focused on 2D objects. A similar study is needed to benchmark the image quality of fine art reproduction workflows for 3D objects.
- Study of new light sources and their implications for reproductions.
  - » There is currently much interest in developing new light sources for the display of art. Motivations include greater reduction of visible radiation to reduce damage, improved viewer experience at lower light levels, and environmental issues. New laws banning traditional (incandescent) light bulbs will also make it necessary to develop new light sources, not only for the display of the artwork but also for museum shops and, of course, for homes where consumers enjoy reproductions purchased to remind them of their museum experience. It is therefore necessary to find suitable alternatives that will strike the right balance between energy efficiency and aesthetics.
  - » Lighting designers and imaging departments of museums and libraries face significant opportunities and challenges as this shift in lighting takes place. New lighting solutions provide

## Section 8: Future Research

opportunities to illuminate artwork while reducing energy costs and the possibility of damage to the artwork. However, these solutions will also have a significant impact on the way artwork is reproduced and on how reproductions are viewed.

- » While most of the current research for new light sources is focusing on the display of the original artwork, the researchers are proposing a study of the reproduction cycle of artwork, from initial capture to the enjoyment of a fine art book in a living room. Such a study would focus on the light sources needed in all the different environments. It is not a question of whether but when suitable alternatives will have to be available for consumers.
- Study the use of appearance models to allow for image use under various light sources (e.g., conservation laboratory with daylight or exhibition area with low light levels).
  - » Changes in viewing conditions in the various areas of a museum where images are looked at on-screen dramatically influences the perceived image quality.
  - » The goal of the use of these models would be keep the appearance of the image at a consistent quality, independent of the viewing environment. Figure 8-1 shows an example of this concept.



Fig. 8-1: Example of image adapted to different viewing environments<sup>1</sup>

- Development of training for attaining standardized workflows.
  - » Today's reproduction workflows necessitate standardization to achieve repeatable high quality results at lower costs. The printing industry has been working on standards for their workflows. ISO certification processes have been implemented in Europe and will soon start in the US and other parts of the world. This development is driven by the globalization of the way print is being produced.
  - » A new ISO standard working group was just launched within ISO TC 42 (photography) with the charter to combine existing guidelines and standards for the quality evaluation of imaging systems. Hand-in-hand with the development of standards is a need for training for the implementation of these standards.
    - Need to define stepping-stones to get to a standardized workflow.

<sup>1</sup> - An image could be adapted depending on where it will be used. The lighter parts of the image represent laptop viewing, while the darker parts represent the image when it is being projected (higher luminance).

- Development of training tools for fine art reproduction.
  - » 85% of symposium attendees who completed the evaluation said that they would be interested in targeted training programs around fine art reproduction workflows.
- Follow-up survey.
  - » As a follow-up to this project, a survey has been developed that will be administered in the upcoming months.
- Round-robin using developed guidelines.
  - » Participating institutions voiced interest in repeating the experiments using the guidelines that were developed in this project.
  - » It would be of interest for the field to conduct these round-robin image benchmarking experiments on a regular basis.
- Study of ways to better facilitate communication among multiple stakeholders.
  - » One of the findings from this project is that it would be beneficial to strategically centralize all threads of imaging in an institution. While much of this work has to happen within an institution, one area for research is the development of IT tools that facilitate communication in projects with a variety of stakeholders.
- Study the way Digital Asset Management Systems (DAMs) change workflows



