# Bruce Leigh Myers, Ph.D.

## PROFESSIONAL WORK & SCHOLARLY ENDEAVORS

Professional work and scholarly endeavors are largely outlined in the Curriculum Vitae, however important initiatives are reviewed and documented here. This includes some examples of published and presented scholarly work; full examples of any of the work included in the CV, or links to availalbe works on line, will be provided upon request.

Provided materials include:

## 1. EXAMPLES OF RECRUITING INITATIVES

In addition to participating in open house activities, visiting high schools to talk about the program and the industry, and providing regular content for social media and website postings, two proactively developed recruitment efforts are highlighted here.

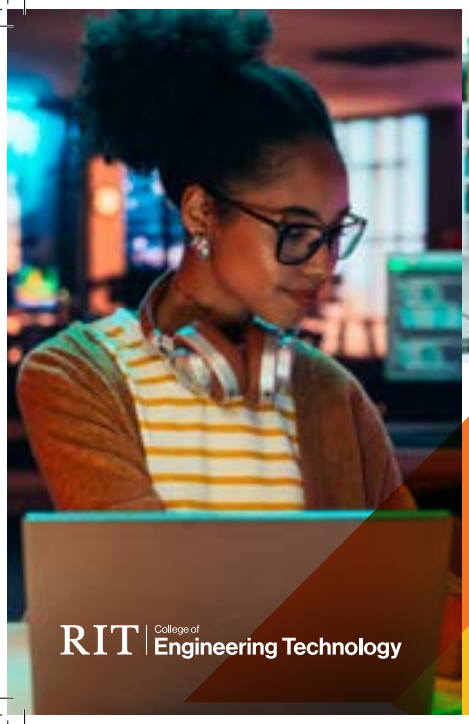
1.1 Graphic Media Day
A one-day long event featuring local printing companies and a trade association where local high schools were invited to attend to learn about careers in the printing industry, held in May, 2024. The invitation for the event follows.

1.2 Alumna Posters
Wrote, designed, and printed posters featuring recent alumni working in thought leadership roles in industry. Posters were displayed in the hallways at the Institute and repurposed for content on the website. Two examples follow.

1.3 Alumni Mentors
Compiled Alumni Mentors, recent graduates working in leadership roles in industry willing to speak with current and prospective students about their experiences.

## 1.1. GRAPHIC MEDIA DAY

Developed Graphic Media Day, a one-day, on-campus event in May of 2024 that invited high schools to bring students to campus and learn about opportunities in the printing industry. Responsibilities included overseeing all aspects of the logistics and content for the event, including coordination among RIT and industry stakeholders, including facilities, food service, speakers, high schools, and the print and graphic communications association.




**You're Invited to Graphic Media Day!**

Bring your students to an event packed with engaging presentations, live demonstrations and the chance to connect with industry leaders!

PRINT & GRAPHIC COMMUNICATIONS ASSOCIATION

RIT College of Engineering Technology
15 Lomb Memorial Drive
Rochester, NY 14623-5608
585-475-5955
rit.edu/cet

Indicia

**Explore the world of graphic media**

**Thursday, May 23** | 10am-1:30pm
RIT Campus | CIMS Conference Center in Louise Slaughter Hall (78)

**Lunch will be provided so registration is required.**

**View details, updates and register here!**

**Questions? Contact**
Bruce Myers
blmppr@rit.edu
585-475-5224

Erin Mills
447 E. Main St.
Columbus, OH 43215

Wrote, designed, and printed posters featuring recent alumni working in thought leadership roles in industry. Posters were displayed in the hallways at the Institute and repurposed for content on the website. The first example follows.

RIT

College of
Engineering Technology

# Kathy Bedard

School of Media Sciences
Bachelor of Science
Alumna Profile

With over 21,000 employees working at over 40 worldwide facilities, **Quad** (NYSE: QUAD) requires a continual stream of top-level talent. To help attract the best and the brightest, they have adopted a corporate training program, in which qualified individuals cycle among various jobs and locations before selecting where they wish to permanently work. This arrangement perfectly suited **School of Media Sciences** alumna **Kathy Bedard**; the 2013 graduate entered the Quad corporate training program shortly after finishing her bachelor of science degree in **Media Arts and Technology**, and has settled in at the Woburn, MA Commercial and Specialty Plant as Customer Account Manager.

Kathy has always been interested in graphics. Like a great deal of **SMS** majors, she looked at several graphic design programs before finding her passion in the industry-relevant curriculum offered by **SMS** at **RIT**. As a high school senior, she did her homework in selecting her career path. Kathy visited both a graphic design firm and the Quad plant in her native Saratoga Springs, NY where she was exposed to the day-to-day operations and employment requirements for both workplaces. Meeting an **RIT** alumnus at the Quad plant, and being aware of the corporate training program, she decided that this was the path for her.

Beginning the corporate training program on the production floor, Kathy was then moved to various administrative roles at Quad locations in the Midwest. When the opportunity to work as a Customer Account Manager at the Woburn facility opened, she knew that this was the job for her. The fast-paced environment, combined with the ability to manage communications with customers and the departments required to produce the final pieces was attractive to Kathy. The Commercial and Specialty Plant, which produces direct mail, in-store signage, posters, wall clings, wide format, sheetfed offset and digital printing for Quad's clients ensures a variety of work that keeps her job interesting. She takes the job from sales, and interacts with the client and the Quad production departments as the projects progress throughout the plant.

Managing daily production meetings is the heart of Kathy's workday, where she employs the skills that were central to the curriculum in her program. Her work is so much more that what most envision when they hear the term "***customer service***." Far from being on the phone all day, Kathy works in an interactive, hands-on, and diverse environment, and achieves satisfaction through seeing graphic jobs completed from start to finish.

Kathy states that the experiential learning inherent in her co-op was central in her career success. While enrolled in the Bachelor of Science program, she worked on the Cunard Cruise line. Like her current job, work on the ship was fast-paced, where she produced graphics seven days a week while travelling the world. This unique experience provides her with great talking points in interviews as hiring managers are genuinely interested in this unique experiential learning experience.

> ***"Kathy appreciates that SMS graduates do not all vie for the same jobs, and that they can tailor their resumes to a wide variety of career opportunities and personal interests."***

Another benefit to **SMS** is the diversity of the course offerings and the types of careers that for which they prepare graduates. Kathy appreciates that **SMS** graduates do not all vie for the same jobs, and that they can tailor their resumes to a wide variety of career opportunities and personal interests.

**SMS** graduates are especially attractive as candidates for Quad's corporate training program, according to Kathy. Coming from a well-rounded curriculum, they are already vested in the industry. The hiring managers at Quad appreciate the students that they see from SMS. ■

RIT

College of
Engineering Technology

# Jinkai Qian

School of Media Sciences
Master of Science
Alumnus Profile

Turning points are pivotal moments in life in which decisive change occurs. For Shanghai native Jinkai Qian, once such turning point was when a professor from the **Master's Degree in Print Media** (MS-PPRT) program at Rochester Institute of Technology (RIT) came to visit the University of Shanghai for Science and Technology (USST). At the time, Jinkai was working on a Bachelor of Science degree in Digital Printing and was intrigued by the curriculum of the **MS-PPRT** program. Researching the RIT program further, he learned of the reputation of the program, including the extensive alumni network and impressive placement of graduates in meaningful jobs at major companies: this convinced Jinkai that his next move would be coming to the US to study at RIT in 2010.

At RIT, **Jinkai** went through the course sequence in the **MS-PPRT** program, which entails three academic semesters followed by thesis work. His coursework and thesis imparted the necessary skills that have helped Jinkai in his co-op experiences and subsequent career.

**Jinkai** names the STEM-based laboratory courses, which employ hands-on exercises that stress critical thinking and technical writing with the latest equipment as especially beneficial in his ensuing endeavors.

**Jinkai** took advantage of both Curricular Practical Training (CPT) and Optional Practical Training (OPT) for paid co-op experiences. Both of his co-ops were on the print production side of the business, first at CSI in Virginia and then at The Matlet Group in Florida. His responsibilities included color management, managing job workflows, working in the pre-media department, and order handling.

After his co-op work, **Jinkai** joined the vendor side of the business with a technical applications job at Techkon USA, a major manufacturer of color measurement devices with offices near Frankfurt, Germany and Boston, MA. Among the award-winning products offered by Techkon USA are hand-held and scanning spectrodensitometers, quality assurance/ink formulation systems, and even a spectrophotometer designed for flexographic printing that measures traceable metrics on a web moving up to 300 meters per minute.

**Jinkai** supports Techkon's customer base throughout North America for installations and on-site training and support. His responsibilities require regular travel to major printing companies throughout the region. In addition to supporting clients, **Jinkai** is regularly in touch with the software and hardware engineers in the corporate offices to make sure that the new products and updates meet the needs of North American printers. As such, **Jinkai** has been trained on the latest printing certifications, including as a G7 Expert, BrandQ Supply Chain expert, and Certified Color Management Professional by IDEAlliance.

> ***"RIT graduates work in the knowledge-based positions… in both production management and upper management positions… they are the most knowledgeable about color, printing, and pre-media applications, as well as the production workflow."***

**Jinkai** cites the key role of his RIT coursework in obtaining his current position. He believes that this helped him to secure the job over several other candidates, and stands as a testament to the relevance of the curriculum. When asked if he meets RIT alumni in his work, he responds: "All the time! I meet RIT alumni at both production facilities and trade shows: RIT graduates work in the knowledge-based positions…in both production management and upper management positions…they are the most knowledgeable about color, printing, and pre-media applications, as well as the graphic production workflow."

Today, **Jinkai** lives with his wife and young son in the Boston suburbs and is pursuing US-resident status, intending to stay long-term. **Jinkai** recognizes that his job at Techkon USA, obtained as a result of his STEM-based Master of Science in **Print Media** degree from RIT, is integral to his aspirations. ■

Compiled Alumni Mentors, recent graduates working in leadership roles in industry willing to speak with current and prospective students about their experiences.

# GMST Alumni Mentors

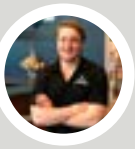
## Career, Co-op, and Industry Guidance

**Do you need advice on your Career or Co-op?**
**Do you need advice on the Industry or the Curriculum?**
**The GMST Mentor group is here to help! Please reach out to the GMST mentor that best aligns with your individual goals and aspirations.**

Kate **Cooper**
cooper.katej@gmail.com

**RIT Student Involvement**
- Varsity volleyball player
- Assistant Editor in Chief SMS Connect
- Part of the 4+1 MBA program and completed MBA from Saunders

After graduating from RIT, Kate joined Cenveo, a large envelope, label, and print manufacturer based out of Stamford, CT. She started as Director of Marketing for their print division and then moved into a role within the IT organization on-boarding new customers to a supply chain platform called Kadena. In September of 2018, Kate was given the opportunity to become the VP of Corporate Communications. In this role she works on corporate marketing efforts, lead generation, marketing operations, stakeholder communications and management.



Mitch **Morgan**
mjm5629@rit.edu

**RIT Student Involvement**
- Technical Lab Specialist, Student Lab Manager, and Gravure Research Assistant
- Production Manager Reporter Magazine
- Hammer Packaging co-op
- Phi Sigma Kappa Fraternity member and president

A 2018 RIT graduate, Mitch joined Hammer Packaging full time as a Continuous Improvement Engineer where he focused mostly on lean manufacturing and waste elimination projects. He was actively involved in the safety team there and had the opportunity to lead the safety team in an interim role until they were able to fill the position. In December 2019, Mitch joined packaging company Brook & Whittle as their Medical Packaging Operations Supervisor where he is responsible for the company's Medical Packaging function, including managing the employees across a 24/5 operation, and working to ensure that operational goals and business objectives are met or exceeded.

Casey **Jabbour**
casey.jabbour@gmail.com

**RIT Student Involvement**
- Editor-in-Chief of SPMetc
- Manager of the DPC/SPM Labs
- President of PUB
- Member of TAGA

After graduating from RIT, Casey spent six months on the Queen Victoria cruise ship as an Assistant Printer. She then spent a year at Condé Nast corporate as a print buyer and a production associate, where she managed all stationary needs for every brand at Condé Nast, and then four years at GQ, where she designed, managed, and produced their mobile editions. Casey would also work on production for the print issue. She then joined a startup in New York called Splice, where she oversaw production, motion, and visual design for their marketing team. Casey earned a Master's in Human Computer Interaction & Design from University of Washington, and is working as a Senior Product Designer at Substantial, a design agency in Seattle.

Nick **Gawreluk**
ntg5533@rit.edu

**RIT Student Involvement**
- Production Manager Reporter Magazine
- President of TAGA
- Varsity cross country & track and field
- Worker at the DPC/SPM Labs

A 2013 RIT graduate, Nick worked for Mimeo in Memphis as an Account Manager before relocating to Berlin, Germany to help the company expand into Central Europe. He joined HP Indigo in 2015 as a Business Analyst in Atlanta and was promoted to Product Manager one year later. He worked with hundreds of printing companies across North America to launch new products and grow the digital print business. He joined Heidelberg in 2018 and relocated to Germany to help the company execute a new business model for workflow automation software. Currently, Nick oversees customer success programs across North America, Brazil, Asia Pacific, and Greater China.

## 2. NEW STUDENT ORIENTATION

While the department chair, I designed and implemented orientation activities for incoming undergraduate students in 2020 and 2021.

For new student orientation week at RIT, incoming, first-year students participate in three days of Institute-level orientation where they learn firsthand all of the "ins-and outs" of the Institute. On the fourth day, known as Academic Day, new students meet with their department. For the Department of Graphic Media Science and Technology, this involves presentations from their Academic Advisor, introductions to the specifics of the curriculum by the faculty, and awareness of options available to them, such as study abroad opportunities. For the students in the BS Media Arts and Technology program, they not only toured the facilities, but used the laboratories in an activity that demonstrates the hands-on nature of the program and results in them taking home a nice memento as a remembrance of the event.

The department brought in Mr. Rob Dumo (robdumoart.com), an accomplished caricature artist, to draw pictures of the students. Once each sitting is done, the students bring their drawings to the digital laboratory where they are instructed on how to scan them so that they have a digital version for their own use. Then, they more on to worktables where they frame the drawings using sectional frames and custom mats. The student activities were overseen by faculty and staff, so everyone got to know each other a bit. The students brought the resulting framed pictures back to their dorm room or home. This activity was a big hit with the students, faculty, and staff, and made the Department of Graphic Media Science and Technology students the envy of their peers in other programs.

This memorable event served to not only orient the students after a long week of orientation meetings, but also to engage them.

The below pictures show students scanning and framing their charicature drawings.




## 3. EXTRACURRICULAR STUDENT ENGAGEMENT

I have chaperoned student groups at various industry events since joining RIT in 2011, notably the Technical Association of the Graphic Arts (TAGA) annual conference, the Digital Solutions Cooperative (DScoop - the HP Indigo User Group) conferences in 2018 and 2023, and several GraphExpo trade shows in Chicago. These all represent tremendous opportunities for students to learn about the industry and network with industry leaders. The TAGA and DScoop conferences work to integrate students, in competitions and to participate in panels where industry leaders ask them questions. I served as the RIT Student TAGA Chapter advisor for several years and assumed that role for the 2025 conference.

Students from RIT network with industry leaders and alumni at the DScoop conference in 2018

Students from printing programs across the US serve on panels at the 2018 DScoop conference


RIT Students proudly show their work at a TAGA Conference

## 4. PUBLISHED & PRESENTED SCHOLARLY WORK

Three of the many examples of published and presented scholarly work are included here. These examples were chosen as they represent different approaches in my research portfolio, including survey research, laboratory research designed to inform pedagogy, and laboratory research involving metrology.

The studies following are:

4.1. Colourimetric Values utilized by U.S. Ink Companies, published in the *International Circular of Graphic Education and Research*, No.9, 2016. The International Circle of Educational Institutes for Graphic Arts: Technology and Management.

4.2. Color Studies Curriculum: Re-Envisioning Josef Albers' Interaction of Color in the Digital Age (with Yue (Julia) Cao), presented at the 2019 Technical Association of the Graphic Arts (TAGA) conference and published in the subsequent proceedings.

4.3. Evaluation of Light Measurement Instruments, presented at the 2019 Technical Association of the Graphic Arts (TAGA) conference and published in the subsequent proceedings.

# Colourimetric Values utilized by U.S. Ink Companies

**Bruce Leigh Myers, Ph.D.**[1]

[1] **Rochester Institute of Technology, Rochester, NY**

Keywords: Colour differencing, DeltaE, Colourimetry, Standard Sperating Procedure, CIE

**Abstract**

**Colourimetry is widely adopted in the printing industry, but the user-selected variables inherent in using the technologies are not widely standardized. In the present study, the current state of the adoption of particular colourimetric variables is examined in an U.S. ink companies. A quantitative, cross-sectional survey was distributed to ink companies inquiring about their selection of instrument geometry, colourimetric illuminant, standard observer and colour differencing method as part of their standard operating procedures. In addition, companies were asked about their choice for quality assurance software and preferred digital file format for colour communication.**

## 1. Introduction

The widespread use of colourimetry has permeated the printing industry; colourimetric values are frequently utilized to manage and control both spot and process colour reproduction and are manifest in not only brand colour control initiatives, but also serve as the cornerstone of printing industry standards and specifications such as ISO/DIS 12647-2 (2012). When correctly implemented, the use of colourimetry enables the concise communication of colour values among stakeholders in the printing workflow, from concept to design to production. Colourimetry is applied in a wide-range of quality assurance applications from incoming materials inspection to process control applications. Clearly, one key goal in the adoption of colourimetry is to drive variance out of the printing workflow. Practitioners, however, must be wary of the myriad of variables inherent in the communication of colourimetric values, including illuminant, standard observer, and colour differencing method: unless properly managed, these variables could result in increasing variance in colour printing processes.

## 2. Need for the Study

Standards and specification committees for the printing industry reference selected colourimetric variables in their publications and mandates for relevant certifications. Many printers have moved from visual analysis and densitometry to colourimetric information for quality assurance applications in response directives from their customers. Print buyers and consumer brand owners increasingly demand consistent colour reproduction worldwide across a variety of substrates and media.

Ink companies in particular are widely regarded as being among the most influential users of colourimetry in printing workflows. The nature of the production of inks has practically mandated that manufacturers are early adopters of colourimetry to assure production consistency. Many ink companies pro-actively provide colourimetric data in reporting with ink shipments: some go as far as to print colourimetric information on the labels of their ink containers. As printers adopt colourimetric controls, they likely consult their respective ink company for assistance in establishing their own standard operating procedures (SOPs), which include the colourimetric variables examined in the present study.

While there are numerous examples of studies that compare various colour differencing methods (e.g.: Yu, 2014; Habekost, 2013; Chung & Chen, 2011) an extensive review of the literature revealed no published studies that examined which colourimetric variables are used by practitioners in this domain. In addition to an examination of which colourimetric variables are utilized, the present study also examines potential correlations that may contribute to a greater understanding here.

## 3. Research Questions

Utilizing a cross-sectional questionnaire instrument designed to examine the colourimetric variables utilized as standard operating procedures by ink companies in the United States is the primary focus of this study. Specifically, the following research questions frame the investigation:

RQ1. Which instrument geometry is utilized?
RQ2. Which illuminant is selected?
RQ3. Which standard observer is selected?
RQ4. Which colour differencing equation is utilized?
RQ5. Which, if any, software is utilized for quality assurance?
RQ6. Which, if any, digital file format is utilized for colourimetric communication?