# APPENDICES

## APPENDIX A: Standards Related to Various Steps of the Workflow

Step	ICC Color Management	Monitor Calibration	Color Space	File Formats
UPDIG	Devices such as monitors, printers, scanners and, ideally cameras should be profiled. All digital files should have embedded profiles.	Gamma: 1.8 to 2.2. White point: 5000K to 6000K. Luminance levels: 80 to 140 cd/m <sup>2</sup> .	Recommend Adobe RGB for general use. Convert to sRGB for web presentations. Photoshop's color management policy should be set to "always preserve embedded profiles" and the "ask when opening" box should be checked. CMYK conversions are best done by someone with knowledge of the press and paper type.	Camera RAW recommended for best quality. Converting from RAW to DNG suggested for archiving. Uncompressed TIFF preferred for printing.
Related Standards	<p>ISO 17321-1, Graphic Technology and photography - Colour characterization of digital still cameras (DSCs) - Part 1: Stimuli, metrology, and test procedures. Spectral-based and target-based methods, use target-based when colorants are known.</p> <p>ISO 17321-2, Graphic Technology and photography - Colour characterization of digital still cameras (DSCs) - Part 2: Methods for determining transforms from raw DSC to scene-referred image data: Method described that uses information about the capture illuminant and scene colorants, should be used for capture of artwork, uses targets.</p> <p>IEC 61966-9, Multimedia systems and equipment - Colour measurement and management - Part 9: Digital cameras</p>	ISO 3664, Viewing conditions - Graphic technology and photography: D65 white point, luminance level of at least 75 cd/m <sup>2</sup> (preferably >100cd/m <sup>2</sup> ), ambient illumination <64 lux (preferably <32lux), with a CCT < 6500K, gray borders, avoid glare.	IEC 61966-2-1, Multimedia systems and equipment - Colour measurement and management - part 2-1: Colour management - Default RGB colour space - sRGB (CRT display, luminance level 80cd/m <sup>2</sup> , D65 white point, gamma of 2.2)	

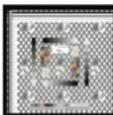
Step	File naming	Resolution	Sharpening	Metadata
UPDIG	Name files with only letters, numbers, hyphens, & underscores. Keep full name, including extension, to 31 characters. Do not duplicate.	Inkjet prints normally need resolutions of 180 to 360 ppi. Continuous tone printing normally requires 240-400 ppi. The offset printing standard is generally considered to be 300 ppi. Resolution of 1.3-2 times the halftone-screen ruling is considered safe.	Capture sharpening is required but images should not be heavily sharpened early in the editing process. Process sharpening should be done after color and tone correction, retouching, image sizing, etc. Photoshop CS2's Smart Sharpen filter is recommended.	The IPTC Core Schema is the current standard for embedding metadata. The metadata should include creator and copyright information. Should be done as early in the workflow as possible. If the original files are RAW, convert to DNG file format or rely on sidecar files.
Related Standards		ISO 12233, Photography - electronic still-picture cameras - Resolution measurements: Metrics include resolving power, SFR, OTF, and MTF. Standard includes test charts. Measurements should be performed on luminance channel.		NISO Data Dictionary - Technical metadata for digital still images: Metadata should be interchangeable, extensible and scalable, image file format independent, consistent, network-ready; should include IP rights; lots of other recommendations.

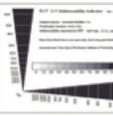
Step	File Delivery	Guide prints & proofs	Archiving	Digital image workflows
UPDIG	FTP. Removable media - CDs, DVDs. Adhesive labels should not be used on optical media.	The method in which the guide print was produced should be clearly conveyed. Profiling the printer used is critical. Absolute Colorimetric rendering intent is recommended.	The issue of who will archive the images must be addressed. Decisions must be made on what kinds of files will be archived and how to protect the archive from format obsolescence (an issue with RAW files) and media failure.	Different workflow choices based on volume and quality needs.
Related Standards		ISO 12646 Graphic Technology - Displays for colour proofing - Characteristics and viewing conditions: Based on CRT, resolution shall allow 1280x1024 pixel image w/o interpolation, 17" diagonal or greater, height of 8.5" or greater, refresh rate of at least 80Hz, non-interlaced, uniformity requirements, viewing illumination specified, gamma of 2-2.4.	ISO 22028-1, Photography and graphic technology - Extended colour encodings for digital image storage, manipulation and interchange - Part1: Architecture and requirements: Includes an annex with guidelines for making the appropriate selection of color encodings for image storage, manipulation, and interchange.	ISO 22028-1, Photography and graphic technology - Extended colour encodings for digital image storage, manipulation and interchange - Part 1: Architecture and requirements: Includes an annex with guidelines for making the appropriate selection of color encodings for image storage, manipulation, and interchange.