In addition, the questionnaire inquires about the size of the responding company. The following hypotheses are tested regarding possible correlations among selected variables:

H1. The data indicate a correlation between size of company and quality assurance software utilized.

H2. The data suggest a correlation between software and colour differencing method.

H3. The data imply a correlation between software and file format utilized for the digital transfer of colourimetric variables.

Understanding the commonly used variables in this field and possible correlations can be relevant for a number of constituencies, including commercial printers and print buyers, industry manufacturers, educators, standards and specifications committees.

## 4. Literature Review

Literature germane to the present topic include published works that describe and define colourimetric variables, and those that compare and contrast those variables through psychophysical analysis.
A brief discussion of the variables examined in the present study is outlined below. Those interested in more detailed analyses here are encouraged to consult the cited sources for more information and specifics on the variables introduced.

### 4.1 Colourimetry, CIELAB, standard observer and standard illuminants

The process of quantifying the perception of colour is known as colourimetry. In industrial use, colourimetry is based on the work of the Commission internationale de l'éclairage, more commonly referred to as CIE, which is generally translated as the "International Commission on Illumination". Established in 1913, the CIE is recognized by the International Standards Organization (ISO) as an international standardization body (Schanda, 2007.)
CIELAB is an opponent colour system adopted by the CIE in 1976 as a colour model based upon a standard observer and standard illuminants (Berns, 2000). It is designed to be a device-independent, universal colour space representative of the range of colours perceptual to the 'average human' with normal colour vision. The CIE has defined two standard observers: a 1931 standard observer based on a testing individuals colour perception using a two degree angle of view, and a 1964 standard observer based upon testing using a ten degree angle of view (Schanda, 2007). Standard illuminants for colourimetry are representations of the spectral power distribution of light in numerical form; the CIE has defined several illuminants to represent particular light sources (Hunt & Pointer, 2011; Berns, 2000). These data are used to calculate the colourimetric values of a sample as it would appear under a light source that corresponds to the selected CIE illuminant.
When CIELAB values are derived from spectrophotometric readings, the standard observer, illuminant and spectral readings are factored to derive XYZ tristimulus values: the CIELAB values are based on those XYZ values (Berns, 2000). The instrument geometry from which the spectral data are derived is also a critically important factor in the use of colourimetry.

**4.2 Instrument Geometry**

Colour measurement instruments utilized by printing ink manufacturers measure the light reflectance of samples relative to a particular reference. Due to the surface characteristics of the samples measured and other factors, the instrument illumination condition and the incident angle of measurement are of critical importance. As detailed in Randall (1997), "Directional" geometry instruments measure directional light at 45 degrees incident to the light source, either illuminating at zero degrees and reading at 45 degrees (0°/45°) or illuminating at 45 degrees and measuring at zero degrees (45°/0°). "Spherical" instruments, otherwise known as d/8°, utilize diffuse lighting and measure at 8 degrees. These instruments generally enable users to read with the specular component of the light source included with, or excluded from, the colourimetric reading. Multi-angle instruments, sometimes called "gonio spectrophotometer" use directional lighting and measure at several angles, often simultaneously. Instruments that measure five angles are common multi-angle devices (Davis, 1996; Teunis, 1996).

**4.3 Colour Differencing Equation, alternately known as colourimetric tolerancing method**

The primary goal of a colourimetric differencing equation is to use objective, quantifiable measurements to replace more subjective visual analyses. Colour differencing equations reduce the colour difference between two samples to a single number. The CIE first published ΔE* (alternately known as ΔE*ab and ΔE76) in 1976 (Berns, 2000). This tolerancing method has been widely utilized in industry and by ISO procedures such as ISO12647-2 and ISO/DIS 15339 (Cheydleur, 2013; Warter, 2011).

In practical use, however, ΔE* proved to be limited as the CIELAB colour space is not visually uniform. In response to this condition, in 1986 The Colour Measurement Committee of the Society of Dyers and Colourists published an equation for determining colour difference, known as ΔEcmc (Hunt & Pointer 2011). The goal of the Committee was to develop a colour difference formula that better handled small colour differences. Later, the CIE created technical committees to examine the perceived limitations of ΔE* (Berns, 2000). Resultant equations of the CIE's work include ΔE94 (alternately known as ΔECIE1994) and ΔE00 (otherwise known as ΔECIE2000) (Hunt & Pointer, 2011; Luo, Chi & Rigg 2000; Wyszecki & Stiles 2000).

In addition to the technical literature, a number of psychophysical studies have been published that examine which colour differencing method best corresponds to human vision. Such research investigated samples with surface characteristics typical for the printing industry, and some have segregated trained and untrained observers in their analysis. These include several studies that have compared ΔE*ab to more current differencing methods in various contexts germane to the printing industry (e.g.: Yu, 2014; Habekost, 2013; Chung & Chen, 2011; Habekost, 2009). Generally, these studies conclude that in nearly all examined applications ΔE00 outperforms ΔE*, however in instances where ΔE00 is compared to other more current tolerancing methods (i.e.: ΔEcmc, ΔE94) results are generally less conclusive.

## 5. Research Design and Methodology

Using a self-reported mailed questionnaire instrument, managers at U.S. printing ink companies were identified using a list of such companies published by Ink World magazine (2014). Using methods suggested by Dillman, Smyth and Christian (2014), potential respondents were mailed an introductory letter, followed by a survey package consisting of a questionnaire instrument and postage-paid return envelope. In addition, a link to an Internet-based survey was provided as an alternative method of responding. Steps were taken to assure that all responses were anonymous. For example, the survey package also included a postage-paid return postcard, so that research subjects could indicate that they responded without revealing which response was theirs. Two weeks after the initial survey package was mailed a reminder was sent to non-respondents, and two weeks after the reminder mailing a second complete survey package was sent to those that did

not respond. Of the 127 U.S. ink companies identified from the sampling frame, four were no longer in business, and one self-disqualified. In total, 49 companies responded out of the potential 122; a response rate of 40%.

## 6. Limitations

As a quantitative, cross-sectional survey, the present study is not designed to uncover the reasons that underlie why ink companies make their particular variable selections. In addition, as the sampling frame was limited to those ink companies in the InkWorld listings, large ink companies with multiple locations were represented by one of their centralized locations. Therefore, a small, single location and perhaps highly specialized ink company has the same weight in the present analysis as did a large organization with numerous locations. Further, this study is limited to those ink companies conducting business in the U.S. In addition, to streamline the questionnaire instrument, variables such as user-defined parametric values inherent in some colour differencing methods (e.g.: the lightness to chroma ratio expressed in the $DE_{cmc}$ equation) are not examined.

## 7. Findings, Data Analysis and Results

The demographic information regarding the respondents is replicated in table 1. Large and smaller companies were generally equally represented: if responding companies are divided among those that employ 50 or less versus 51 or more there was a nearly even split.

| Size of company | | |
|---|---|---|
| **Number of employees** | **N** | **%** |
| < 10 | 8 | 16.3 |
| 11 - 25 | 11 | 22.4 |
| 26 - 50 | 5 | 10.2 |
| 51 - 100 | 9 | 18.4 |
| 101 - 500 | 9 | 18.4 |
| > 500 | 5 | 10.2 |
| Don't know/Decline | 2 | 4.1 |

**Table 1:** Companies in this study

Table 2 displays results pertaining to user standard operating procedures relevant to instruments and software: instrument geometry, quality assurance software and file format. In these instances, over 80% of users reported utilizing directional 0°/45° or 45°/0° measurement instruments. Four ink companies reported utilizing multi-angle instruments, while three reported using spherical instruments for their standard operating procedure. Turning to software, over 50% of the ink companies responding reported using X-RiteColour Master for their quality assurance needs. X-Rite iQC was the second most utilized software, with ten reported users and four reported using X-Rite ColourQuality as their standard. The only non-X-Rite software with more than one reported user was Datacolour Tools software, utilized by four of the respondents.

In terms of digital file format, the .mif format dominated with over 40% of users reported utilizing this particular type of file for transferring colourimetric information. This was followed by all versions of the .CxF file format with over 16% of users, and the standard file format for Microsoft Excel representing just over 8% of reported users. Of all of the variables examined here, file format resulted in the highest number of "Don't know," "Decline to answer," and questionnaires with no answer selected represented 35% of the returned surveys.

| Instrument and Software Variable | | |
|---|---|---|
| **Instrument Geometry** | **N** | **%** |
| 0º/45º or 45º/0º | 40 | 81.6 |
| Sphere d/8º | 3 | 6.1 |
| Multi-angle/Gonio | 4 | 8.2 |
| None/Decline | 2 | 4.1 |
| | | |
| **Software** | | |
| ColourMaster | 25 | 51 |
| iQC | 10 | 20.4 |
| ColourQuality | 4 | 8.2 |
| Tools | 3 | 6.1 |
| Smart | 1 | 2 |
| BASF | 1 | 2 |
| MeasureColour | 1 | 2 |
| Other/None/Decline | 4 | 8.2 |
| | | |
| **File format** | | |
| .mif | 20 | 40.8 |
| .Cxf (any version) | 8 | 16.3 |
| .xls/.xlsx | 4 | 8.2 |
| None/Don't know/Decline | 17 | 34.7 |

**Table 2:** Information on instruments, software and file formats

Table 3 displays responses from colourimetric variables, namely illuminant, standard observer and colour differencing methods preferred as SOP. The "daylight" illuminants of D50 and D65 dominated as SOPs for responding ink companies, accounting for over 90% of users. Over one half of the respondents reported using D50, and over 40% selected D65. In terms of standard observer, the ten degree (1964) standard observer was utilized by over 53% of respondents, with nearly 39% choosing the two degree (1931) standard observer.

| Colourimetric Values | | |
|---|---|---|
| **Illuminant** | **N** | **%** |
| D50 | 25 | 51 |
| D65 | 20 | 40.8 |
| F2 | 1 | 2 |
| None/Don't know/Decline | 3 | 6.2 |
| | | |
| **Observer** | | |
| 10º 1964 | 26 | 53.1 |
| 2º 1931 | 19 | 38.8 |
| Other/None/Decline | 4 | 8.1 |
| | | |
| **Colour differencing method** | | |
| $\Delta E_{cmc}$ | 22 | 44.9 |
| $\Delta E^*_{ab}$ | 12 | 24.5 |
| $\Delta E^*_{00}$ | 8 | 16.3 |
| $\Delta E^*_{94}$ | 2 | 4.1 |
| $\Delta E^*_{ch}$ | 1 | 2.0 |
| None/Don't know/Decline | 4 | 8.1 |

**Table 3:** Colourimetric Variables

When examining colour differencing method, ΔEcmc is the most widely used among U.S. ink companies with nearly 45% of respondents indicating this is their choice for colourimetric tolerancing, while over 24% of ink companies reported using ΔE*, and ΔE00 accounted for just over 16%.

Turning to potential correlations among selected variables, the analysis examined correlations between the size of the company and the quality assurance software utilized, between the quality assurance software and colour differencing method, and between the quality assurance software and the file format. Due to the relatively low number responses, to test for correlations the data were regrouped to reduce the number of categorical variables, as illustrated in Table 4:

| Categorical Variables for Correlational Analysis | |
|---|---|
| | N |
| **Size of company** | |
| ≤ 50 employees | 24 |
| > 50 employees | 23 |
| **Quality Assurance Software** | |
| ColourMaster | 25 |
| Other than ColourMaster | 20 |
| **Colour Differencing Method** | |
| ΔEcmc | 22 |
| Other than ΔEcmc | 23 |
| **File format** | |
| .mif | 20 |
| Other than .mif | 12 |

**Table 4:** Categorical Variables for correctional analysis

In an examination of a potential correlation between size of company and quality assurance software selection, a chi-square test for association was conducted. All expected cell frequencies were greater than five. There was a statistically significant association noted between size of company and quality assurance software selection, $\chi 2(1) = 5.31$, $p = .021$. There was a moderately strong association between company size and software, $\varphi = 0.351$, $p < .05$. The data suggest that those companies with 50 employees or less are more likely to utilize X-RiteColour Master as their SOP for a quality assurance software.

In an examination of a potential correlation between quality assurance software selection and colour differencing method utilized, a chi-square test for association was again utilized. All expected cell frequencies were greater than five. There was no found statistically significant association between quality assurance software selection and colour differencing method, $\chi 2(1) = 1.96$, $p < 0.16$. As the data indicate no association, the null hypothesis here is retained and it is concluded that software choice and colour differencing method are not significantly correlated. Finally, turning to an examination of a correlation between quality assurance software and file format, one cell had an expected cell count as less than five. Therefore the results of the Fisher's Exact Test are reported: $p < .005$ (2-sided). This finding suggests that those companies utilizing X-RiteColour Master are more likely to utilize the .mif file format as their preferred method for communicating colourimetric data digitally.

## 8. Analysis

In an examination of the types of instruments utilized by U.S. ink companies, it is no surprise that directional 0°/45° and 45°/0° instruments are the most widely adopted, as it is likely that densitometry is commonly still utilized in addition to colourimetric data, and 0°/45° or 45°/ 0° geometry is mandated by standards bodies for ANSI status density readings (Brehm, 1999.) Further, such instruments are generally less expensive, easier to use and available with smaller measurement apertures than their spherical and multi-angle counterparts.

The usage of daylight illuminants is also to be expected, although some may find it interesting that the D50 illuminant only represented one-half of the respondents: this particular illuminant condition is widely utilized in the U.S. printing industry as referenced in ISO 13655:2009. Likewise, respondents reported adoption of the two degree (1931) standard observer at 38% versus 53% adopting the ten degree observer. This finding may also be curious to some, as standards committees in the printing industry generally utilize the two degree choice.

The reported preferred use of ΔEcmc as a colour differencing equation by many ink companies is of particular note as ΔEcmc is not recognized by graphic arts standards and specifications committees to the extent of ΔE* and ΔE00 (Cheydleur 2013, Warter 2011. The second most widely used colour differencing method in this study is ΔE* and the more current ΔE00 represents the third most popular choice among responding ink companies. It is noteworthy that the data indicate if the number of ink companies using ΔE* and ΔE00 are combined, they still do not equal the nearly 45% of companies adopting ΔEcmc

as a part of their standard colourimetric operating procedure.

In the examination of quality assurance software, clearly the X-Rite products enjoy the majority of the market share with U.S. ink companies, three of their software products are adopted by nearly 80% respondents. X-RiteColour Master is the most widely utilized, and is most likely the choice of smaller companies. The prevalence of the .mif digital file format may speak to the dominance of X-RiteColour Master as a software choice for quality assurance use as the format been a default selection of Colour Master users for many years.

## 9. Conclusions & Implications

In 1986, Fred Davis published a technology acceptance model for empirically testing new end-user information systems: theory and results, where he posited that perceived ease of use and perceived usefulness were direct antecedents to technology adoption. It is suggested here that the technology acceptance model (TAM) is an appropriate lens to view the implications of the present study. Clearly, the sheer diversity of colourimetric variables reported as SOPs by U.S. ink companies represents an interesting condition for the commercial printing industry: stakeholders who desire more homogeneity among the colourimetric variables utilized by industry are advised to build the case for the usefulness of selected methods to overcome the inconvenience of the incumbent changing their current SOP. For example, the present study indicates that a large percentage of responding ink companies prefer to utilize DEcmc. This particular tolerancing method is not recognized in ISO12647-2 (2013) which references ΔE* as a normative parameter with $\Delta E_{00}$ as the informative parameter (Cheydleur, 2013). Psychophysical colour differencing research that limits comparisons of ΔE* to ΔE00 could be leaving out wide swaths of the industry; users of DEcmc would be understandably unfazed by such studies. If DEcmc is meeting the needs of such companies, the moves of standards committees may hold little sway, especially if unsupported by convincing psychophysical evidence of the superiority of one colour differencing method over another. Restated in the view of Davis' TAM (1986), the perceived usefulness one colourimetric tolerancing method versus another may not be sufficiently significant to warrant a change.

This finding further suggests that the recent adoption of the file CxF3 file as an ISO standard format (ISO 17972-1: 2015) may not have an immediate impact on what U.S. ink companies continue to use: especially if this case is similar to the persistent use of DEcmc by many. It is reasonable to conclude that if ink companies and their constituents are utilizing file formats other than CxF3, and their selected formats perform well in their workflows, they will likely see little reason to switch unless a case for the superiority of CxF3 can be clearly and empirically supported. As with colour differencing methods, the recognition of standards bodies may be of little consequence to contented users of other formats.

## 10. Future research

Future researchers could adopt a more qualitative approach to print providers and buyers to obtain a richer understanding of the salient factors driving the choices that ink companies make in regard to colourimetric variables. Further, as this research is limited to U.S. ink companies, researchers may choose to examine ink companies outside of the U.S.

In addition, the present study potentially builds upon a rich tradition of technology adoption studies conducted since the seminal Rogers' Diffusion of Innovations was first published in the early 1960's (Rogers, 2003). As such, a point of reference for future potential researchers examining U.S. ink companies use of colourimetry and the respective variables is provided. Subsequent researchers may choose to re-examine ink companies in the future to better ascertain the stage of adoption of the variables examined here, as well as the relative influence of standards committees and software vendors on these variables.
Finally, researchers may wish to replicate this study with actual printers to better ascertain which vari-

ables such companies choose to select as part of their standard operating procedures: such studies could result in noteworthy comparisons to the present work.

**References:**

[1] Berns, R. S., (2000). "Billmeyer and Saltzman's principles of colour technology" 3rd ed. New York: Wiley.

[2] Brehm, P. (1999). "Introduction to densitometry: a user's guide to print production measurement using densitometry" (2nd ed.). Alexandria, VA: Graphic Communications Association.

[3] Cheydleur, R. (2013). "The Latest Scoop on ISO 12647, 15339, & More". Printing Industries of America, the Magazine, 5(9), 12-13.

[4] Chung, R. and Chen, P. (2011, September). "Determining CIEDE2000 for Printing Conformance." Paper presented at the The International Association of Research Organizations for the Information, Media and Graphic Arts Industries (iarigai) Research Conference, Budapest, Hungary.

[5] Davis, F.D., Jr. (1986). "A Technology acceptance model for testing new end-user information systems: theory and results". (Order No. 0374529, Massachusetts Institute of Technology).

[6] Davis, D.J. (1996). "An investigation of multi angle spectrophotometry for coloured polypropylene compounds" Society of Plastic Engineers/ANTEC 1996 Proceedings, 219-228.

[7] Dillman, D. A., Smyth, J. D., & Christian, L. M. (2014). "Internet, phone, mail, and mixed-mode surveys : the tailored design method" 4th ed. Hoboken, NJ: Wiley.

[8] Habekost, M. (2013): "Which colour differencing equation should be used?" International Circular of Graphic Education and Research No. 6.

[9] Habekost, M. (2009): "The Applicability of Modern Colour Differencing Equations in the Graphic Arts Industry". TAGA 2009 annual conference. Pittsburgh: TAGA

[10] Hunt, R., & Pointer, M. (2011). "Wiley-IS&T Series in Imaging Science and Technology: Measuring Colour" 4th Ed. Somerset, NJ, USA: John Wiley & Sons. ISO TC130. (2015, June): ISO/DIS 17972-1. Geneva, Switzerland.

[11] ISO TC130. (2012, February): ISO/DIS 12647-2. Geneva, Switzerland.

[12] ISO TC130. (2009, November): ISO/DIS 13655. Geneva, Switzerland.

[13] Luo, M.R., Cui, G., Rigg, B. (2000) "The Development of the CIE 2000 Colour-Difference Formula: CIEDE2000". Colour Research and Application, 26, 340-350.

[14] Randall, D. L. (1997). "Instruments for the measurement of colour" Colour technology in the textile industry. 2nd ed. Research Triangle Park, NC: American Association of Textile Chemists and Colourists, 9-17.

[15] Rogers, E. M. (2003). "Diffusion of innovations" 5th ed. New York: Free Press.

[16] Schanda, J. N. (2007). "Colourimetry: understanding the CIE system". Vienna, Austria & Hoboken, N.J.: CIE/Commission internationale de l'eclairage ; Wiley-Interscience.

[17] Teunis, B.D. (1996). "Multi-Angle Spectrophotometers for Metallic, Pearlescent, and Special Effects Colour" Society of Plastic Engineers/ANTEC 1996 Proceedings, 209-217.

[18] "The U.S. Ink Directory" (2014) InkWorld Issue: 1 Volume: 20 January/February, Rodman Publishing. Ramsey, NJ.

[19] Yu, C. (2014). "The Effect of Optical Brightening Agent (OBA) in Paper and Illumination Intensity on Perceptibility of Printed Colours". Retrieved from ProQuest Dissertations and Theses. (Order No. 1572010)

[20] Warter, L. C. (2012). "Predictability: Relating process control and colour management-ISO 12647 and 15339". Printing Industries of America, the Magazine, 4(4), 97-99.

[21] Wyszecki, G. N., & Stiles, W. S. (2000). "Colour science: concepts and methods, quantitative data, and formulae" (Wiley classics library ed.). New York: John Wiley & Sons.

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# Color Studies Curriculum: Re-Envisioning Josef Albers' Interaction of Color in the Digital Age

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# Color Studies Curriculum: Re-Envisioning Josef Albers' Interaction of Color in the Digital Age

Yue (Julia) Cao and Bruce Leigh Myers, Ph.D.

Keywords: Josef Albers, simultaneous contrast, spectrophotometer, color studies, color management

**Abstract**

This study considers the possibility of using digital technologies to improve established color studies teaching methods, which are largely based on visual evaluation. Experiments utilized in this study are based on work outlined in Josef Albers' *Interaction of Color* (2009). Albers, a famous artist and art educator, has made significant contributions to the field of color studies. In this paper, the researchers conduct two experiments to assess the efficacy of two different approaches to Albers' traditional methods of color studies pedagogy by seeking to replicate examples from *Interaction of Color*.

In the first approach, modern ICC-profile-based color management tools are used with an inkjet printer to determine if two illustrations featured in *Interaction of Color* can be faithfully reproduced. In the second approach, color measurement technologies are used to ascertain if colorimetry can be useful in selecting optimal paper samples from a set of Color-aid papers, a collection of 314 screen printed papers especially utilized by students studying color in curricula prescribed by Albers.

The illustrations selected from I*nteraction of Color* for the study are based on the visual phenomena described as 'Two Colors as One' and 'One Color as Two'; these phenomena are otherwise termed 'simultaneous contrast' (e.g.: Long, 2015; Fairchild, 2005, Berns, 2000).

The results of this study reveal limitations of these digital methods as compared to visual evaluation when replicating the visual effects of illustrations from *Interaction of Color* and provide insights that may enhance future curricula in color study fields.

Rochester Institute of Technology

## Introduction and Background

For decades, art educators teaching color studies have utilized the pedagogy pioneered by Josef Albers, which is articulated and illustrated in his landmark treatise *Interaction of Color*. The first version of Interaction of Color was published in 1963 by Yale University Press, and included screen-printed, precisely produced color reproductions of Albers' work. The edition featured impressive color reproductions replicating many of the color phenomena as Albers had originally conceived for teaching. Rare booksellers now advertise these original volumes for thousands of dollars. In 1971, an inexpensive, mass-produced version of *Interaction of Color* became widely available; these do not feature the precise color reproduction of the 1963 volume. Nonetheless, this mass-produced edition, retailing for under $20, has sold over 250,000 copies ("*Interaction of Color*," 2019). This edition is extensively used by students and educators in color studies courses. In 2009, Yale University Press re-published a carefully produced edition of the 1963 edition of *Interaction of Color* to the original 1963 standards: these sell for approximately $250 and are endorsed by the Josef and Anni Albers Foundation. This 2009 volume, otherwise known as *Interaction of Color: New Complete Edition*, offers a relatively affordable, finely reproduced version of *Interaction of Color*.

In color studies classes based on Albers' curricula, students are typically shown examples of the relative nature of color, and then asked to reproduce the phenomena using colored papers. Students are asked to use visual analysis to compare and select the papers that would best replicate the respective effect. Despite color measurement devices and software products now being widely available, a review of the relevant literature revealed no studies that utilized colorimetry or a color-managed workflow to explore other methods to approach color studies curricula. The present study proposes bringing these exercises into the digital and color measurement age; the objective is to quantify select exercises and determine the efficacy color-managed workflow and color measurement technologies in this context.

Critical to the framing of the present study is the recognition that in Albers' curriculum, he recommends that students use color papers in their exercises, rather than paints or other media. According to Albers, color papers provide innumerable colors in a range of shades and tints ready for immediate use. The papers are therefore simple and efficient, making them highly practical and enabling students to compare neighboring and contrasting colors. Other reasons for using color papers are cited by Albers (2009):

- Color paper avoids the difficult, time-consuming, and tedious mixing of paints.
- Students sustain interest and save time and materials without discouraging failures from mixing or imperfectly matching of spoiled paints and papers.
- Color paper permits repeated use of precisely the same color without any slight change in tone, light, or surface quality.
- Working with color paper is simple, inexpensive, and orderly, mostly requiring adhesive and a razor blade; tools and equipment for handling paints are unnecessary.
- Texture, which often hides a poor conception, is avoided; students need not worry about brush marks and strokes, incalculable changes from wet to dry, or other circumstances.

In the late 1940s, Albers began using a specific commercially-available set of color papers in his classes, known as Color-aid brand papers (Horowitz, 2006). According to the Color-aid corporation website: "Since 1948 Color-aid Corp. has been manufacturing the Color-aid system of colored paper. Initially developed as a backdrop for photographers, Color-aid was soon thereafter discovered by Josef Albers and has since then become an indispensable teaching tool in art and design classes" ("Color-aid," 2019). Today, Color-aid papers consist of 314 color papers sold in kits intended for color study.

## Research Questions

This study sought to answer the following questions:

1. Can a color managed inkjet printer effectively recreate examples from *Interaction of Color* (2009)?
2. Can colorimetry be used to effectively select optimal Color-aid papers to recreate the visual effects illustrated in the new complete edition of Interaction of Color (2009)?

## Materials

The materials utilized in the present study include the 2009 edition of *Interaction of Color*, Color-aid papers, color measurement hardware, software including Adobe Photoshop, standardized color viewing, a computer monitor display optimized for critical color evaluation, and an inkjet printer. In addition, knowledge of the criteria conducive to the visual phenomenon known as simultaneous contrast is a critical component of the present study, therefore it is listed and explained here.

1. *Interaction of Color: New Complete Edition* (2009). As previously indicated, this carefully produced edition offers faithful color reproduction of Albers' original work. For this study, two examples were selected: one illustrated "one color as two," in which the same color appears as two contingent upon the adjacent and surrounding colors, and "two colors as one," in which two different colors appear to be more similar due to the effect of adjacent and surrounding colors.

2. Color-aid Papers, a commercially available set of 314 color papers commonly used by students in color studies classes, and recommended by Albers himself (Horowitz, 2006).

3. Color Measurement Hardware including:
   a. X-Rite i1 Pro 2 Spectrophotometer
   b. X-Rite SpectroEye Spectrophotometer

4. Software
   a. X-Rite i1 Profiler (otherwise known as i1 Publish) for ICC-Profile based color management
   b. X-RiteColor Master QA Master II, a color database
   c. Adobe Photoshop
   d. Microsoft Excel

5. Standardized color viewing: A GTI Color Matcher Standardized Viewing Booth

6. Computer monitor display: color-managed NEC PA242 Monitor for soft proofing

7. Inkjet Printer: Epson SureColor P5000

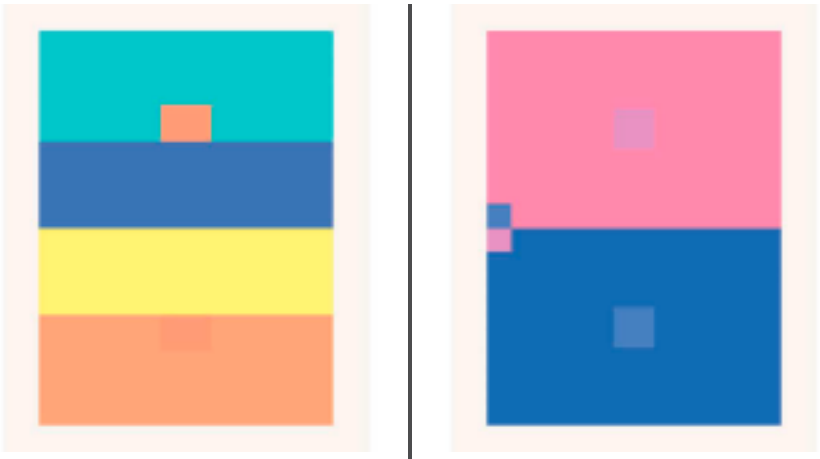
8. Knowledge about simultaneous contrast. Long (2015) defined simultaneous contrast as "[what] happens when a color is touching or, especially, is surrounded by another color. In this phenomenon, vision helps interpret and differentiate what is seen, by heightening or exaggerating the difference between colors, and the adjustments are made in hue, value, and chroma to both colors" (p. 47). In addition, Hoskin (2019), outlined the following criteria regarding simultaneous contrast:
   - Adjacent colors shift toward the complement of the other;
   - Mixed hues are more influenced than pure hues;
   - Dull colors change more easily than bright;
   - Light values are easier to change;
   - Strong contrast will create more extreme change (value); and
   - Less contrast results in less change.

## Methods

The first research question evaluates the ability of a color managed inkjet printer to effectively recreate examples from *Interaction of Color* (2009). The following steps were taken:

- Select and measure illustrations from Interaction of Color
- Recreate the illustrations using Adobe Photoshop
- Profile the inkjet printer
- Output the Photoshop illustrations on the color-managed inkjet printer
- Visually evaluate the results in standardized viewing condition
- Adjust and re-output the results if needed

An example illustrating "two colors as one" and an example illustrating "one color as two" were selected from *Interaction of Color* (2009), representations of these are illustrated in Figure 1.



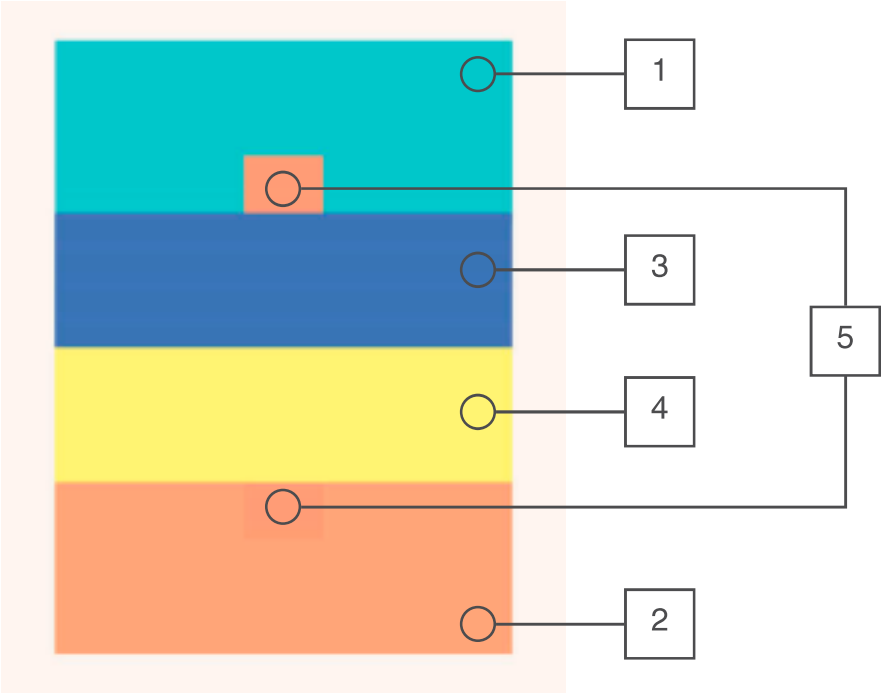
'One Color as Two': Colors in small squares are the same but appear different because of their different backgrounds and other relative conditions.

'Two Colors as One': Colors in small squares are different but appear similar because of their different backgrounds and other relative conditions.

***Figure 1.*** *Illustrations from Interaction of Color (2009) used in the present study.*

Using the X-Rite SpectroEye, CIELAB colorimetric values at D50/2° were measured from the illustrations in *Interaction of Color* (2009) and the values were recorded.

The researcher measured the dimensions of elements which comprise the illustrations. Using Adobe Photoshop, wire frame outlines were created at the same size as the original illustrations, which were subsequently filled with colors at the same CIELAB values as were measured, as illustrated in Table 1.

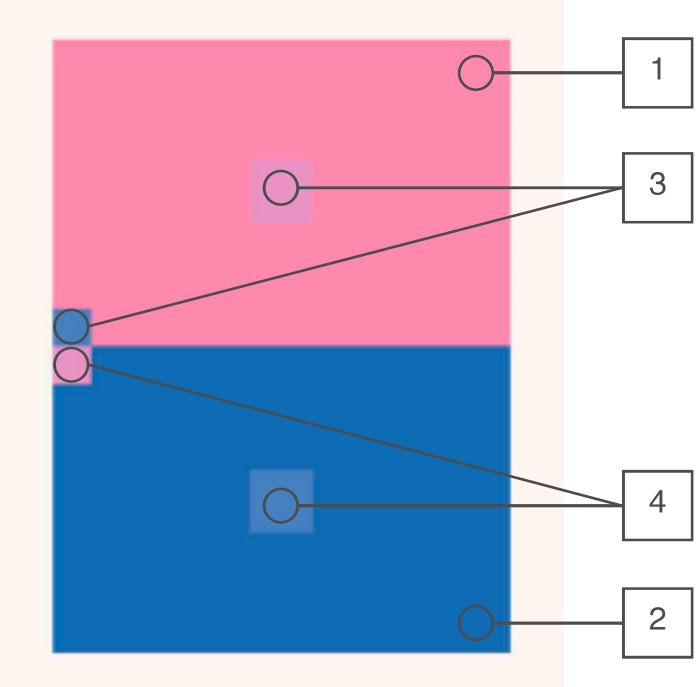



| | L* | a* | b* | C* | h° |
|---|---|---|---|---|---|
| 1. | 64.67 | -28.10 | -14.13 | 31.45 | 206.69 |
| 2. | 69.06 | 24.67 | 49.36 | 55.19 | 63.45 |
| 3. | 40.31 | 6.77 | -31.67 | 32.38 | 282.07 |
| 4. | 90.78 | -8.3 | 63.13 | 63.68 | 97.49 |
| 5. | 63.29 | 15.54 | 29.37 | 33.22 | 62.14 |

***Table 1.*** *Colorimetric Readings from Interaction of Color (2009)*

'One Color as Two': When separated by the highly chromatic, contrasting yellow and blue (#3 and #4), and placed against different backgrounds (#1 and #2), color #5 appears to be two different colors. Note that color #5 can be described as "mixed" and "achromatic."

**‘Two Colors as One’**



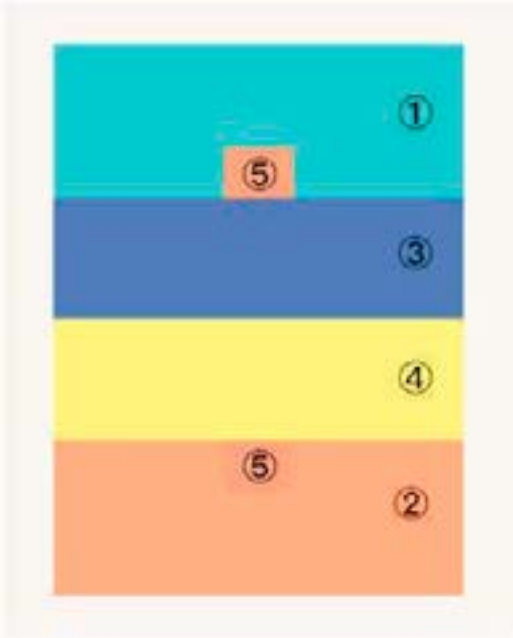

| | L* | a* | b* | C* | h° |
|---|---|---|---|---|---|
| 1. | 67.87 | 36.79 | 2.00 | 36.85 | 3.12 |
| 2. | 34.44 | 7.75 | -29.48 | 30.48 | 284.73 |
| 3. | 66.78 | 24.64 | -6.97 | 25.60 | 344.21 |
| 4. | 45.10 | 2.50 | -27.24 | 27.34 | 275.23 |

‘Two Colors as One’: When looking at the middle of the illustration, the small squares (#3 and #4) appear similar. On the far left, these same colors are placed next to each other where the differences are more noticeable. Note that colors #3 and #4 can be described as “mixed” and “achromatic.”

A limitation is noted here: Adobe Photoshop is not intended to be used for precise colorimetric applications. CIELAB values in Photoshop are input in whole numbers only, whereas the SpectroEye reports colorimetric values in two decimal places. In addition, Photoshop does not support the selection of illumination and observer values.

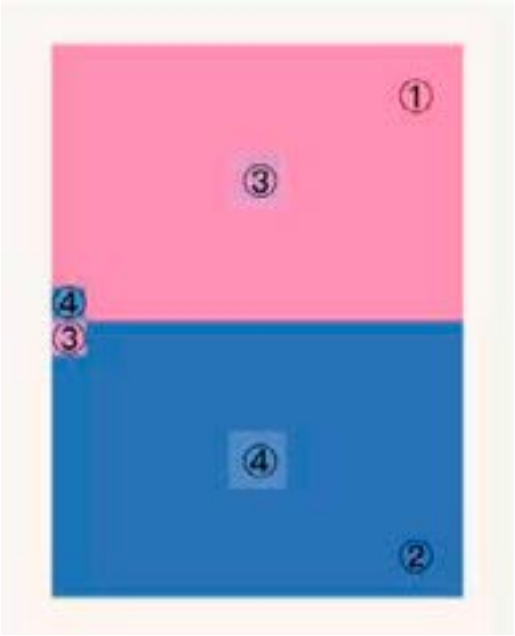
To profile the inkjet printer, a method described by Ashe (2014) was employed using the X-Rite i1 Profiler software and the i1 Pro 2 spectrophotometer. All of the output in the present study was completed using the printer driver only, as such, an RGB profile was built. While it is recognized that a Raster Image Processor (RIP) may have offered more accurate color management, the researchers chose to utilize lower-cost options as they will be more accessible in many classroom environments.