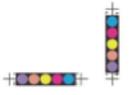
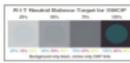
## Appendices

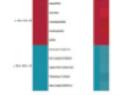
Step	Lighting	Targets	Manual processing
UPDIG			
Related Standards	ISO 7589, Photography - Illuminants for sensitometry - Specifications for daylight incandescent tungsten and printer: Daylight: 5500K, Tungsten: 3050K, Photoflood: 3400K.	ISO 17321-1, Graphic Technology and photography - Colour characterization of digital still cameras (DSCs) - Part 1: Stimuli, metrology, and test procedures: Recommends 24 patch ColorChecker and 237 patch ColorChecker DC for use with target-based method, which should be used when colorants are known.	ISO 22028-1, Photography and graphic technology - Extended colour encodings for digital image storage, manipulation and interchange - Part 1: Architecture and requirements: Includes an annex with guidelines for making the appropriate selection of color encodings for image storage, manipulation, and interchange.
	ISO 12232, Photography - electronic still-picture cameras - Determination of ISO speed: Useful for obtaining proper exposure and determining low light capability.		
	ISO 14524, Photography - electronic still-picture cameras - Methods for measuring opto-electronic conversion functions (OECFs); Provides method for measuring the functional relationship between the focal-plane log exposure or scene luminance and the digital output levels of the camera; includes test chart.		
	ISO 15739, Photography - electronic still-picture cameras - Noise measurements: Important in determining dynamic range of the camera, includes test chart.	ANSI IT8.7/2, Graphic technology - Color reflection target for input scanner calibration.	

## APPENDIX B: List of Targets Used in the Graphic Arts Industry

Targets	Topic	Name	Description	Quality Measures	Analysis	Origin
	Input Device Color Characterization	Color Checker	This target has 24 color patches - 6 neutral, CMYRGB, 6 hard to reproduce colors, & 6 natural colors. The Colorchecker can be used to profile input devices, or as a known reference point for a cameras white balance.	* Tone Reproduction	Measurement	Xrite
	Input Device Color Characterization	Color Checker SG	This target is made up of 140 patches sporadically displaced. The ColorChecker SG is made specifically for digital photography and can accurately profile an input device.	* Tone Reproduction * Input Device Color Profiling	Measurement	Xrite
	Input Device Performance	Device Level Target	Provides input device performance measurements. It can test for illumination uniformity, spatial distortion, and resolution variability. The target is best utilized for scanner benchmarking and process control.	* Spatial Attributes of input device * Tone Reproduction	Measurement	Image Science Assoc.
	Input Device Performance	Object Level Target	Provides input device performance measurements, such as sampling rate (dpi), resolution, color, tone, and noise. The target fits discreetly along side the objects being digitized.	* Spatial Attributes of input device * Tone Reproduction	Measurement	Image Science Assoc.
	Input Device Performance	Universal Test Target	Provides complete image quality data for high end input devices - camera and scanner systems, while following current ISO standards. The target has background checker board, gray bars, scales, gray scales, color patches, slanted edges, visual resolution structures, borders and lines.	* Spatial Attributes of input device * Tone Reproduction	Measurement	Image Engineering

Targets	Topic	Name	Description	Quality Measures	Analysis	Origin
	Output Device Resolution	4 Color Resolution Target	Tests for a devices mechanical resolution. The target will visually show a devices capability and stability of reproducing the fine patterns.	* Fine detail * Resolution	Visual	Franz Sigg RIT
	Output Device Resolution	Ray Target	Indicates directional effects of an output device and provides a visual indication of resolution. Star shaped moirés will appear due to interference with the rays. As the addressability of the device increases, the moiré becomes less visible.	* Directional defects * Resolution	Visual	Franz Sigg RIT
	Output Device Resolution	4 Color Fan Target	Tests for a systems resolution and aliasing for 4 color output. The target is one way to verify exposure and poor registration. The target is very sensitive to directional effects.	* Directional defects * Registration * Resolution	Visual	Franz Sigg RIT
	Output Device Addressability	Addressability Target	Is able to determine the actual mechanical addressability of an output device (vs. the manufactures stated addressability). At the point where the fine lines can be resolved, is where a corresponding addressability is listed (e.x., 1200 spi).	* Device Addressability	Visual	Franz Sigg RIT
	Output - Process Control	Color Bar	The color bar enables the user to monitor solid, tint & overprint ink density, dot gain, wet-ink trapping, resolution, as well as inking uniformity. This allows the user to conduct process control of a system.	*Tone Reproduction	Measurement	Franz Sigg RIT