Once the Photoshop illustrations were output on the profiled inkjet printer and allowed to dry, they were evaluated in the standardized viewing condition. It was noted that some of the colors were visually good matches to the original from Interaction of Color (2009), while others exhibited more difference. As these examples represent a limited number of solid colors, the respective target CIELAB values in Photoshop were adjusted to obtain a better match. After two such iterations for each illustration, the results provided a good visual match to the originals. Colorimetric data from the resulting prints are compared to data from in Interaction of Color (2009) is reproduced in Tables 2 and 3.




| Color | *Interaction of Color (2009)* | | | | |
|---|---|---|---|---|---|
| | L* | a* | b* | C* | h° |
| 1. | 64.67 | -28.10 | -14.13 | 31.45 | 206.69 |
| 2. | 69.06 | 24.67 | 49.36 | 55.19 | 63.45 |
| 3. | 40.31 | 6.77 | -31.67 | 32.38 | 282.07 |
| 4. | 90.78 | -8.3 | 63.13 | 63.68 | 97.49 |
| 5. | 63.29 | 15.54 | 29.37 | 33.22 | 62.14 |
| Color | Optimized Inkjet | | | | |
| | L* | a* | b* | C* | h° |
| 1. | 63.35 | -28.25 | -15.99 | 32.47 | 209.51 |
| 2. | 68.20 | 25.68 | 48.92 | 55.25 | 62.3 |
| 3. | 39.05 | 0.53 | -29.58 | 29.58 | 271.03 |
| 4. | 88.14 | -4.33 | 67.58 | 67.71 | 93.67 |
| 5. | 62.48 | 15.38 | 29.02 | 32.84 | 62.08 |
| Color | Difference | | | | |
| | ΔL* | Δa* | Δb* | ΔC* | Δh° |
| 1. | -1.23 | 0.15 | -1.86 | 1.02 | 2.82 |
| 2. | -0.86 | 1.01 | -0.44 | 0.06 | -1.15 |
| 3. | -1.26 | -6.24 | 2.09 | -2.8 | -11.04 |
| 4. | -2.64 | 3.97 | 4.45 | 4.03 | -3.82 |
| 5. | -0.81 | -0.16 | -0.35 | -0.38 | -0.06 |

***Table 2.*** *Colorimetric readings from 'One Color as Two' from Interaction of Color (2009)*




| Color | *Interaction of Color (2009)* | | | | |
|---|---|---|---|---|---|
| | L* | a* | b* | C* | h° |
| 1. | 67.87 | 36.79 | 2.00 | 36.85 | 3.12 |
| 2. | 34.44 | 7.75 | -29.48 | 30.48 | 284.73 |
| 3. | 66.78 | 24.64 | -6.97 | 25.60 | 344.21 |
| 4. | 45.10 | 2.50 | -27.24 | 27.34 | 275.23 |
| Color | Optimized Inkjet | | | | |
| | L* | a* | b* | C* | h° |
| 1. | 65.86 | 35.64 | 7.82 | 36.49 | 12.37 |
| 2. | 33.81 | 7.45 | -35.65 | 36.42 | 281.80 |
| 3. | 66.79 | 24.78 | -4.10 | 25.11 | 350.61 |
| 4. | 44.36 | 5.13 | -25.04 | 25.56 | 281.58 |
| Color | Difference | | | | |
| | ΔL* | Δa* | Δb* | ΔC* | Δh° |
| 1. | 2.01 | 1.15 | 5.82 | 0.36 | 9.25 |
| 2. | 0.63 | 0.30 | 6.17 | 5.94 | -2.93 |
| 3. | 0.01 | 0.14 | 2.87 | 0.49 | 6.40 |
| 4. | 0.74 | 2.63 | 2.20 | 1.78 | 6.35 |

***Table 3.*** *Colorimetric readings from 'Two Colors as from Interaction of Color (2009)*

Turning to the second research question, which applies colorimetry to the selection of Color-aid papers, the same colorimetric target values from *Interaction of Color* (2009) as used for the first research question were employed. In addition, colorimetric values from each of the 314 Color-aid paper samples were measured with the X-Rite SpectroEye and input into the X-RiteColor Master QA Master II database. These values were also exported to Microsoft Excel for analysis.

Two strategies were employed to use the colorimetric values to select the optimum Color-aid papers. The first involves simply selecting the lowest $\Delta E_{00}$ Color-aid paper from the target colorimetric values for each color in the respective illustrations, this is referred to as the "lowest ΔE" method. The second method involves selecting "anchor color(s)" for each illustration from the Color-aid, and then selecting the other colors based on the colorimetric relationship of those "anchors" to the other colors, consistent with the colorimetric relationships in *Interaction of Color*. This is referred to as the "anchor color" method. Once the Color-aid papers were selected for each method, the colorimetric values of the respective Color-aid papers were input into the Photoshop wireframes, and the results were evaluated as soft proofs on the color managed NEC monitor.

### Lowest $\Delta E_{00}$ Method

The general steps of the lowest $\Delta E_{00}$ method were as follows:

Step 1: Search the X-RiteColor Master QA Master II database for the lowest $\Delta E_{00}$ (i.e., the colorimetric values obtained from the illustrations in *Interaction of Color* (2009) were used to search for the closest Color-Aid in the Color Master database); in this instance, Color-aid papers within ten $\Delta E_{00}$ are reported;

Step 2: Add the obtained L*a*b* colorimetric values from the respective lowest $\Delta E_{00}$ Color-aid into Photoshop wireframes.

Step 3: Soft-proof and analyze results (i.e., calibrate NEC Monitor using i1 Profiler and i1 Pro 2, compare soft proof of Photoshop wireframes containing colorimetric values of selected Color-aid to those from the 2009 new complete edition of *Interaction of Color*).

Data collected in this experiment appear in Tables 4 and 5

| | *IoC** Color #1 | Color-aid BG-T3 | Δ | C-T3 Color-aid | Δ | Color-aid | |
|---|---|---|---|---|---|---|---|
| L* | 34.67 | 70.73 | 6.06 | 71.45 | 6.78 | | |
| a* | -28.1 | -33.83 | -5.73 | -28.95 | -0.85 | | |
| b* | -14.13 | -14.61 | -0.48 | -19.81 | -5.68 | | |
| C* | 31.45 | 36.86 | 5.41 | 35.08 | 3.63 | | |
| h° | 206.69 | 203.36 | -3.33 | 214.38 | 7.69 | | |
| $\Delta E_{00}$ | | | 5.43 | | 6.21 | | |
| | **Color #2** | **O-P1-1** | **Δ** | | | | |
| L* | 69.06 | 70.36 | 1.3 | | | | |
| a* | 24.67 | 26.77 | 2.1 | | | | |
| b* | 49.36 | 50.74 | 1.38 | | | | |
| C* | 55.19 | 57.37 | 2.18 | | | | |
| h° | 63.45 | 62.18 | -1.27 | | | | |
| $\Delta E_{00}$ | | | 1.44 | | | | |
| | **Color #3** | **V-P1-1** | **Δ** | **B-P1-1** | **Δ** | | |
| L* | 40.31 | 42.37 | 2.06 | 42.16 | 1.85 | | |
| a* | 6.77 | 8.51 | 1.74 | -1.07 | -7.84 | | |
| b* | -31.67 | -26.08 | 5.59 | -36.59 | -4.92 | | |
| C* | 32.38 | 27.44 | -4.95 | 36.61 | 4.23 | | |
| h° | 282.07 | 288.07 | 6 | 268.32 | -13.75 | | |
| $\Delta E_{00}$ | | | 4.84 | | 8.10 | | |
| | **Color #4** | **YC-T1** | **Δ** | **Y-T1** | **Δ** | | |
| L* | 90.78 | 89.95 | -0.83 | 89.55 | -1.23 | | |
| a* | -8.3 | -9.15 | -0.85 | -0.78 | 7.52 | | |
| b* | 63.13 | 61.87 | -1.26 | 65.9 | 2.77 | | |
| C* | 63.68 | 62.54 | -1.14 | 65.9 | 2.22 | | |
| h° | 97.49 | 98.41 | 0.92 | 90.68 | -6.81 | | |
| $\Delta E_{00}$ | | | 0.86 | | 4.81 | | |
| | **Color #5** | **O-P2-2** | | **ROP22** | | **YOP31** | |
| L* | 63.29 | 65.49 | 2.17 | 62.59 | -0.7 | 55.97 | -7.32 |
| a* | 15.54 | 17.1 | 1.56 | 23.3 | 7.76 | 9.66 | -5.88 |
| b* | 29.37 | 33.35 | 3.98 | 25.57 | -3.8 | 30.43 | 1.06 |
| C* | 33.22 | 37.48 | 4.26 | 34.59 | 1.37 | 31.92 | -1.3 |
| h° | 62.14 | 62.86 | 0.72 | 47.65 | -14.49 | 72.39 | 10.25 |
| $\Delta E_{00}$ | | | 2.46 | | 6.61 | | 7.99 |

**IoC* refers to *Interaction of Color (2009)***

***Table 4.*** *Closest Color-aid in Color Master Database ('One Color as Two').*

| | *IoC** Color #1 | Color-aid RC-T3 | Δ | Color-aid RC-T4 | Δ | Color-aid | |
|---|---|---|---|---|---|---|---|
| L* | 67.87 | 70.95 | 3.08 | 75.24 | 7.37 | | |
| a* | 36.79 | 45.56 | 8.77 | 35.07 | -1.72 | | |
| b* | 2 | 7.29 | 5.29 | 6.7 | 4.7 | | |
| C* | 36.85 | 46.14 | 9.29 | 35.7 | -1.15 | | |
| h° | 3.12 | 9.09 | 5.79 | 10.81 | 7.69 | | |
| $\Delta E_{00}$ | | 4.72 | | 6.33 | | | |
| | **Color #2** | **V-S1** | **Δ** | **V-P1-1** | **Δ** | | |
| L* | 34.44 | 32.01 | -2.43 | 42.37 | 7.93 | | |
| a* | 7.75 | 9.17 | 1.42 | 8.51 | 0.76 | | |
| b* | -29.48 | -22.2 | 7.28 | -36.08 | -6.6 | | |
| C* | 30.48 | 24.02 | -6.46 | 27.44 | -3.04 | | |
| h° | 284.73 | 292.45 | 7.72 | 288.07 | 3.34 | | |
| $\Delta E_{00}$ | | 5.83 | | 7.29 | | | |
| | **Color #3** | **MP-1-2** | **Δ** | **MP-2-2** | **Δ** | | |
| L* | 66.78 | 73.75 | 6.97 | 61.02 | -5.76 | | |
| a* | 24.64 | 21.17 | -3.47 | 22.2 | -2.37 | | |
| b* | -6.97 | 0.65 | 7.62 | 0.92 | 7.89 | | |
| C* | 25.6 | 21.18 | -4.42 | 22.29 | -3.31 | | |
| h° | 344.21 | 1.76 | 342.45 | 2.37 | -341.84 | | |
| $\Delta E_{00}$ | | 7.64 | | 7.3 | | | |
| | **Color #4** | **V-P1-1** | **Δ** | **BP1-1** | **Δ** | **BP2-1** | **Δ** |
| L* | 45.1 | 42.37 | -2.73 | 42.16 | -2.94 | 38.7 | -6.4 |
| a* | 2.5 | 8.51 | 6.01 | -1.07 | -3.57 | -3.26 | 5.76 |
| b* | -27.24 | -26.08 | 1.16 | -36.59 | -9.35 | -20.22 | 7.02 |
| C* | 27.34 | 27.44 | 0.1 | 36.61 | 9.27 | 20.48 | -6.86 |
| h° | 275.23 | 288.07 | 12.84 | 268.32 | -6.91 | 260.84 | -14.39 |
| $\Delta E_{00}$ | | 6.15 | | 6.99 | | 7.38 | |

**IoC* refers to *Interaction of Color (2009)***

***Table 5.*** *Closest Color-aid in Color Master Database ('Two colors as one')*

**Anchor Color Method**

The next steps involved selecting an "anchor" color or colors from the Color-aid set, and then selecting the rest of the colors based on the relationships of the other colors to those "anchors" in the original illustration from *Interaction of Color* (2009).

The general steps of the anchor color method were as follows:

Step 1: Examine the lowest $\Delta E_{00}$ colorimetric data collected to select anchor color(s) for the respective illustrations.

Step 2: Examine the relationships between the anchor color(s) and other colors displayed in *Interaction of Color* (2009). Knowledge of simultaneous contrast from Hoskin (2019) and Long (2015) are used in to guide these selections.

Step 3: Search the Color-aid database for samples that best represent the relationship to the anchor color(s). In this step, the colorimetric relationships (i.e.: $\Delta L^*$, $\Delta a^*$, $\Delta b^*$) from *Interaction of Color* (2009) are applied to the selected anchor color to obtain a theoretical colorimetric standard representing the measured relationship to the selected anchor color. This theoretical colorimetric standard is then used to search the Color-aid database for the Color-aid samples that best represent the relationship to the selected anchor color.

Step 4: The selected colorimetric values from the Color-aid database are added into Photoshop wireframes.

Step 5: The resulting Photoshop wireframe is soft-proofed and analyzed results (i.e., NEC Monitor calibrated and profiled using i1 Profiler and i1 Pro 2, the resulting soft proof of the Photoshop wireframes containing colorimetric values of selected Color-aid are compared to those from the 2009 new complete edition of *Interaction of Color*).

These general steps are illustrated in Figure 2.

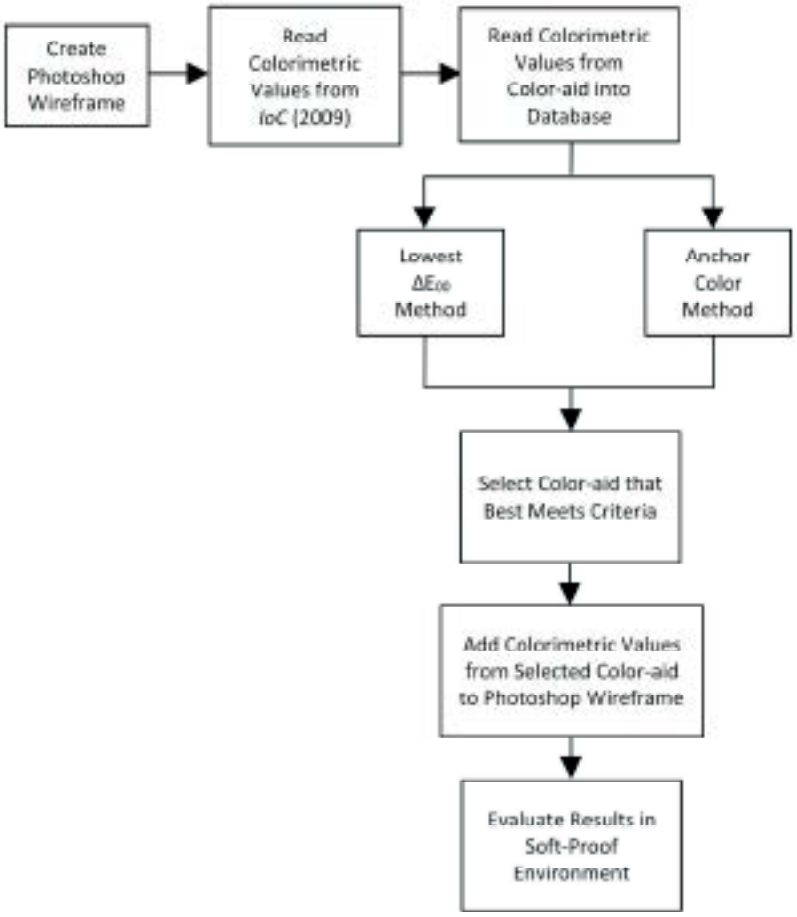



***Figure 2.*** *General Procedure for Colorimetric Selection of Color-aid Papers*

**Anchor Color Method: 'One Color as Two'**

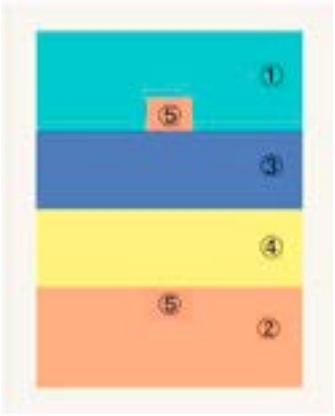
In the case of 'One Color as Two,' the decision to select three anchor colors from the Color-aid set was made. This was due to the nature of the highly chromatic blue and yellow (colors #3 and #4 in the present illustration, as reproduced in Table 6). The function of these two colors in the present illustration was to separate and influence color that appears as two (#5 in the present illustration). The yellow, in particular, had a Color-aid sample that was nearly identical to the *Interaction of Color* (2009) illustration in the Color-aid set ($\Delta E_{00}$ = 0.86). Of the two Color-aid blues within ten ΔE00 of the Interaction of Color (2009) illustration, the one perceived as the purest blue was chosen ($\Delta E_{00}$ = 04.84, Color-aid VP1-1 L*=42.37, a*=8.51, b*=-26.08, C*=27.44, h°= 288.07). Color-aid #O-P1-1 was selected to represent the orange (#2 in the illustration), as it exhibited the lowest $\Delta E_{00}$-of the remaining Color-aid choices when compared to *Interaction of Color* (2009), as illustrated in Table 4.


| | *IoC* Color #2 | O-P1-1 | Δ |
|---|---|---|---|
| L* | 69.06 | 70.36 | 1.3 |
| a* | 24.67 | 26.77 | 2.1 |
| b* | 49.36 | 50.74 | 1.38 |
| C* | 55.19 | 57.37 | 2.18 |
| h° | 63.45 | 62.18 | -1.27 |
| $\Delta E_{00}$ | | | 1.44 |
| | ***IoC*** **Color #3** | **V-P1-1** | **Δ** |
| L* | 40.31 | 42.37 | 2.06 |
| a* | 6.77 | 8.51 | 1.74 |
| b* | -31.67 | -26.08 | 5.59 |
| C* | 32.38 | 27.44 | -4.95 |
| h° | 282.07 | 288.07 | 6 |
| $\Delta E_{00}$ | | | 4.84 |
| | ***IoC*** **Color #4** | **YC-T1** | **Δ** |
| L* | 90.78 | 89.95 | -0.83 |
| a* | -8.3 | -9.15 | -0.85 |
| b* | 63.13 | 61.87 | -1.26 |
| C* | 63.68 | 62.54 | -1.14 |
| h° | 97.49 | 98.41 | 0.92 |
| $\Delta E_{00}$ | | | 0.86 |

***Table 6.*** *Anchor Colors Selected for 'One Color as Two'*

To search for the remaining potential Color-aid colors, the original color relationships were needed. These figures were based on the relationship between Color #1 and Color #3; Color #2 and Color #5, and Color #1 and Color #5.

Using the colorimetric Color-aid anchor color O-P1-1 (representing Color #2) and the Color-aids selected for colors #3 and #4 (V-P1-1 and YC-T1, respectively), the colorimetric relationships were used to create a theoretical colorimetric standard, which was subsequently used to search the Color-aid database for those Color-aid samples for the closest that exhibit the colorimetric relationships illustrated in *Interaction of Color* (2009). These are illustrated in Table 7.




The highly chromatic blue (#3) and yellow (#4) were selected from the Color-aid set, the orange (#2) was selected as an anchor color using Color-aid #O-P1-1. Once selected, the colorimetric relationships between colors #1 and #3; #2 and #5; and #1 and #5 were be determined and implemented. The relationship from *Interaction of Color* (2009) is then applied to the Color-aid anchor colorimetric values, which was used as a theoretical standard with which to search the Color-aid database for the closest papers to that theoretical standard. Matches within ten $\Delta E_{00}$ are reported.

| Colorimetric Relationships from *IoC*, Colors #1 and #3 | | | |
|---|---|---|---|
| | *IoC* Color #1 | *IoC* Color #3 | Relationship |
| L* | 64.67 | 40.31 | -24.36 |
| a* | -28.10 | 6.77 | 34.87 |
| b* | -14.13 | -31.67 | -17.54 |

| | #3 Anchor Color-aid V-P1-1 | Relationship | Theoretical Standard | Color-aid BGP 2-2 |
|---|---|---|---|---|
| L* | 66.73 | -24.36 | 42.37 | 62.34 |
| a* | -36.36 | 34.87 | 8.51 | -21.89 |
| b* | -8.54 | -17.54 | -26.08 | -4.54 |

| Colorimetric Relationships from *IoC*, Colors #2 and #5 | | | |
|---|---|---|---|
| | *IoC* Color #2 | *IoC* Color #5 | Relationship |
| L* | 69.06 | 63.29 | -5.77 |
| a* | 24.67 | 15.54 | -9.13 |
| b* | 49.36 | 29.37 | -19.99 |

| | #2 Anchor Color-aid O-P1-1 | Relationship | Theoretical Standard | Color-aid O-P2-2 | Color-aid YOP2-1 | Color-aid RO-P2-2 |
|---|---|---|---|---|---|---|
| L* | 70.36 | -5.77 | 64.59 | 65.46 | 64.04 | 62.59 |
| a* | 26.77 | -9.13 | 17.64 | 17.10 | 12.47 | 23.30 |
| b* | 50.74 | -19.99 | 30.75 | 33.35 | 40.21 | 25.57 |

| Colorimetric Relationships from *IoC*, Colors #1 and #5 | | | |
|---|---|---|---|
| | *IoC* Color #1 | *IoC* Color #5 | Relationship |
| L* | 64.67 | 63.29 | 1.38 |
| a* | -28.10 | 15.54 | 43.64 |
| b* | -14.13 | 29.37 | 43.50 |

| | #1 Anchor Color-aid BGP2-2 | Relationship | Theoretical Standard | Color-aid O-P2-2 | Color-aid YOP2-1 |
|---|---|---|---|---|---|
| L* | 62.34 | 1.38 | 63.72 | 65.46 | 64.04 |
| a* | -21.89 | 43.64 | 21.75 | 17.10 | 12.47 |
| b* | -4.54 | 43.50 | 48.04 | 33.35 | 40.21 |

***Table 7.*** *Searched Potential Color-aid, 'One Color as Two'*

As indicated in Table 7, the relationship between colors #1 and #3 in *Interaction of Color* (2009) along with the previously selected anchor Color-aid representing color #3 were used to create a theoretical colorimetric standard to search the database and select a Color-aid best representing this relationship. In this case, only one Color-aid was within ten $\Delta E_{00}$, namely BGP2-2. This color was therefore selected to represent color #1.

Looking at the relationship between colors #2 and #5 from *Interaction of Color* (2009), a similar procedure was used based on the previously selected Color-aid representing color #2. In this case, three examples were within ten $\Delta E_{00}$: Color-aid numbers O-P2-2, YOP2-1, and RO-P2-2. As color #5 is the most critical, the next step examined the relationship between colors #1 and #5, using the previously selected Color-aid BGP2-2 for color #1. Here, two samples were within ten $\Delta E_{00}$: O-P2-2 and YOP2-1. The decision was therefore made to select Color-aid O-P2-2 to represent color #5, as this color exhibited the closest relationships between colors #1 and #2 as expressed in *Interaction of Color* (2009) given the selected anchor Color-aid selections.

**Anchor color method: 'Two Colors as One'**

Turning to the 'Two Colors as One' illustration, a similar procedure was followed except in this case only one anchor color was selected. As shown in Table 5, the closest $\Delta E_{00}$ match to any of the colors in this illustration from *Interaction of Color*(2009) was Color-aid RCT3 as matched to Color #1, this therefore became the anchor.

To search for potential Color-Aid colors, the original color relationships were needed. These relationships were based on those between colors #1 and #2, colors #2 and #3, and colors #2 and #4.


The Color-aid with the lowest ΔE00 to any of the four colors in this illustration was selected as the anchor, namely Color-aid RCT3 as color #1. Once selected, the colorimetric relationships between colors #1 and #2; #1 and #3; and #2 and #4 were be determined and implemented. The relationship from *Interaction of Color* (2009) is then applied to the Color-aid anchor colorimetric values, which was used as a theoretical standard with which to search the Color-aid database for the closest papers to that theoretical standard. Matches within ten $\Delta E_{00}$ are reported.

| Colorimetric Relationships from *IoC*, Colors #1 and #2 | | | |
|---|---|---|---|
| | *IoC* Color #1 | *IoC* Color #2 | Relationship |
| L* | 67.87 | 34.44 | -33.43 |
| a* | 36.79 | 7375 | -29.04 |
| b* | 2.00 | -29.48 | -31.48 |

| | #1 Anchor Color-aid RCT3 | Relationship | Theoretical Standard | Color-aid V-S1 |
|---|---|---|---|---|
| L* | 70.95 | -33.43 | 37.52 | 32.01 |
| a* | 45.56 | -29.04 | 16.52 | 9.17 |
| b* | 7.29 | -31.48 | -24.19 | -22.20 |

| Colorimetric Relationships from *IoC*, Colors #1 and #3 | | | |
|---|---|---|---|
| | *IoC* Color #1 | *IoC* Color #3 | Relationship |
| L* | 67.87 | 66.78 | -1.09 |
| a* | 36.79 | 24.64 | -12.15 |
| b* | 2.00 | -6.97 | -8.97 |

| | #1 Anchor Color-aid RCT3 | Relationship | Theoretical Standard | Color-aid RCT4 |
|---|---|---|---|---|
| L* | 70.95 | -1.09 | 69.86 | 75.24 |
| a* | 45.56 | -12.15 | 33.41 | 35.07 |
| b* | 7.29 | -8.97 | -1.68 | 6.70 |

| Colorimetric Relationships from *IoC*, Colors #2 and #4 | | | |
|---|---|---|---|
| | *IoC* Color #2 | *IoC* Color #4 | Relationship |
| L* | 34.44 | 45.10 | 10.66 |
| a* | 7.75 | 2.50 | -5.25 |
| b* | -29.48 | -27.24 | -2.24 |

| | #2 Anchor Color-aid V-S1 | Relationship | Theoretical Standard | Color-aid V-P1-1 |
|---|---|---|---|---|
| L* | 32.01 | 10.66 | 42.67 | 42.37 |
| a* | 9.17 | -5.25 | 3.92 | 8.51 |
| b* | -22.20 | -2.24 | -24.44 | -26.08 |

***Table 8.*** *Searched Potential Color-aid, 'One Color as Two'*

As illustrated in Table 8, once Color-aid RCT3 was selected representing color #1, and the relationship between colors #1 and #2 from *Interaction of Color* (2009) was calculated and applied to create a theoretical standard with which to search the database, only one Color-aid was within ten $\Delta E_{00}$, namely V-S1. This color was therefore selected to represent color #2.

Similar procedures were then applied to select color #3, where the relationship between colors #1 and #3 yielded only one Color-aid sample within ten $\Delta E_{00}$ to represent color #3: Color-aid # RCT-4. Likewise, with Color-aid #V-S1 representing color #2, factoring the differences from *Interaction of Color* (2009) to search the database resulted in one Color-aid sample to represent color #4, which was V-P1-1. The next step was to add the colorimetric values from the selected Color-aid samples to the respective Photoshop wireframes, and to soft proof and analyze the outcome, as discussed in the Results section.

## Results

For the first research question, after two iterations with a profiled inkjet printer good visual matches were obtained for both the "one color as two" and "two colors as one" illustrations. Relevant colorimetric values are shown in Tables 2 and 3. This indicates that color managed inkjet printers can be used to effectively replicate the simultaneous contrast phenomena displayed in Interaction of Color.

To address the second research question, the methods described were utilized to select representative Color-aid samples to represent the colors in *Interaction of Color* (2009), namely, by selecting the lowest $\Delta E_{00}$ for each color and alternatively by selecting Color-aid anchor color or colors and then selecting the remaining Color-aid samples based on the relationships

expressed in the original volume. The resulting selected Color-aid numbers for each method are illustrated in Tables 9 and 10.

### *One Color as Two*

Upon comparing the lowest $\Delta E_{00}$ method and 'anchor color with relationships' method in the 'One Color as Two' case, the lowest ΔE00 Color-aid selections better represented simultaneous contrast as seen in *Interaction of Color* (2009).

### *Two Colors as One*

Upon comparing the lowest $\Delta E_{00}$ method and 'anchor color with relationships' method in the 'Two Colors as One' case, the 'anchor color with relationships' method Color-aid selections better represented simultaneous contrast as seen in *Interaction of Color* (2009).


| Color # | Lowest $\Delta E_{00}$ method | Anchor color method |
|---|---|---|
| 1 | BG-T3 | BG-P2 |
| 2 | O-P1-1 | O-P1-1 |
| 3 | V-P1-1 | V-P1-1 |
| 4 | Yc-T1 | Yc-T1 |
| 5 | O-P2-2 | O-P2-2 |

***Table 9.*** *Resulting Color-aid selections for lowest $\Delta E_{00}$ and anchor-color method: One Color as Two*


| Color # | Lowest $\Delta E_{00}$ method | Anchor color method |
|---|---|---|
| 1 | RC-T3 | RC-T3 |
| 2 | V-S1 | V-S1 |
| 3 | M-P1-1 | Rc-T4 |
| 4 | V-P1-1 | V-P1-1 |

***Table 10.*** *Resulting Color-aid selections for lowest $\Delta E_{00}$ and anchor-color method: Two Colors as One*

## Conclusions

Research question one asked: "Can a color managed inkjet printer effectively recreate examples from *Interaction of Color* (2009)? The present study indicates that, indeed, today's inkjet printing technology and widely available color management tools can be used to effectively to reproduce the simultaneous contrast examples in *Interaction of Color*.

The second research question asked: "Can colorimetry be used to effectively select optimal Color-aid papers to recreate the visual effects illustrated in *Interaction of Color* (2009)?" The results of the present study here do not support that using colorimetry to select color papers to represent simultaneous contrast is a substitute for visual analysis. Colorimetry, therefore, seems to be limited in its application in this context. The well-documented visual non-uniformity of the CIELAB colorspace is likely a factor here.

However, the results suggest that, as students can use color managed inkjet printers to replicate illustrations from *Interaction of Color*, they can effectively output colors to supplement gaps in the Color-aid assortment. This means that they do not need to turn to paint mixing when an ideal Color-aid sample is not available. This finding therefore supports the some goals of Albers' color studies curricula, namely that solutions should be simple, quick, practical and allow more choices.

**Limitations and Further Study**

In this experiment, the researcher did not compare the size and proximity of simultaneous contrast colors from the illustrations; however, it is documented these factors may influence the effects of simultaneous contrast. The present study only examined direct replications of Albers' work, in color studies classes students are typically shown these as examples only, and asked to replicate the effect using their own color combinations, shapes and proximities.

Therefore, as in the present study the researcher focused on quantitative color evaluation, subsequent research could include experiments related to the size and proximity of simultaneous contrast colors using psychophysical experiments and visual evaluation. Moreover, as previously noted, Photoshop is not a truly scientific colorimetric tool, and represents an important limitation, and the experiments in this study considered the printer driver exclusively, and no raster image processor was considered. Lastly, the selected illustrations were duplicated using Color-aid papers; no paint mixing or other emissive color methods (e.g., monitor, tablet, or phone) were considered. Finally, it is suggested that classroom studies could be developed to ascertain the efficacy of various applied teaching methods in real teaching environments. It is suggested that future researchers consider these factors in designing experiments in this domain.

References

Albers, J. (2009). *Interaction of color*. New Haven, CT: Yale University Press.

Ashe, T. (2014). *Color management & quality output: Working with color from camera to display to print*. Retrieved from https://ebookcentral.proquest.com

Barnes and Noble (2019, March 1). *Interaction of Color*. Retrieved from https://www.barnesandnoble.com/w/interaction-of-color-josef-albers/1125545061?ean=9780300179354.

Color-aid (2019, March 1.). *Color-aid*. Retrieved from https://coloraid.com/.

Fairchild, M. D. (2005). *Color appearance models* (2nd ed.). Hoboken, NJ: Wiley.

Horowitz, F. (2006). *Josef Albers: to open eyes: the Bauhaus, Black Mountain College, and Yale*. New York: Phaidon Press.

Hoskin, J. (2019). *Application of Albers' Interaction of Color to Color Evaluation.* GoToWebinar, January 9, 2019. Inter-Society Color Council.

Long, J. (2015). *The new Munsell student color set (Fourth Edition)*. New York: Fairchild Books.

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# Evaluation of Light Measurement Instruments

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# Evaluation of Light Measurement Instruments

Bruce Leigh Myers, Ph.D.

Keywords: Bland-Altman plot, Tukey mean difference plot, light measurement, correlated color temperature, standardized viewing, color rendering index

The International Standards Organization (ISO) defines standards to ensure that viewing conditions are consistent when evaluating printed samples through ISO 3665 (2009), Graphic technology and photography – viewing conditions. The need for this standard stems from the necessity for human visual assessment as the key arbiter of the quality of complex images, and the tendency for various lighting conditions to shift the appearance of a color, specifically in relation to other adjacent colors.

Among the conditions specified by ISO 3665 (2009) are Correlated Color Temperature (CCT) and Color Rendering Index (CRI). Berns (2000) describes CCT as "Temperature, usually expressed in kelvins, of a blackbody radiator that most closely resembles the color of a stimulus of equal brightness" (p. 4). Color rendering is described by Field (2004) at "…the degree to which a test illuminant (e.g., fluorescent light) renders colors similar in appearance to their appearance under a reference daylight illuminant of the same color temperature" (p. 4). A method for determining CRI is defined by the Commission Internationale de l'Éclairage (CIE) for a given light source. Field (2004) states: "The optimal CRI (that for daylight, or for such continuous sources as tungsten lamps) is given as 100" (p. 4). CRI is expressed as CRI Ra, with Ra representing the international standard for CRI as defined by CIE 13.3-1995.

Both CCT and CRI Ra are quantifiable by a range of instruments, including traceable Spectroradiometers specifically designed for the purpose, general-use Spectrophotometers that can read CCT and CRI Ra, and handheld instruments designed for photographic applications that measure CCT.

The present study seeks to compare readings from a traceable Spectroradiometer with those from various other meters across a range of seven viewing booths, some of which are known to be out of specification. The goal is to ascertain how much variance can be expected when using these varied meters when compared to a

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traceable benchmark instrument. For the purposes of this study, the benchmark instrument is referred to as the reference instrument, and the other measurement devices are the test instruments. The instruments used in this study are detailed on Table 1.

| Meter | Metrics Measured | |
|---|---|---|
| Reference Instrument | | |
| SpectriLight ILT950 Spectroradiometer International Light Technologies, NIST Traceable/ISO17025 Accredited Calibration | CCT | CRI Ra |
| Test Instruments | | |
| X-Rite i1 Pro 2 Spectrophotometer | CCT | CRI Ra |
| Minolta Color Meter IIIF | CCT | |
| LUXI and Cine Meter II App / Mobile Phone Based Solution | CCT | |
| Gossen SixtiColor (1957) | CCT | |

***Table 1.*** *Measurement Instruments*

To determine the variability of the seven viewing booths used, at least 10 readings were taken with the SpectriLight ILT 950 in each booth, as illustrated in Table 2. As ISO 3665 (2009) mandates a CRI Ra value over 90, it is noted that booths 1 and 2 are in compliance, booths 3,4, and 5 are nearly out of specification for that metric, and booths 6 and 7 are well out of compliance. This level of variance represents a range of variability that provides a means to compare the instruments tested across dissimilar viewing conditions.

| Booth # | *n* | CCT Mean | CCT *SD* | CRI Ra Mean | CRI Ra *SD* |
|---|---|---|---|---|---|
| 1 | 30 | 4844.73 | 18.92 | 94.58 | 0.17 |
| 2 | 30 | 4816.03 | 10.47 | 96.28 | 0.06 |
| 3 | 10 | 4843.30 | 33.67 | 92.58 | 0.46 |
| 4 | 10 | 5024.80 | 11.23 | 91.29 | 0.14 |
| 5 | 10 | 4751.80 | 75.20 | 90.32 | 1.30 |
| 6 | 10 | 4589.20 | 32.55 | 83.18 | 0.55 |
| 7 | 10 | 4589.50 | 39.67 | 82.29 | 0.44 |

***Table 2.*** *Mean and Standard Deviation of CCT and CRI Ra of Light Booths as measured with ILT950*

For a test instrument, measurement technique cannot be considered accurate unless measurements of a particular variable by the test instrument agrees closely with a reference instrument across all applied instances. A graphical approach to analyzing the comparison of a test and reference method that addresses these concerns as advanced by Bland and Altman (1986) and is referred to as the Bland-Altman (B-A) plot, and alternatively known as the Tukey Mean-Difference plot. Bland and Altman are credited with popularizing the use of this technique, and in the words of Earthman (2015): "They did not invent the method, but they advocated its application to the comparison of medical devices, laboratory tests, and other clinical techniques to ascertain bias in one method compared with another" (p. 794).

A B-A plot illustrates the mean difference between the two methods on the x-axis, and difference between paired readings of the two methods on the y-axis includes calculations of limits of agreement (LOA) when applicable (typically described as mean difference +/- 1.96 standard deviation to represent 95% confidence).

The procedure for comparison is to first calculate the difference between the two methods as a new variable, and then to conduct a one sample *t*-test on this result to examine a potential systematic bias. When examining CRI Ra, 95% LOAs are calculated to visually analyze how far apart measurements are likely for most applications; these LOAs are determined by multiplying the standard deviation of mean difference by 1.96, and then adding/subtracting the resulting value from the mean difference.

**Comparison of the ILT950 with the X-Rite i1 Pro 2**

For this analysis, three different i1 Pro2's were used with the results averaged to compare to the ILT950. One hundred ten readings for each instrument were taken across the viewing seven booths. CCT and CRI Ra metrics were evaluated.

**Correlated Color Temperature**

A one-sample t-test was conducted to ascertain if the mean difference is significantly different than zero. The mean difference between the ILT950 and the average of the i1Pro 2 instruments ($M$ =138.67, $SD$ = 72.45) was significantly higher than zero $t(109) = 20.03$, $p < .001$.

A visual evaluation of the B-A plot shown in Figure 1 suggests that variation is dependent upon the magnitude of measurement. Readings nearer to 5,000 kelvins appear to have less variance than those further below, and readings above the 5,000 kelvins mark appear to be nearer to zero as shown by the dashed line in the plot. Across a range of viewing conditions, however, the results suggest that these units should not be used interchangeably. It is noted that the bias is not consistent, therefore subtracting a constant value from the i1Pro 2 readings to match the

ILT950 would not be recommended. Further, the presence of proportional bias is not clear, the variability recorded is evidently inconsistent.