Targets	Topic	Name	Description	Quality Measures	Analysis	Origin
	Output - Process Control	Gray Bar	The gray bar enables the monitoring of the color balance and inking uniformity of the system. It visually shows the color balance when the 3-color neutral appears to have a tint, enabling process control of the system.	* Tone Reproduction * Gray balance	Measurement	Franz Sigg RIT
	Output - Tone Reproduction	Multicolor Scale	The target can effectively study the tone reproduction of a process. This customizable step wedge can define up to 8 spot colors and as many as 4 CMYK colors with up to 150 steps.	*Tone Reproduction	Measurement	Franz Sigg RIT
	Output - Registration	Traffic Light Registration Scale	The target visually shows if an output device is misregistered. The circles are very sensitive to change showing a white sliver when out of register. There are targets for 4-7 color jobs.	* Registration	Visual	Franz Sigg RIT
	Output - Registration	Visual Registration Scale	The target tests for misregistration by magnifying moirés. The amplitude of the misregistration can be visually quantified without a loupe. This target can be used for any digital system.	* Registration	Visual	Franz Sigg RIT
	Output - Gray Balance	Neutral Balance Target for SWOP	This target visually indicates if an output device produces a neutral gray with specified SWOP C, M, Y values. A black only background provides a means to visually compare the two.	* Gray balance	Visual	Franz Sigg RIT

Targets	Topic	Name	Description	Quality Measures	Analysis	Origin
	Output - Gray Balance	Gray balance Chart	This target determines what combinations of CMY, results in neutral gray. With constant cyan values across the target, varying magenta and yellow give different tints of gray.	* Gray balance * Tone Reproduction	Visual & Measurement	Franz Sigg RIT
	Output - Tone Reproduction	100 Step Chart	This large step wedge is for CMYK and overprint colors (RGB). Each wedge has increments of 1 percent dot area, and are useful in determining the tone reproduction of a CMYK output.	* Tone Reproduction	Measurement	Franz Sigg RIT
	Output - Process Control	Color Profile Target	This target is able to test if color management was handled properly through profile conversions by changing color to indicate an error in profiles being read.	* ICC Color Profile check	Visual	Michael Riordan RIT
	Output - Characterization	IT8.7/4R-2005	This target defines a data set for profiling an output device. This target can be printed and measured, to create an ICC profile for that printer/ink/substrate combination.	* Tone Reproduction * Output Device Color Profiling	Measurement	ANSI
	Output - Characterization	GRACoL Proof2Press	The Proof2Press (P2P) target profiles an output device. This target is meant to better analyse the gray balance of an output device.	* Tone Reproduction * Gray balance	Measurement	IDEAlliance
	Output - DevProcess Control	ISO 12647-7 Digital Control Strip	This CMYK control strip is used as a control for pre-press proofs. Additionally, it can be used for process control of a systems production, where there is room outside of the image area.	* Tone Reproduction	Measurement	IDEAlliance /ISO