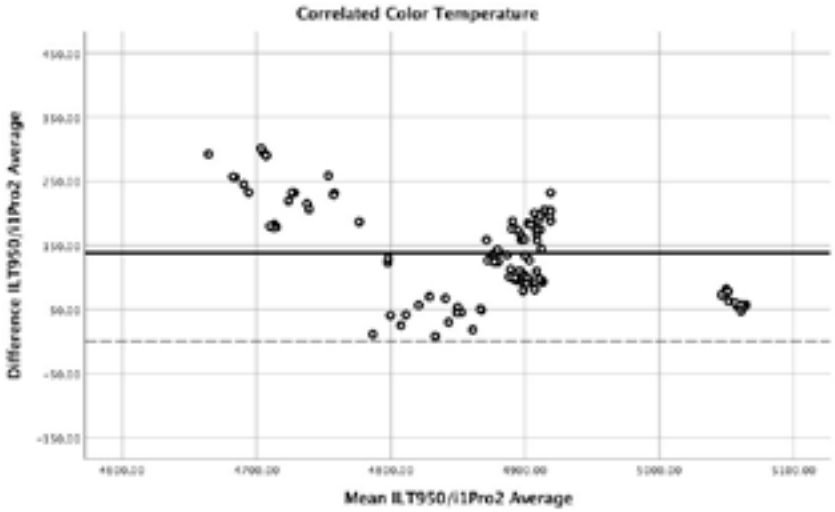


***Figure 1.*** *Bland-Altman Plot comparing CCT readings from ILT950 with the average of the X-Rite i1Pro 2 across the range of viewing booths. The bold solid horizontal line indicates the mean difference, the dashed line indicates zero.*

**Color Rendering Index**

Turning to an analysis of the CRI Ra values obtained in the comparison of the reference ILT950 and the average of the i1 Pro 2's, a one-sample t-test was used to determine systematic bias. In this instance, the mean difference ($M$ = 1.10, $SD$ = 0.84) was higher than zero $t(109) = 13.73$, $p < .001$. This suggests that the test i1 Pro 2 consistently measures CRI Ra higher than the reference ILT950.

The B-A plot, as shown in Figure 2, indicates that variation is dependent upon the magnitude of the measurement, with variation decreasing as the values approach the ideal 100. Inconsistency in the apparent variability, together with the observation that several readings are beyond the 95% LOA, suggest that these devices should not be used interchangeably.

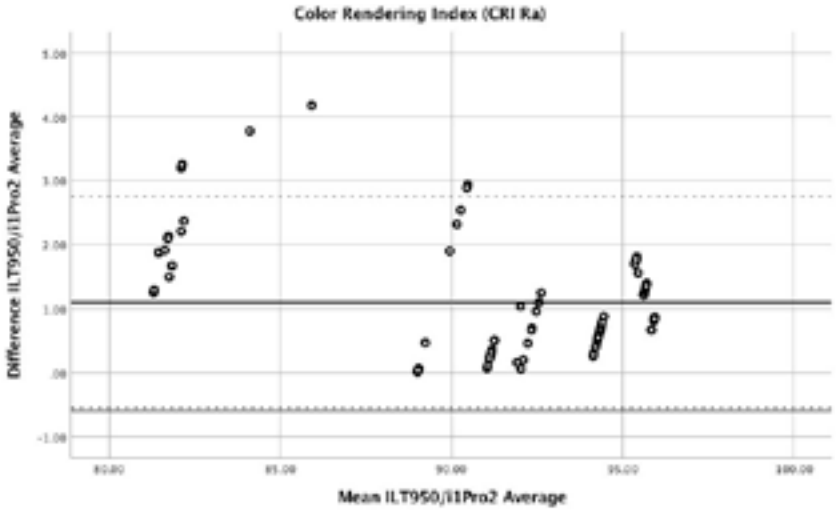


***Figure 2.*** *Bland-Altman Plot comparing CRI Ra readings from ILT950 with the average of the X-Rite i1Pro 2 across the range of viewing booths. The bold solid horizontal line indicates the mean difference, the dashed lines indicate the 95% limits of agreement.*

**Comparison of the ILT950 with the Konica Minolta Color Meter IIIF (CMIIIF)**

The CMIIIF is a hand held color meter designed for photographic and cinema graphic applications. It is A battery-operated, simple and easy to use instrument, and measures CCT but not CRI Ra.

**Correlated Color Temperature**

In comparison with the Spectroradiometer ILT950, the CMIIIF exhibited systematic bias ($M = 400.51$, $SD = 436.10$) with a mean difference greater than zero $t(69)$ 7.68, $p < .001$. An examination of the B-A plot, once again the observed variation is dependent upon the magnitude of measurement. As the kelvins exceed 5,000, the difference tends to increase, suggesting that no constant value subtracted from the test instrument values across the range of measured conditions would allow these devices to be used as substitutes for each other in practical applications across a variety of viewing conditions.

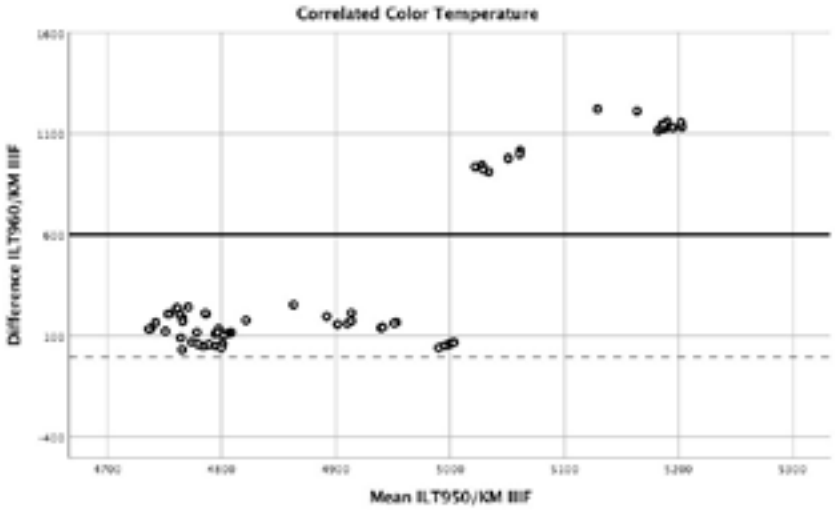


***Figure 3.*** *Bland-Altman Plot comparing CCT readings from ILT950 with the Konica Minolta CMIIIF across the range of viewing booths. The bold solid horizontal line indicates the mean difference, the dashed line indicates zero.*

**Comparison of the ILT950 with the LUXI For All and Cine Meter II**

The LUXI For All is an attachment for mobile devices, including smart phones and tablets that feature a front-facing camera. The attachment acts as a diffuser, allowing the camera to be used as a light meter. The LUXI For All comes with an app that is functional as an exposure meter, but when combined with the Cine Meter II iOS app, which has the ability to read CCT among other attributes, the combination was used to compare the benchmark ILT950 Spectroradiometer. Like the Konica Minolta Color Meter IIIF, this solution is designed for photographic and cinema graphic applications. It is hoped that as a low-cost alternative to the other solutions examined, the LUXI and Cine Meter II would be an interesting test in the present context.

It is important to note that the Cine Meter II app recommends that the solution be adjusted to comply with another device of known accuracy. It is therefore implied that this solution is not intended to be a primary meter, but rather a low-cost supplemental solution to another instrument. In the current study, the LUXI and Cine Meter II were adjusted to comply with the ILT950 for a reading near 5,000 kelvins.

**Correlated Color Temperature**

A one-sample *t*-test was performed to examine if the mean difference between the two solutions was significantly different than zero across the range light booths in the present study. The mean difference between the ILT950 and the LUXI with the

Cine Meter II app ($M$ =168.03, $SD$ = 112.62) was significantly higher than zero $t(69) = 12.48$, $p < .001$ .

A visual evaluation of the B-A plot in Figure 4 suggests lower variance near 5,000 kelvins; perhaps this is not surprising as this is where the devices were correlated. Across the range of light booths examined, the results indicated that the agreement between these two instruments is not reliable, with inconsistent biases noted.

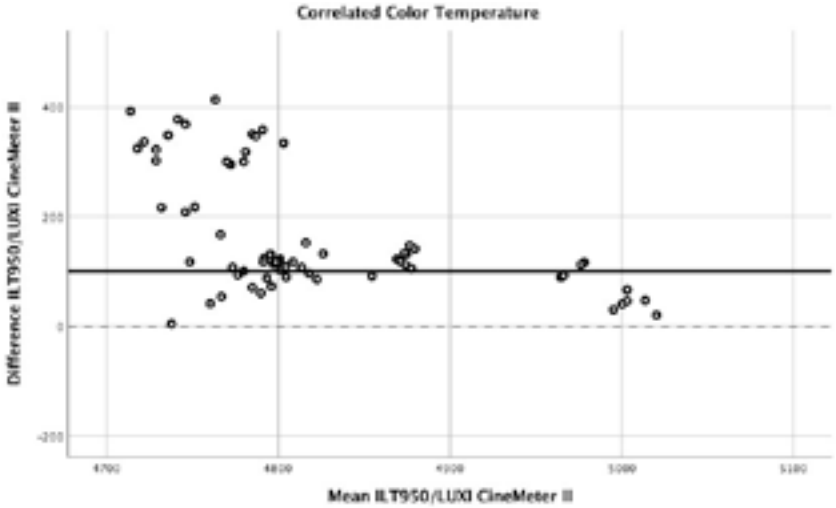


***Figure 4.*** *Bland-Altman Plot comparing CCT readings from ILT950 with the LUXI For All with Cine Meter II app across the range of viewing booths. The bold solid horizontal line indicates the mean difference, the dashed line indicates zero.*

**Comparison of the ILT950 with the Gossen Sixticolor**

Finally, a Gossen Sixticolor meter was tested and compared to the reference ILT 950. Manufactured in the 1950's, the Sixticolor is another photographic light color meter. This particular meter uses a selenium photo cell and "match-needle" metering: the ambient light powers the movement of the needle, therefore the device requires no batteries. Further, this device uses only red and blue filters in the optics, and being entirely analog does not output readings with the precision of the other devices tested. Nonetheless, it is hoped that a comparison here would be of interest.

**Correlated Color Temperature**

When compared to the ILT950, the Sixticolor test instrument exhibited systematic bias ($M$ = 532.86, $SD$ = 188.37) with a mean difference greater than zero $t(69)$ 23.67, $p < .001$. In an examination of the B-A plot in Figure 5, the observed variation is evidently dependent upon the magnitude of measurement. In instances where the recorded kelvins were less than 4,800 the difference tends to increase, suggesting

that no constant across the range of measured conditions would allow these devices to be used in substitute for each other.

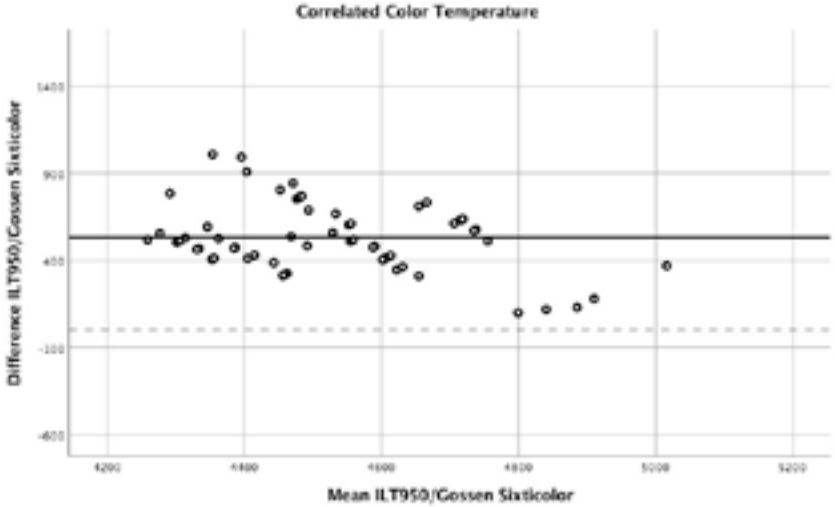


***Figure 5.*** *Bland-Altman Plot comparing CCT readings from ILT950 with the Gossen Sixticolor across the range of viewing booths. The bold solid horizontal line indicates the mean difference, the dashed line indicates zero.*

**Conclusions and Implications**

As compliance to standards becomes increasingly important, graphic professionals look to ways to assure that they are adhering to the specifications published by the relevant standards bodies. While Spectroradiometers are designed for the purpose of measuring the attributes which comprise ISO 3665 2009 *Graphic technology and photography – viewing conditions* are available, these devices are not in widespread use. It is more likely that a multi-use Spectrophotometer, such as the X-Rite i1 Pro 2, be re-purposed for such applications. Alternatively, graphics professionals may look to instruments specifically designed for photographic applications to measure CCT, which is perhaps the most prominent metric of standardized color viewing.

The present study compared a Spectroradiometer as a reference instrument, to several test instruments, namely, the X-Rite i1 Pro 2 and three photographic light color meters, with a goal of determining if these devices can be used interchangeably.

When examining the i1 Pro 2, both CCT and CRI Ra were compared to the reference instrument, here, the ILT 950. In both instances, it is determined that the differences examined do not suggest that these devices can be substituted for each other.

The same was true in an examination of CCT as measured by the reference instrument when compared to three photographic light color meter solutions: the

Konica Minolta Color Meter IIIF, the LUXI For All with Cine Meter II App Mobile solution, and the Gossen Sixticolor.

In each instance of instrument comparison, the variation was dependent upon the magnitude of the readings. In looking at CCT, it is interesting to note that the readings for the test instruments were nearer to the reference instrument when the viewing condition was closer to 5,000 kelvins. Likewise, in examining CRI Ra with the i1 Pro 2 as compared to the reference ILT 950, the readings from the two devices appeared to be closer the nearer the viewing condition was to the ideal 100.

This suggests that, although at present these lower-cost test instruments cannot be empirically supported as substitutes for a traceable Spectroradiometer, the nearer the viewing condition is to the ISO standard the closer the test instruments are to the reference instrument. As discussed, in the case of the LUXI For All with the Cine Meter II app, the test solution was adjusted to match the reference meter in this condition, but this was not the case for the other solutions.

It is also important to recognize that the present analysis does not address clinical importance. For example, the differences recorded with the i1 Pro 2 in terms of CCT and CRI Ra may be within the acceptable tolerances of some facilities in terms of assuring the compliance of their viewing conditions, at least in a relative way. A user may choose to measure a viewing condition when new, and use the instrument to check those values over time. It is also relevant to note that the manufacturers of these devices make no claim on their devices being a substitute for a certified and traceable Spectroradiometer.

When absolute readings are required, however, the data obtained indicate that, for practitioners, the test instruments evaluated are no practical substitute for the reference instrument. Such users are therefore recommended to invest in a traceable Spectroradiometer or employ the services of a qualified and equipped vendor to provide such data to assure their compliance. Strict adherence to the viewing booth manufacturer's recommendation for usage hours and age of their light sources is also suggested.

**References**

Berns, R. S., Billmeyer, F. W., & Saltzman, M. (2000). *Billmeyer and Saltzman's principles of color technology* (3rd ed.). New York: Wiley.

Bland, J.M., Altman, D.G. (1986). Statistical Methods for Assessing Agreement Between Two Methods of clinical Measurement. *Lancet*, 307-310.

Earthman, C. P. (2015), Body Composition Tools for Assessment of Adult Malnutrition at the Bedside. *Journal of Parenteral and Enteral Nutrition*, 39: 787-822.

Field, G. G., & Graphic Arts Technical Foundation. (2004). *Color and its reproduction : fundamentals for the digital imaging and printing industry* (3rd ed.). Pittsburgh: GATF Press.

International Organization for Standardization. Standard ISO 3665. *Graphic technology and photography – viewing conditions* Geneve: ISO; 2009.

# 5. CURRICULUM DEVELOPMENT EXAMPLES

Examples of curriculum development are included here, including:

- 5.1. MS Packaging Science Capstone Manual (Summer, 2025)
- 5.2. New Courses for the MS Packaging Science program (current project)
  - 5.2.1. Package Printing Materials and Processes - Graduate
  - 5.2.2. Packaging Science Laboratory Methods - Graduate
- 5.3. New Courses for the BS Packaging Science program (Fall, 2025)
  - 5.3.1 Package Printing Workflow - Undergraduate
  - 5.3.2 Package Printing Materials and Processes - Undergraduate

The most current curriculum development activities are provided here, including work at the graduate and undergraduate levels. In both cases, these modifications are driven by input from the Industry Advisory Board, organizations hiring students for Co-op positions, and recent alumni. Both constituencies recommended the integration of knowledge regarding printing technologies as a key expectation for packaging professionals. In addition, hiring organizations consistently cite writing and knowledge regarding metrology and quality control as important expectations for graduates from the program. Further, the Institute stresses the need for meaningful, empirical degree culminations. These priorities mandated curriculum revisions.

As the current graduate program director, I was charged with writing an MS Capstone Manual to clearly define student expectations in the Summer of 2025, which is provided here. A new MS Thesis Manual was also developed and is available by request. New courses were also developed for the MS Packaging Science Program: the course descriptions, topics, and outcomes of two of these courses are provided as examples of this work, namely Package Printing Materials and Processes and Packaging Science Laboratory Practices.

At the undergraduate level, two printing-related courses were developed and approved in 2025: Package Printing Workflow and Package Printing Materials and Processes. The course descriptions, topics, and outcomes for these courses are also provided.

Previous curriculum development work is also available upon request, including a major revision of courses in the BS and MS programs for the printing curriculum, including program naming, required course sequencing, HEGIS codes (New York State Taxonomy of Academic Programs), integration of relevant general education courses, revisions of existing courses, development of new courses, program level outcome assessments, and overseeing all aspects of program and course revision at the Program, College, Institute, and State levels.

MASTER OF SCIENCE DEGREE

# CAPSTONE MANUAL

**Department of Packaging and Graphic Media Science**

**College of Engineering Technology**

**Rochester Institute of Technology**

## Part I: Department Of Packaging and Graphic Media Science Empirical Capstone Research Policies

### Empirical Capstone Requirement

The Department of Packaging and Graphic Media Science (PGMS) at Rochester Institute of Technology (RIT) awards the Master of Science (MS) degree to graduate students who have completed all required coursework and successfully designed, executed, and defended an Empirical Capstone. The Capstone serves as a culminating experience, completed through a three-credit Capstone course. Students who select this option often pursue careers in industry, including roles in both production and vendor sectors.

The Empirical Capstone is expected to meet the quality and length standards of a scholarly journal article. Students are strongly encouraged to submit their completed Capstone for publication in a peer-reviewed journal or to present their work at an academic conference, accompanied by a research poster. The final Empirical Capstone Manuscript must adhere to the content, formatting, and presentation standards outlined in this manual.

All Empirical Capstones must contribute new knowledge to the field through the use of sound research techniques and scientifically valid methodologies. The research must be empirical in nature, employing quantitative, qualitative, or mixed-method approaches. This process is supported by a required three-credit Capstone course, which provides the foundation for rigorous academic inquiry.

Before enrolling in the Capstone course, students must have an approved Capstone Proposal. This proposal must be reviewed and approved by a Research Professor within the PGMS department, who agrees to serve as the Capstone Advisor. Detailed requirements for the proposal are provided in this manual.

Capstone Proposals must be submitted by Week 10 of the Fall or Spring semester preceding the semester in which the student intends to enroll in the Capstone course. Submission during the Summer semester is permitted only with the approval of the Capstone Advisor. Capstone Proposals will not be reviewed during the first week of the semester in which the student plans to enroll in the Capstone course.

### Purpose of This Manual

This manual outlines the requirements for the MS Empirical Capstone submitted to PGMS within the College of Engineering Technology (CET) at RIT. It provides guidance on the required content, formatting, and presentation of both the Capstone Proposal and the final Empirical Capstone Manuscript.