## Resource Information for Test Targets

- Color Checker (Xrite) - [http://www.xrite.com/product\\_overview.aspx?ID=820](http://www.xrite.com/product_overview.aspx?ID=820)
- Color Checker SG (Xrite) - [http://www.xrite.com/product\\_overview.aspx?ID=938](http://www.xrite.com/product_overview.aspx?ID=938)
- Color Checker Grayscale (Xrite) - [http://www.xrite.com/product\\_overview.aspx?ID=943](http://www.xrite.com/product_overview.aspx?ID=943)
- Device Level Target (Image Science Association) - [http://www.imagescienceassociates.com/mm5/merchant.mvc?Screen=PROD&Store\\_Code=ISA001&Product\\_Code=DL1&Category\\_Code=TARGETS](http://www.imagescienceassociates.com/mm5/merchant.mvc?Screen=PROD&Store_Code=ISA001&Product_Code=DL1&Category_Code=TARGETS)
- Object Level Target (Image Science Association) - [http://www.imagescienceassociates.com/mm5/merchant.mvc?Screen=PROD&Store\\_Code=ISA001&Product\\_Code=OL1&Category\\_Code=TARGETS](http://www.imagescienceassociates.com/mm5/merchant.mvc?Screen=PROD&Store_Code=ISA001&Product_Code=OL1&Category_Code=TARGETS)
- Universal Test Target - [http://image-engineering-shop.de/shop/article\\_ETC-TE262¥001/TE262-Universal-Test-Target](http://image-engineering-shop.de/shop/article_ETC-TE262¥001/TE262-Universal-Test-Target)
- 4 Color Resolution Target - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- Ray Target - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- 4 Color Fan Target - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- Addressibility Target - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- Color Bar - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- Gray Bar - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- Multicolor Scale - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- Traffic Light Registration Scale - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- Visual Registration Scale - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- Neutral Balance Target for SWOP - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- Gray Balance Chart - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- 100 Step Chart - Franz Sigg: [fxsprr@rit.edu](mailto:fxsprr@rit.edu)
- Color Profile Target – Michael Riordan: [mprppr@rit.edu](mailto:mprppr@rit.edu)
- IT8.7/4R- 2005 (ANSI) - <http://webstore.ansi.org/IT8.7/4R-2005>
- GRACoL Proof2Press (IDEAlliance) - [http://www.idealliance.org/industry\\_resources/branding\\_media\\_and\\_color/gracol](http://www.idealliance.org/industry_resources/branding_media_and_color/gracol)
- ISO 12647-7 Color Control Bar (IDEAlliance/ISO) - [http://www.idealliance.org/industry\\_resources/branding\\_media\\_and\\_color/gracol/idealliance\\_iso\\_126477\\_2009\\_color\\_control\\_wedge](http://www.idealliance.org/industry_resources/branding_media_and_color/gracol/idealliance_iso_126477_2009_color_control_wedge)

## APPENDIX C: Sample Workflow Documentation Sheets

### Capture Illumination & Camera Documentation Sheet

Museum: \_\_\_\_\_

Camera System (Make & Model): \_\_\_\_\_

Camera Capture Settings:

White Balance Settings: \_\_\_\_\_

ISO: \_\_\_\_\_

File Format: \_\_\_\_\_

Aperture: \_\_\_\_\_

Profile: \_\_\_\_\_

Was flat-fielding performed? \_\_\_\_\_

If yes, please describe procedure \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Was sharpening applied? \_\_\_\_\_

If yes, please describe procedure \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_

Was a target used to verify capture? \_\_\_\_\_

If yes, please describe \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_

Illuminant type (include brand & bulb): \_\_\_\_\_

Lighting Ratio: \_\_\_\_\_

Quality of light (direct, diffuse, etc.): \_\_\_\_\_

Modifiers used (honeycomb, baffle, etc.) \_\_\_\_\_

Polarization used? \_\_\_\_\_

Draw a diagram below of lighting setup including all possible details.

### Proofing Documentation Sheet

Design Software: \_\_\_\_\_

RIP System (Printer Manufacturer or Third-Party): \_\_\_\_\_

Proofer System (make & model): \_\_\_\_\_

Light Booth (make & model): \_\_\_\_\_

Light Booth Bulbs (make & model): \_\_\_\_\_

Color Temperature: \_\_\_\_\_

Lighting conditions in the viewing room \_\_\_\_\_

Proofing Viewing Distance: \_\_\_\_\_

Surround conditions of the image on the screen \_\_\_\_\_

Is the print/screen held in the hand while standing right up against the artwork? Explain if not. \_\_\_\_\_

Are both print/screen and the artwork in the same field of view or do you have to turn your head? \_\_\_\_\_

Is the comparison done within a controlled light booth? \_\_\_\_\_

Does anybody judge the proof outside of the light booth? \_\_\_\_\_

### Post Processing Documentation Sheet

Image Processing Software: \_\_\_\_\_

Operating System: \_\_\_\_\_

Monitor: \_\_\_\_\_ Date of Calibration: \_\_\_\_\_

White Point: \_\_\_\_\_

Gamma: \_\_\_\_\_

Brightness: \_\_\_\_\_

Adjustments made:

Tone Curve: \_\_\_\_\_

Contrast: \_\_\_\_\_

Color: \_\_\_\_\_

Sharpening: \_\_\_\_\_

Other: \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

COMMENTS/NOTES:

## APPENDIX D: Interview Questions

### Mellon Experiment - Hard Copy

- Q1) With regard to the print found to be the best reproduction of the artwork, do you feel it is an acceptable reproduction for your application? What do you consider your applications?
- Q2) Where along the line of the ranked prints do you feel the reproductions shift from being acceptable to unacceptable?
- Q3) What characteristics of the reproductions do you feel were important in your decisions regarding the reproduction rankings and acceptability? You may answer this regarding specific images.
- Q4) What is your job title? Job setting?
- Q5) What is your educational background?
- Q6) Are you typically involved in the assessment of image quality in your work? Would you consider it part of your job description?
- Q7) Generally, how often are you involved in image quality assessment?
- Q8) Can you describe a situation when you were involved in image quality assessment?
- Q9) Can you describe a situation when unacceptable image quality in a reproduction caused you difficulty?
- Q10) Under what lighting conditions do you make image quality assessments? Do you make comparisons to the original? In the gallery? Please give details.

### Mellon Experiment – Soft Copy

- Q11) Do you feel that your adjusted image is an acceptable reproduction?
- Q12) What characteristics of the images do you feel were important in your decisions regarding the adjustments you made? You may answer this regarding specific images.
- Q13) Are you typically involved in the image proofing at work? Would you consider it part of your job description?
- Q14) How is proofing accomplished in your work environment? Do you use ink jet printers? Kodak Approval®? Who is involved? What is the room environment?
- Q15) How many iterations are typically needed to achieve an acceptable proof print?
- Q16) If so, generally, how often are you involved in image proofing?
- Q17) Do you know what soft proofing is? How do you feel about soft proofing? Do you feel that acceptable quality can reliably be obtained?

## Photo Studio and Publications Department

- Q1) Do you have internal technical guidelines about image submission that you can share with us?
- Q2) Do you have technical guidelines for the designers that are processing the images?
- Q3) Are the same people processing the images for printing and display?
- Q4) Do you have technical guidelines about image submission that you share with authors?
- Q5) Can you describe the “travel” of an image from the photo studio into the bookstore? Who is involved (curator, photographer, graphic designer, etc.)
- Q6) How do you choose a printer?
- Q7) Do you have a list of printers you are working with that you could share? Or could you point us to a printer in Europe that you have been using?
- Q8) Who is selecting the paper?
- Q9) Do you print to ISO standards? Are you asking for this? Are the printers suggesting this?
- Q10) Is there a difference in using standards in Europe vs. Asia in terms of the printers you are working with?
- Q11) What is the book you are most proud of? Why?
- Q12) If you had three wishes, what are the three things you would change in your current workflow?
- Q13) Do you make a selection on screening used?
- Q14) Do you use/plan to use print on demand for books?
- Q15) What is your opinion/concern on print on demand for fine art books?
- Q16) Is there a feed back loop to the photographer after a book has been printed?
- Q17) Do you use focus groups to find out what customers like about your publications?
- Q18) What is your professional background/role in the publication department?
- Q19) Can we contact you for a follow-up?