Students are also encouraged to consult the Wallace Memorial Library's "InfoGuides," which provide valuable resources for academic style usage, citations and research. For example, a particularly relevant guide can be found at: https://infoguides.rit.edu/citation/styles.
To access additional InfoGuides, visit the Wallace Memorial Library homepage, click on "Research and Instruction," and select "InfoGuides."

**Contents of This Manual**

The chapters that follow provide detailed instructions on the research process, roles and responsibilities of the Capstone Student and Capstone Advisor, as well as the content and formatting requirements for both the Capstone Proposal and the Empirical Capstone Manuscript.

## Part II: Steps To Completion of the Master's Capstone

### Capstone Writing Overview

Capstone Proposals and Manuscripts must adhere to academic writing standards. All submissions should be thoroughly drafted, revised, edited, proofread, and formatted prior to submission. Capstone Advisors do not serve as copy editors.

#### *Key Considerations for Academic Writing*

**Time Management Resources.** Proper academic writing is a time-intensive process. Many students benefit from external support. The RIT Academic Success Center offers tools and strategies for effective time management. Further, The Dissertation and Thesis Calculator from the Wallace Memorial Library helps students plan their writing timeline.

**Writing Support.** The University Writing Program provides writing assistance to graduate students through scheduled appointments. In addition, many students choose to hire professional editors to review their writing for grammar and clarity. A list of recommended editors is available through the Writing Center and the Publishing Support Center at the Wallace Memorial Library. Students are responsible for initiating contact and making contractual arrangements with editors. The department does not fund editing services. Regardless of the tools or services used, the Capstone Student remains fully responsible for the content and quality of their submitted work.

*Note:* The use of anonymous online editing services or generative Artificial Intelligence (AI) tools for writing, editing, and proofreading is discouraged. Students must retain full authorship of their work and be prepared to defend it. As generative artificial intelligence cannot defend its work, AI cannot author work.

**Formatting Requirements.** Students are responsible for ensuring that their documents comply with the formatting standards outlined in the Capstone Manual. Formatting is considered part of the content.

Students may choose their preferred tools for word processing, citation management, and other research-relevant software applications. RIT provides helpful resources through the Wallace Memorial Library and LinkedIn Learning to support the use of many of these tools.

#### *Capstone Topic Selection*

Capstone topics must be both meaningful and feasible:

- Meaningful: The topic should be grounded in academic literature and address a gap in existing knowledge.
- Feasible: The project must be achievable using available resources.

**Curricular Sequence and Capstone Process**

The MS in PGMS culminates in an empirical project that demonstrates scholarly engagement and critical thinking. The Capstone process includes:

- Approval of a Capstone Proposal by a Research Professor who agrees to serve as the Capstone Advisor, and a secondary advisor identified from RIT faculty
- Completion of a three-credit Capstone Course under the Advisor's supervision.
- Final grading for the Capstone Course is completed by the Capstone Advisor.

***Selecting a Capstone Advisor***

Students are expected to actively engage with faculty and coursework mindful of their need to identify a suitable Capstone Advisor. Faculty members are unlikely to support students who demonstrate a lack of motivation or engagement in their coursework.

***Choosing a Capstone Topic***

Strong Capstone topics that result in efficient, meaningful empirical research projects are typically the result of deep immersion in the scholarly literature. Students who struggle to define a topic often have not spent sufficient time reviewing academic sources. This process is emphasized in the GRCS-701 Research Methods course.

***Utilizing Department Resources***

Students should consider the equipment and processes available within the department when designing their projects. Lectures and laboratory experiences can serve as valuable inspiration for feasible research ideas.

***Capstone Research Supplies***

Capstone research often requires a variety of supplies, including:

- Basic materials (e.g., paper, ink for testing)
- Specialized software not provided by RIT
- Participant incentives (e.g., snacks for psychophysical studies)

*Note:* The department does not provide or procure supplies for Capstone projects. Students are responsible for any costs incurred unless prior arrangements have been made with their Capstone Advisor.

***Academic Integrity***

All Capstone Proposals and Manuscripts must fully comply with RIT's academic integrity policies, including: RIT Policy D08.0 – Student Academic Integrity Policy

***Human Subjects Research***

Any Capstone project involving human subjects or human-derived materials must receive prior approval from RIT's Human Subjects Research Office (HSRO). This requirement applies to:

- Psychophysical studies
- Interviews
- Surveys
- Focus groups
- Other research involving human subjects

Failure to obtain HSRO approval is a violation of federal law and university policy. More information and required forms are available at: https://www.rit.edu/hsro/

**Capstone Course Deadlines**

Capstone manuscripts must be completed by Week 10 of the semester in which the student is enrolled in the Capstone course. This deadline allows time for:

- Final review and approval
- Submission to academic journals or conferences
- Participation in events such as the RIT Graduate Showcase

This timeline also supports students preparing for post-graduation plans, including job searches and Optional Practical Training (OPT) opportunities.

**Capstone Process: Step-by-Step Timeline**

***Step 1: Establish a Research Agenda***

All PGMS students are required to complete GRCS-701 Research Methods, which includes assignments such as a literature review, research objectives, and a preliminary methodology. Students should use the content from this course, ongoing immersion in the scholarly literature, and other curriculum experiences to develop a research agenda that results in a research project that is both meaningful and feasible.

*Note:* It is considered best practice to develop a research question based on immersion in the scholarly literature. Ideally, the question should emerge from gaps or patterns identified in scholarly sources. A common mistake is to start with a preconceived idea and then search for literature to support it. This backward approach often leads to a disjointed and incoherent literature review, making the writing process significantly more difficult and time consuming.

***Step 2: Identify a Capstone Advisor***

Students should select a PGMS Research Professor whose research interests align with their topic and schedule a meeting to discuss the research project and request that Professor serve as their Capstone Advisor. Working collaboratively, the Student and Capstone Advisor will develop the research concept. NOTE: the Capstone Advisor is not obligated to provide the student with a research concept or topic.

***Step 3: Prepare the Capstone Proposal***

Students must compose their proposal using the guidelines provided in **Part IV: The Capstone Proposal** of this Capstone Manual. The proposal should be developed in close coordination with the Capstone Advisor.

***Step 4: Schedule the Proposal Meeting***

The completed proposal must be submitted to the Capstone Advisor by Week 10 of the semester prior to Capstone course enrollment. This timeline allows for necessary revisions before the semester ends. The Capstone Student completes and signs and procures the signature of the Capstone Advisor on the Capstone Proposal Approval form and delivers the completed form to the Academic Advisor. The Capstone Proposal Approval form is found at the end of this manual.

*Note:* Faculty are not obligated to review proposals during final exams, academic breaks, or the summer term. Proposals will not be reviewed during the first week of the semester in which the student intends to enroll in the Capstone Course.

***Step 5: Enroll and Complete the Capstone Course***

Upon approval, the student may enroll in the three-credit Capstone course. All work must be completed as outlined in the approved proposal, supported by regular meetings with the Student and Capstone Advisor during the semester of enrollment in the Capstone Course.

The final manuscript must meet all content, formatting, and presentation standards specified in the Capstone Manual in **Part V: The Capstone Manuscript**.

**Ongoing Communication.** It is the student's responsibility to schedule regular meetings with their Capstone Advisor to discuss their research progress. Ideally, such meetings should be scheduled at least every other week. Procrastination resulting in hurried submissions are strongly discouraged. For example, a rushed Capstone Manuscript submitted at the Week 10 deadline of the Capstone course may result in a poor grade, which could require repeating the course or jeopardize the student's standing in the program. Capstone Advisors are not obligated to assign an incomplete grade in the Capstone course due to delays caused by student inaction.

***Step 6: Submit the Final Manuscript***

Both printed and electronic versions of the final manuscript must be submitted to the Capstone Advisor by Week 10 of the Capstone course.

***Step 7: Post Capstone Approval Activities***

After the manuscript is approved, students are encouraged to:

- Submit their work to an academic journal or conference
- Create a research poster for display in the department or at the RIT Graduate Showcase, as supported by the RIT Graduate School
- Share a summary and photos relevant to their research for possible inclusion in RIT News

Students should also consult their Academic Advisor for information regarding graduation and commencement.

## Part III: The Capstone Course, Roles, and Responsibilities

### The Capstone Course

The three-credit Capstone Course is graded like any other course in the curriculum sequence; it is an academic, credit-earning course. It is akin to an independent study, where students are expected to remain self-directed and self-motivated throughout the semester in which they are enrolled. The Capstone Advisor is responsible for assigning a grade at the completion of the course, as defined by RIT Policy D05.0, see: https://www.rit.edu/policies/d050.

***The Graduate student***

The Graduate Student shall:

- Approach the Capstone process in a mature and professional manner.
- Take the primary responsibility for the administration of Capstone research and direction as set out by the Research Professor serving as the Capstone Advisor.
- Take initiative to communicate regularly with the Capstone Advisor while enrolled in the three-credit Capstone course, especially in matters related to research and progress. This is of particular importance, given the nature of research, academic writing, and the Week 10 deadlines. Meetings should be regularly scheduled throughout the semester.
- Be informed about the specific regulations and policies governing the PGMS Graduate Capstone process, specifically by reading and following the guidelines that have been laid out in this manual.
- Work closely with the Capstone Advisor to ensure that all requirements for Capstone Proposal development, research, and final Capstone document are met.
- Manage time effectively to balance the demands of Capstone research, coursework, and possibly external employment. Planning for and conducting Capstone research, including managing equipment and materials concerns and remaining current on the relevant scientific literature, are among the student's primary responsibilities.
- Respect the need of the Capstone Advisor to allocate their time and other resources in ways that are not involved with the Capstone.
- Recognize that the Capstone Advisor is responsible for monitoring the accuracy, validity, and integrity of the student's research to ensure a scholarly result and a positive reflection on the student, the advisor, the PGMS, the CET, and RIT.
- Acknowledge the contributions of the Capstone Advisor and other members of the research team to the student's work in all publications and conference presentations resulting from the Capstone research.
- Participate at an appropriate level in discipline-based activities, such as seminars and conferences, as a component of professional development.

- Complete and distribute appropriate Capstone Proposal Approval Form as outlined in this manual in a timely manner.

***Capstone Advisor***

- Approves the Capstone Proposal, allowing the student to enroll in the Capstone Course.
- Supervises and guides the student's Capstone research throughout the Capstone Course.
- Reviews and approves the Capstone Proposal and the Capstone Manuscript.
- Assigns a grade at the end of the three-credit Capstone course.
- Checks the submission of the Capstone Proposal and Capstone Manuscript for scholarly integrity through Turnitin prior to approval of the respective documents.

## Part IV: The Capstone Proposal

The Capstone Proposal, required before the beginning of actual work on the MS Capstone and enrollment in the respective Capstone course, is intended to provide the Capstone Advisor with a clear picture of the research intent, including:

- The significance of the project within the framework of established knowledge,
- The plans for undertaking the project,
- The equipment, space, materials required and available, and
- The project hours involved.

A timetable shall be developed to demonstrate that the research and completed Capstone Manuscript can be completed in the time available, as discussed below.

**Style and formatting**

As indicated, Capstone Students must seek approval from a PGMS Research Professor to serve as a Capstone Advisor. This process normally begins with a conversation between the Student and the Capstone Advisor about an empirical research project and research question. The Student then needs to write a proposal for the research and achieve approval from the Capstone Advisor: this is required for the Student to enroll in the three-credit Capstone Course.

During the Capstone course, the Student completes the empirical research outlined in the proposal and writes a research report of a quality and length that can be submitted to a Scholarly Journal to earn a grade in the Capstone course. The grade in the Capstone course is assigned by the Capstone Advisor.

RIT Research Professors have autonomy to select the academic style that they wish their students to follow throughout the Capstone process, including the Capstone Proposal and the Capstone Manuscript. The Student therefore is required to discuss this important factor with their Capstone Advisor. Popular Academic Styles include APA, Chicago, MLA, and IEEE.

Required sections for the Capstone Proposal are provided below.

**Required Sections of the Capstone Proposal**

Each Capstone Proposal must be written in standard U.S. English, follow academic writing conventions, and comply with both this manual and the approved academic style.

The proposal must include the following sections. The sections serve as Level One headings in the Capstone proposal:

***Title Page***

The title should concisely reflect the primary focus of the research project. The formatting of the Title Page is defined by academic style selected.

***Introduction***

Provides context for the research topic, often beginning with a broad overview. Supporting information may include citations from trade press, general media, textbooks, and trend reports.

***Literature Review***

Summarizes existing scholarly work to demonstrate the student's expertise and to justify the research by identifying a gap in current literature.

***Methods***

Outlines the research design and methodology, including required resources and delimitations of the study.

***Timeline***

Presents a project timeline with project-hours that align with the structure of the three-credit Capstone course. Graduate-level expectations are approximately nine hours per week per three-credit course. The timeline should aim for submission of the final manuscript by Week 10 of the semester and include a breakdown of expected project hours.

The timeline should also include a budget indicating any anticipated expenses.

*Note:* The Department is not obligated to provide funding for materials required for Capstone research.

***Conclusion***

Summarizes the significance of the proposed research and next steps.

***References***

Lists all sources cited, formatted according to the selected academic style.

**Purpose and Process of the Capstone Proposal**

Ideally, the Capstone Proposal should be as complete and polished as possible so that it may later serve as a draft of the final manuscript with minimal revisions. It should also function as a reference document throughout the research process. Students are advised to print at least one hard copy for personal use.

The proposal also serves a protective function for both the student and the department. It acts as a contract that outlines expectations and prevents students from engaging in open-ended projects that could delay graduation.

If significant changes occur during data collection, students must submit a revised proposal and obtain their Advisor's approval for the modified project. Consequences of deviation, including delayed graduation, visa complications, or exceeding the seven-year program limit, are the student's responsibility and not that of the Advisor or the Department.

Students should therefore approach the proposal with careful planning and awareness of possible external challenges. Capstone Advisors must be provided with both electronic and printed copies of the Capstone proposal.

**Formatting the Capstone Proposal**

The sections for the Capstone Proposal as outlined in this section are required for all Proposals. However, as the Capstone Proposal must be completed outside of the Capstone Course structure, Capstone Advisors have autonomy on the level of formality acceptable for the formatting of the Proposal. This warrants a discussion between the Capstone Student and the Capstone Advisor on this topic.

Capstone Students should be aware that as much of the Capstone Proposal can be repurposed for the Capstone Manuscript, the Capstone Student may choose to fully adopt the formatting structure as outlined in **Part V The Capstone Manuscript** for their Capstone Proposal, as informed by the chosen Academic Style.

## Part V: The Capstone Manuscript

### Capstone Manuscript Formatting and Writing

The Capstone Manuscript represents one of the final academic requirements for students pursuing the Master of Science (MS) degree through the Capstone culmination option. It is a scholarly journal-length document that presents the results of empirical research, formatted and cited according to the selected academic style. The manuscript is completed as part of the three-credit Capstone Course and is intended to demonstrate the student's research capabilities and academic rigor.

All Capstone manuscripts must be written in standard U.S. English and must adhere to both this manual and the selected academic style. Previously submitted Capstone projects should not be used as formatting models, especially if they conflict with current guidelines or the chosen academic style. The Capstone Manuscript must adhere to strict formatting guidelines to ensure it meets publication standards.

#### *Formatting*

Formatting requirements for the Capstone Manuscript are more rigorous than those for the Capstone Proposal. These requirements are largely determined by the selected academic style, and students should allocate sufficient time to ensure proper formatting.

The following elements must align with the chosen academic style:

- Fonts: Font usage for body text, tables, figures, and equations.
- Footnotes (if used).
- Page Formatting: Standard U.S. letter size (8.5 x 11 inches) in portrait orientation.
- Text Alignment: Left-justified body text unless otherwise specified.
- Page Margins.
- Indentation: With special attention to block (long) quotations.
- Page Breaks: Used appropriately to separate sections and format page elements.
- Spacing: Line spacing for body text and spacing between sections, tables, and figures.
- Pagination: Page numbering throughout the manuscript.
- Headings: Proper use of major and minor headings.
- In-text citations and References.
- Appendices, including numbering of appendices (if used).
- Tables, Figures, and Equations: Numbered, titled, and formatted per style guidelines.

*Note:* Tables and figures should not occupy consecutive pages. Landscape orientation may be used sparingly for tables or figures to enhance readability. All tables and figures must be

referenced in the body text before they appear. Screen captures are not acceptable for tables. Figures must be of sufficiently high resolution to ensure clarity in print.

**Reproducing Tables and Figures.** When reproducing tables or figures from scholarly sources, proper citation is required. In some cases, permission from the copyright holder must be obtained and included in an appendix. When using Microsoft Office, it is recommended to create tables in Excel and paste the data into a Word table for better formatting control.

### *Equations*

Equations must follow the formatting rules of the selected academic style. They should be created using the word processor's equation editor, centered on the page, and labeled with right-aligned Arabic numerals in parentheses. Screen captures are not acceptable for equations. A common formatting method is to place the equation in the center cell of a borderless three-column table, with the equation number centered and aligned to the right in the rightmost cell. When referencing equations in the text, use the number only (e.g., "as shown in (2)") rather than "Equation (2)."

## Writing

### *Paragraph Structure*

Capstone students should ensure that paragraphs are logically structured. Each paragraph should begin with a clear topic sentence, followed by supporting sentences and appropriate transitions. Ideas must be presented in a coherent and organized manner. Bulleted or numbered lists should be avoided in favor of full paragraph development.

### *Inclusive Language*

Inclusive, bias-free language must be used throughout the manuscript, except in direct quotations. If the selected academic style does not provide guidance on inclusive language, students should follow APA's recommendations, see: APA Inclusive Language Guidelines.

### *Perspective*

The manuscript should be written in the third-person perspective. This approach supports objectivity, professionalism, and clarity by focusing attention on the subject rather than the author. Although some academic styles permit the use of first-person in describing the researcher's actions, students should avoid first-person unless explicitly approved by their Capstone Advisor.

### *Revising, Editing, and Proofreading*

Producing a high-quality manuscript requires multiple rounds of revision, editing, and proofreading. Students are reminded that their Capstone Advisor is not responsible for copyediting. Professional writing assistance may be necessary to ensure the manuscript meets academic standards.

**Capstone Manuscript Structure**

The Capstone Manuscript must include the following sections: each formatted according to the selected academic style:

- Title Page
- Abstract
- Introduction
- Literature Review
- Research Objectives
- Methods
- Results
- Discussion
- Conclusion
- References
- Appendix or Appendices (if applicable)

*Note:* Section titles may vary depending on the academic style chosen. Students should use terminology for the sections consistent with their selected style guide.

All sections, except the Title Page, should be formatted as Level 1 headings in the Capstone Manuscript.

***Title Page***

The Title Page should follow the formatting guidelines of the selected academic style. It typically includes the manuscript title, student's name, institution, course, instructor, and date of submission.

***Abstract***

The Abstract provides a concise summary of the Capstone Manuscript. The abstract typically ranges from 150 to 250 words, depending on the selected academic style. Students may also include a list of keywords at the end of the abstract (not included in the word count). Although the abstract appears at the beginning of the manuscript, it is usually written after the main sections are completed. A "working abstract" may be developed early to guide research.

***Introduction***

The Introduction prepares the reader for the study by:

- Establishing the background and significance of the topic
- Presenting broad context supported by credible sources (e.g., trade press, trend reports, meta-analyses from the scholarly literature)
- Narrowing the focus from a general overview to the specific research question

The goal of the Introduction is to engage the reader and clearly introduce the research topic.

A concluding paragraph should summarize the Introduction and transition to the next section.

***Literature Review***

The Literature Review should be written in paragraph form and from the third-person perspective. It should primarily focus on scholarly sources, including academic journal articles, conference papers and proceedings, dissertations, and theses. When writing the literature review, it is helpful for the Capstone Student to view their role as that of a curator, organizing and presenting relevant research for the benefit of the reader. The reviewed literature should be synthesized and clearly communicated using appropriate introductory statements, transitions between ideas, and concluding remarks to create a cohesive narrative.

This Literature Review should:

- Demonstrate the researcher's expertise
- Provide scholarly context for the study
- Identify gaps in the existing literature

Each source should be discussed in at least two robust paragraphs. As a general rule, if a study can be summarized in the literature review using only its title or abstract, it is insufficient. The review should include a rationale for the selection of sources (e.g., most recent, most relevant, or most widely cited studies). Minor headings may be used to organize themes within the literature review.

A concluding paragraph should summarize the Literature Review and transition to the next section, Research Objectives.

***Research Objectives***

This section builds on the identified gap in the literature in paragraph form, and presents:

- The research objectives
- Research questions and/or hypotheses
- Variables under investigation
- Delimitations of the study: delimitations define the scope of the research, including what is included or excluded. Definitions of key terms—especially abstract concepts—may be included here and should be grounded in scholarly literature.

A concluding paragraph should summarize the Research Objectives and transition to the Methods section. It is not a good practice to have a heading entitled "gap," rather the gap in the literature should be implicitly identified in paragraph form.

***Methods***

Note: This section may be titled "Methodology" depending on the academic style selected. Students should use the appropriate term consistent with their chosen style guide.

The Methods section serves two primary purposes:

- To inform the reader of the procedures used in the study, which supports the perceived validity of the results, and
- To provide sufficient detail for future researchers to replicate or build upon the study.

Following introductory paragraph(s), this section should clearly describe the research design and procedures in paragraph form. The methodology must demonstrate how the chosen methods align with the research objectives and justify their appropriateness.

**Data Collection.** A detailed explanation of how data were collected is required. This includes:

- Sampling methods
- Data sources
- Instruments used
- Procedures followed
- Flowcharts or diagrams created by the student may be included to illustrate the process. The data collection approach must align with the variables identified in the Research Objectives section.

**Data Analysis.** This subsection should describe how the collected data is analyzed. The analysis methods must be appropriate for the research design and clearly linked to the research questions or hypotheses. It is generally considered superfluous to list any widely-used software products that were employed for data analysis (e.g., Excel, MiniTab, MatLab, R, SPSS) in the Capstone Manuscript.

**Research Involving Physical Measurement Instruments.** If the study involves metrology:

- Manufacturer manuals should be cited to confirm adherence to recommended procedures.
- Model numbers and revision numbers of instruments should be included (serial numbers are generally unnecessary unless, although if a single instrument was used throughout that can be noted).
- Relevant standards or specifications should be discussed and included in the References section.

***Research Involving Specialized Software.*** If the study involves specialized software, the software name, version number, and operating system should be specified.

*Note*: The department does not procure specialized software for individual Capstone projects.

***Research Involving Surveys.*** For survey-based research:

- Describe the survey instrument and sampling frame.
- Discuss the reliability and validity of the instrument in paragraph form.
- If using a commercial or widely reviewed instrument, cite its review from the *Buros Mental Measurements Yearbook.*
- Include details of pilot testing.

*Note*: The full survey instrument and pilot test results should be placed in an Appendix, not in the Methods section.

A concluding paragraph should summarize the Methods section and transition to the Results section.

***Results***

The Results section presents the findings of the study. It should begin with introductory paragraph(s) and focus solely on the data and avoid interpretation or discussion of implications. If statistical analyses are used, they must be presented in accordance with the selected academic style, including proper formatting of statistical terms and abbreviations.

**Presentation of Results.** The presentation of results should be structured to clearly communicate the findings of the study. Tables and figures are tools that should be used to supplement the narrative, not replace it. Each visual element must be numbered and formatted in accordance with the selected academic style guide and should be referenced within the text to guide the reader through the data. Bulleted lists should be avoided, in favor of writing in paragraph form.

A concluding paragraph should summarize the Results and transition to the Discussion section.

***Discussion***

The Discussion section interprets the findings in relation to the research objectives and questions in paragraph form. It should begin with introductory paragraph(s) and include:

- A summary of the findings
- An explanation of how the findings contribute to the scholarly literature
- A discussion framed by the research questions and hypotheses
- Implications, including the potential impact of the findings on various constituencies, including industry practitioners, academics, policymakers, researchers, and educators.

Special attention should be given to unexpected or curious findings.

***Future Research***

The Discussion section should identify directions for future research, often based on the delimitations of the current study. Suggestions on how future researchers might expand or refine the study should be included. Any unusual findings may impact possible future research and should be recalled here.

A concluding paragraph should summarize the Discussion section and transition to the Conclusion section.

***Conclusion***

The Conclusion section summarizes the Capstone study, reflecting on the findings and their broader implications, in paragraph form. It should:

- Recap the research objectives and how they were addressed
- Highlight key findings
- Emphasize the significance of the study
- Reinforce the contribution to the field

This section should be concise and clearly written, providing closure to the manuscript.

***References***

*Note:* This section may be titled "Bibliography" depending on the academic style selected.

The References section lists all sources cited in the manuscript, formatted according to the selected academic style. The Capstone Student should ensure that:

- Every in-text citation appears in the References section
- Only cited sources are included in the References (with the exception of personal communications, if applicable)

***Appendix or Appendices***

Appendices, if used, include supplementary material that supports the manuscript but is not essential to the main text. Examples include:

- Extended definitions or conceptual discussions
- Human subjects' documentation (e.g., HSRO approval, informed consent forms)
- Full versions of survey instruments or interview schedules
- Pilot test results

All appendices must be referenced in the body of the manuscript where relevant.

## Part V: Resources

### PGMS Research Professors

Dr. Bilge Altay bnappr@rit.edu
Dr. Sneh Bangar spbipk@rit.edu
Dr. Carlos Diaz-Acosta cdamet@rit.edu
Dr. Kyle Dunno kppipk@rit.edu
Dr. Changfeng Ge cfgmet@rit.edu
Dr. Malcolm Keif mgkppr@rit.edu
Dr. Bruce Myers blmppr@rit.edu

### Helpful Links

**Research Poster Printing:** CET Tech Poster Printing: https://cettech.rit.edu/PosterPrinting

**RIT Policies:** Links to RIT Student Policies: https://www.rit.edu/policies/student-policy-reference

**Wallace Memorial Library Resources:**
Copyright Basics: https://infoguides.rit.edu/c.php?g=1199116&p=8770198

Dissertation and Thesis Calculator: https://wmlapps.rit.edu/dissertation-calculator/

Fair Use: https://infoguides.rit.edu/c.php?g=1199116&p=8770201

InfoGuides: https://infoguides.rit.edu/

# Capstone Proposal Acceptance Form

| | | | |
|---|---|---|---|
| Student: | Click or tap here to enter text. | Date: | Click or tap to enter a date. |
| Degree: | Click or tap here to enter text. | | |
| Capstone Title: | Click or tap here to enter text. | | |
| Phone: | Click or tap here to enter text. | Mobile: | Click or tap here to enter text. |

☐ Accepted

## Signatures

Capstone Proposal Acceptance Approval is required to enroll in Capstone Course

| | | | |
|---|---|---|---|
| Advisor: | Click or tap here to enter text. | Signature: | |

Submit form to Academic Advisor

## 5.2.1. PACKAGE PRINTING MATERIALS & PROCESSES

3-Credits, 700-Level Graduate. Two hour lecture + two hour lab.

**Course Description**

Nearly all packages include printed elements, making package printing an essential part of the production process. Package printing uses materials and technologies relevant for mass production as well as those for lower-volume work, including customization and prototypes. This range of production applications rely on a broad set of techniques and materials and technologies which frame the content and topics of this course. Through lectures and hands-on laboratory exercises, this course prepares students to be conversant in the processes and materials used for printing on paper, board, plastics, and other substrates using conventional and digital imaging technologies. The course also highlights ink applications, color reproduction, and embellishment techniques.

**Course Topics**

1. Digital Printing Technologies
    1.1. Inkjet
    1.2. Electrophotographic
2. Conventional Printing Technologies
    2.1. Offset Lithography
    2.2. Flexographic
    2.3. Gravure
    2.4. Screen Printing
3. Printed Embellishments
4. Inks & Coatings
    4.1. Formulation
    4.2. Testing & Standards
5. Substrates
    5.1. Papers & Rigid
    5.2. Plastics & Foils
6. Printing Supply Chain
7. Color
    7.1. Brand Color Control
    7.2. Process Control for Color Reproduction

## Course Student Learning Outcomes and Assessment

| Course Student Learning Outcome | Assessment Method |
|---|---|
| Describe and compare digital the application of digital printing technologies including inkjet and electrophotographic. | Laboratory Report, Performance-Based Examination |
| Describe and compare conventional printing technologies such as offset lithography, flexography, gravure, and screen printing for suitability in various packaging contexts. | Laboratory Report, Performance-Based Examination |
| Analyze the role of printed embellishments in enhancing package aesthetics and functionality. | Laboratory Report, Examination |
| Assess and implement ink and coating formulations and testing protocols based on performance criteria and industry standards. | Laboratory Report, Examination |
| Differentiate among substrate types including papers, rigid materials, plastics, and foils based on printability and end-use requirements. | Laboratory Report, Performance-Based Examination |
| Describe the interactions between substrates and printing processes to optimize print quality for packaging applications. | Laboratory Report, Examination |
| Diagnose printing supply chains with emphasis on efficiency, sustaina-bility, and technological integration. | Laboratory Report |
| Apply principles of color science to control brand color consistency across different printing platforms. | Laboratory Report, Performance-Based Examination |
| Implement process control strategies to ensure accurate color reproduction in package printing workflows. | Laboratory Report, Examination |

## 5.2.2. PACKAGING SCIENCE LABORATORY PRACTICES

3-Credits, 700-Level Graduate. Two hour lecture + two hour lab.

**Course Description**

Effective, efficient, and safe laboratory practices that result in professional data analysis and reports are the hallmark of packaging professionals and are a core expectation of master's level students in the applied sciences. This requires deep understanding of metrology, applications, best practices, and stewardship of laboratory equipment and materials. In this course, learners are oriented to the packaging laboratories and equipment in the department for physical and optical materials testing, including the applications, standard operating procedures, metrics, industry standards, and specifications supporting them. Effective use of laboratory equipment and instruments, including sample selection and preparation, are emphasized. Analysis of laboratory-based data supported by measurement systems analysis techniques is applied to physical and optical testing methods and procedures, supporting learner deliverables including written laboratory reports and research posters.

**Course Topics**

1. Lab Safety
2. Standard Operating Procedures
3. Standard and Specification Bodies
4. Measurement Systems Analysis and Process Control
   - 4.1. Reliability, Validity, Traceability
5. Metrology Analysis
   - 5.1. Comparison of Instruments, Methods, and Standards
6. Laboratory Reports and Research Posters
   - 6.1. Deriving Meaning from the Data
   - 6.2. Tables and Figures
7. Testing and Analysis of Substrates
   - 7.1. Abrasion Resistance
   - 7.2. Air Permeability
   - 7.3. Coefficient of Friction
   - 7.4. Edge Crush Testing
   - 7.5. Heat Sealing
   - 7.6. Impact Testing
   - 7.7. Tensile Strength
   - 7.8. Paper Smoothness Testing
   - 7.9. Wall Thickness

4.8. Testing and Analysis of Inks, Solutions, and Image Masters
- 4.8.1. Conductivity
- 4.8.2. Flexographic and Lithographic Plate Measurement
- 4.8.3. pH
- 4.8.4. Proofing and Drawdowns
- 4.8.5. Tack
- 4.8.6. Viscosity

4.9 Testing and Analysis of Printed Products
- 4.9.1 Appearance
  - 4.9.1.1 Gloss
  - 4.9.1.2. Bidirectional Reflectance Distribution Function
- 4.9.2 Fade Testing/Accelerated Ageing
- 4.9.3. Color
  - 4.9.3.1 Densitometry, Colorimetry, and Spectrophotometry
  - 4.9.3.2 Standardized Viewing Conditions

## Course Student Learning Outcomes and Assessment

| Course Student Learning Outcome | Assessment Method |
|---|---|
| Identify potential hazards in a laboratory environment; describe appro-priate safety protocols; demonstrate compliance with lab safety proce-dures during all experimental activities. | Written deliverable, performance-based examination |
| Interpret and follow standard operating procedures (SOPs) for labora-tory equipment and processes; develop SOPs for new or modified lab activities. | Performance-based examination, written deliverables |
| Explain the role of major standards organizations (e.g., ASTM, ISO, TAPPI) in packaging and printing; compare specifications from different bodies and justify their application in testing scenarios. | Written deliverables, examination |
| Apply measurement systems analysis (MSA) techniques to assess instrument performance; analyze and develop process control charts to evaluate stability; assess the traceability of measurement results to recognized standards. | Written deliverables |
| Perform metrology analysis using appropriate instruments and interpret results; evaluate sources of measurement uncertainty and propose methods to minimize error; compare instruments and methods for ac-curacy and precision; construct clear and accurate laboratory reports that represent experimental findings, create tables and figures that visualize data and adhere to scientific conventions. | Laboratory reports and research posters |
| Conduct standardized tests on substrates, inks, solutions, image mas-ters; analyze and interpret test results to evaluate material perfor-mance and suitability. | Laboratory reports and research poster, performance-based examination |
| Assess printed products for color, appearance, and fade resistance. | Laboratory reports and research posters, performance-based examination |

## 5.3.1. PACKAGE PRINTING WORKFLOW

3-Credits, 700-Level Graduate. Two hour lecture + two hour lab.

**Course Description**

Package printing is customized manufacturing. This course emphasizes the processes involved in producing package printing efficiently while maintaining standards while meeting and exceeding brand owner expectations. Combining relevant production-related technologies including metrology, specifications, and international standards with prepress application through production workflow and finishing tools, learners will complete laboratory exercises preparing them to be proficient in the practice of industry-relevant package printing production.

**Course Topics**

1. Branding Standards for Packaging
2. Quality Control for Imaging Masters
   - 2.1. Offset Lithographic Printing Plates
   - 2.2. Flexographic Printing Plates
3. Color Reproduction
   - 3.1. Process Color Printing
     - 3.1.1. Expanded Gamut Color Printing
     - 3.1.2. Preparing Raster Images
   - 3.2. Spot Color
4. Image Structure for Production
   - 4.1. Layouts
   - 4.2. Dielines
   - 4.3. Bleeds
   - 4.4.Gluing
   - 4.5. Nesting
   - 4.6. Step & Repeat
5. Segmentation
   - 5.1. Variable Data
   - 5.2. Personalization
6. Prepress Technologies
   - 6.1. Screening
     - 6.1.1. Conventional
     - 6.1.2 .Frequency Modulated
   - 6.2. Prepress Trapping
7. Press Characterization
   - 7.1. Neutral Gray-Based Characterization
   - 7.2. ICC Profiling
8 .Control Targets
9. Workflow Automation
10. Proofing
    - 10.1. Press and Proof Approval Processes & Technologies
    - 10.2. Standardized Viewing

## Course Student Learning Outcomes and Assessment

| Course Student Learning Outcome | Assessment Method |
|---|---|
| Interpret brand owner standards for packaging to ensure visual consistency and brand integrity across print platforms. | Laboratory Report, Performance-Based Examination |
| Assess quality control procedures for imaging masters used in offset lithographic and flexographic printing plate production. | Laboratory Report, Performance-Based Examination |
| Differentiate between process color and spot color reproduction methods, including expanded gamut printing. | Laboratory Report, Performance-Based Examination |
| Optimize raster images for print production workflows. | Laboratory Report, Examination, Performance-Based Examination |
| Produce image structures for printed package production by applying principles of layout design, dielines, bleeds, nesting, and step and repeat techniques. | Laboratory Report, Performance-Based Examination |
| Design segmentation strategies using variable data and personalization to enhance targeted packaging communication. | Laboratory Report, Examination |
| Evaluate prepress technologies including conventional and frequency modulated screening and trapping methods for print readiness. | Laboratory Report, Examination, Performance-Based Examination |
| Implement press characterization techniques such as neutral gray-based characterization and ICC profiling to optimize print performance. | Laboratory Report, Examination |
| Assess control targets to monitor and maintain consistency throughout the printing workflow. | Laboratory Report, Examination, Performance-Based Examination |
| Evaluate automated workflow systems to streamline prepress and press operations. | Laboratory Report |
| Manage proofing processes and technologies to ensure accurate and timely production approvals. | Laboratory Report, Examination, Performance-Based Examination |

## 5.3.2. PACKAGE PRINTING MATERIALS & PROCESSES

3-Credits, 400-Level Undergraduate. Two hour lecture + two hour lab.

**Course Description**

Nearly all packages include printed elements, making package printing an essential part of the production process. Package printing uses materials and technologies relevant for mass production as well as those for lower-volume work, including customization and prototypes. This range of production applications rely on a broad set of techniques and materials and technologies which frame the content and topics of this course. Through lectures and hands-on laboratory exercises, this course prepares students to be conversant in the processes and materials used for printing on paper, board, plastics, and other substrates using conventional and digital imaging technologies. The course also highlights ink applications, color reproduction, and embellishment techniques.

**Course Topics**

1. Digital Printing Technologies
   1.1. Inkjet
   1.2. Electrophotographic
2. Conventional Printing Technologies
   2.1. Offset Lithography
   2.2. Flexographic
   2.3. Gravure
   2.4. Screen Printing
3. Printed Embellishments
4. Inks & Coatings
   4.1. Formulation
   4.2. Testing & Standards
5. Substrates
   5.1. Papers & Rigid
   5.2. Plastics & Foils
6. Printing Supply Chain
7. Color
   7.1. Brand Color Control
   7.2 Process Control for Color Reproduction

## Course Student Learning Outcomes and Assessment

| Course Student Learning Outcome | Assessment Method |
|---|---|
| Describe and compare digital the application of digital printing technologies including inkjet and electrophotographic. | Laboratory Report, Performance-Based Examination |
| Describe and compare conventional printing technologies such as offset lithography, flexography, gravure, and screen printing for suitability in various packaging contexts. | Laboratory Report, Performance-Based Examination |
| Analyze the role of printed embellishments in enhancing pack-age aesthetics and functionality. | Laboratory Report, Examination |
| Assess and implement ink and coating formulations and test-ing protocols based on performance criteria and industry standards. | Laboratory Report, Examination |
| Differentiate among substrate types including papers, rigid materials, plastics, and foils based on printability and end-use requirements. | Laboratory Report, Performance-Based Examination |
| Describe the interactions between substrates and printing processes to optimize print quality for packaging applications. | Laboratory Report, Examination |
| Diagnose printing supply chains with emphasis on efficiency, sustainability, and technological integration. | Laboratory Report |
| Apply principles of color science to control brand color consistency across different printing platforms. | Laboratory Report, Performance-Based Examination |
| Implement process control strategies to ensure accurate color reproduction in package printing workflows. | Laboratory Report, Examination |