## APPENDIX E: Publications And Presentations

- Frey, F. (2008, October). *Benchmarking Art Image Interchange Cycles*. Invited Talk. National Gallery of Art, Washington, DC.
- Frey, F., & Farnand, S. (2009, October). *Benchmarking Art Image Interchange Cycles*. ImageMuse meeting, MoMA, NYC.
- Farnand, S., Frey, F., & Andersen, E. (2009, October). *Benchmarking Art Image Interchange Cycles: Image Quality Experimentation*. AIC 2009, Sydney, Australia.
- Frey, F., Farnand, S., Jiang, J., & Andersen, E. (2010, June). *Current Practices in Fine Art Symposium*. Rochester Institute of Technology, Rochester, NY.
- Frey, F., & Farnand, S. (2010, August). *Evaluating Current Workflows in Fine Art Reproduction – Experimental Report to Participants*. Boston, MA.
- Frey, F., & Farnand, S. (2010, August). *Evaluating Current Workflows in Fine Art Reproduction – Experimental Report to Participants*. NYC.
- Jiang, J., Frey, F., & Farnand, S. (2010, October). *Evaluating CATs as Predictors of Observer Adjustments in Soft Copy Fine Art Reproduction*. CIC2010, San Antonio, TX.
- Farnand, S. (2010, October). *Re-examining our Objective: Imaging, Accuracy, and Expectations*. Panel discussion. Museum Computer Network Conference, Austin, TX.
- Farnand, S., Jiang, J., & Frey, F. (2011, January). *Comparing Hard Copy and Soft Copy Results in the Study of the Impact of Workflow on Perceived Reproduction Quality of Fine Art Images*. SPIE/IS&T Electronic Imaging Symposium: Vol. 6811, San Francisco, California.
- Farnand, S., Jiang, J., & Frey, F. (2011, April). *Image Quality in Fine Art Reproduction: Hard-copy versus Soft-copy*. Invited Talk. Eastman Kodak Company, Rochester, NY.
- Farnand, S. & Frey, F. (2011, June). *The Impact of Lighting on Perceived Quality of Fine Art Reproductions*. AIC 2011, Zurich, Switzerland.
- Frey, F. & Farnand, S. (2011, June). *Evaluating Current Workflows in Fine Art Reproduction – Experimental Review for the Metropolitan Museum of Art*. NYC.
- Farnand, S. & Frey, F. (2011, October). *Comparing Offset Lithographic and Liquid Electrophotographic Results in the Study of the Impact of Workflow on Perceived Reproduction Quality of Fine Art Images*. NIP27, Minneapolis, MN.
- Gamm, B., Frey, F., & Farnand, S. (2011, October). *An Analysis of the Factors Influencing Paper Selection for Books of Reproduced Fine Art Printed on Digital Presses*. NIP27, Minneapolis, MN.
- Jiang, J., Frey, F., & Farnand, S. (2011, November). *Evaluating the Perceived Quality of Soft-copy Reproductions of Fine Art Images With and Without the Original Present*. Submitted for CIC2011, San Jose, CA.

## APPENDIX F: Team Members



Franziska Frey is the Interim Administrative Chair and McGhee Distinguished Professor at the School of Print Media and a Core member of the Graduate Program Faculty of the PhD and masters programs in Imaging Science in the Center for Imaging Science at Rochester Institute of Technology, Rochester, NY. She is teaching courses in Digital Asset Management and Cross Media Publishing and is involved in research projects in the Sloan Printing Industry Center at RIT and the Munsell Color Science Laboratory. Franziska was also a Faculty in the “Mellon Advanced Residency Program in Photograph Conservation” at George Eastman House, International Museum of Photography. Franziska Frey received her Ph.D. degree in Natural Sciences (Concentration: Imaging Science) from the Swiss Federal Institute of Technology in Zurich, Switzerland in 1994. Before joining the faculty of the School of Print Media, she has worked as a research scientist at the Image Permanence Institute at RIT. Her work has primarily focused on establishing guidelines for viewing, capturing, quality control, and archiving digital images. Franziska publishes, consults, and teaches in the US and around the world on various issues related to establishing digital image databases and digital libraries. She is also involved in several international standards groups.



Susan Farnand is a graduate of Cornell University, with a B.S. in Engineering, and the Rochester Institute of Technology’s Masters of Imaging Science program. She worked for many years at Eastman Kodak Company on assignments involving electrophotography and imaging science, before leaving to pursue an opportunity as a research scientist and co-director of the newly established Printer Research and Imaging Systems Modeling (PRISM) lab at the Rochester Institute of Technology. In this capacity, she is involved with investigations into gloss appearance, fusing and toner interactions, and various aspects of image quality assessment. She has also taught color science to a variety of audiences and participated in International Standards efforts including Co-Chairing the effort to generate a standard methodology for perceptual image quality measurement and Chairing the INCITS W1.1 ad hoc team charged with developing a standard for color rendition for printing systems.



Jun Jiang is a Ph.D. candidate in Munsell Color Science Laboratory in the Chester F. Carlson Center for Imaging Science at Rochester Institute of Technology. He is currently doing research on visual editing and cross-media color reproduction of artworks in museums and computational photography.

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- CGATS/SWOP TR005: 2007, Graphic technology - Color characterization data for SWOP® proofing and printing on U.S. Grade 5 coated publication paper.
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