STUDENT-CENTERED GEOGRAPHIC INFORMATION SCIENCE EDUCATION:

FLIPPING THE CLASSROOM, GRADUATE STUDENTS ON CURRICULUM, AND QGIS

by

EMILY SNOW CASTELLUCCI

(Under the Direction of John A. Knox)

ABSTRACT

Geographic Information Science (GIScience) has undergone rapid change in the past several years, and this has introduced new challenges for teaching and learning geographic information systems (GIS) technology. The projects presented here are intended to examine three of these new challenges in greater detail, particularly with a focus on substantial learning and especially student-centered learning.

The first research project applies the “flipped” classroom model as an alternative to the traditional lecture/lab model. Specifically, this project addresses how instructors and students engage with first-time attempts at flipping the classroom in GIScience courses. It also considers how these experiences inform future research into the appropriateness of the flipped classroom approach for teaching and learning GIScience. Most and least favorable flipped classroom experiences are discussed. Results indicate the importance of instructor buy-in and incorporating accountability measures into the flipped classroom design.

The second research project gathers graduate students’ reflections, via one-on-one interviews, on their past and desired learning experiences in GIScience, considering recently completed courses offered by the Geography Department at the University of Georgia. These interviews are examined to determine how graduate students' reflections might inform curriculum revision and enhancement, both at the departmental level and beyond. Participants' responses indicate a strong interest in more preparation for careers after graduation, both academic and especially non-academic. As part of this, participants expressed a strong desire for more opportunities to develop programming skills.

The third research project addresses the potential for free and open source software for GIS to facilitate significant learning experiences, since demand for graduates with free and open source software experiences continues to grow. A standalone workshop experience, emphasizing participants' learning of color for cartographic application using QGIS, a free and open source software, was designed and facilitated ten times. Feedback from participants was gathered using surveys. Results suggest that substantial learning was achieved, that QGIS was beneficial for participants' learning, that QGIS can and should be incorporated into regular GIScience curriculum, and that concepts and software previously reserved for advanced courses can be taught to students in introductory courses.

INDEX WORDS: geography education, Geographic Information Science (GIScience), flipped classroom, graduate students, curriculum, QGIS

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DEDICATION

In memory of my dad, CW3 David W. Snow, who encouraged my learning from an early age and who believed that education is a door to opportunity, a door that should never be taken for granted. Even though it has been almost twelve years, I doubt I would be where I am today if it were not for the choices my dad was led to make in his life. I am very thankful to finish the work he started, and I feel as though this dissertation and this Ph.D. is just as much his as it is mine. I love and miss you, Dad. Much love, your Pumpkin.

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I am under no delusions that this work was accomplished by my own strength and will. Rather, I attribute the success of this endeavor to the strength and will of God, in whom I have trusted. "Lord, you establish peace for us; all that we have accomplished, you have done for us" (Isaiah 26:12). I am deeply grateful for the many, many people that God brought into my life during this time, who have all contributed to this experience in substantial ways.

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CHAPTER 1

INTRODUCTION

Context and Research Questions

Geographic information science (GIScience) is "an experimental research field that has geographic space as its object of study, geographic information as its means of representing knowledge and geographic information systems [GIS] as its disciplinary tool" (Painho et al., 2012).[1] It is a rapidly evolving field, and there are numerous challenges that often arise when attempting to teach and learn it effectively, particularly staying up-to-date with the technology and best pedagogical practices as well as remaining relevant to students' needs. This research project explores how the teaching and learning of GIScience might be enhanced to address recent developments in this field, while maintaining a student-centered approach to teaching and learning. A few of these recent developments within GIScience include the following:

- the expanding knowledge of what does and does not "work" in the GIScience classroom, a product of proliferating interest in scholarship of teaching and learning (SoTL) research in GIScience;
- the attempt to define the core, extent, and boundaries of GIScience and the competencies expected of a GIScience professional, since these factors affect what is and is not taught in any GIScience program; and
- the increasing accessibility of geographic information systems (GIS) software, due to the growing maturity of free and open source software for GIS, particularly QGIS (previously known as QuantumGIS).

This dissertation addresses these developments in the form of three separate research projects, each with a unique twist to shed new light on the implications that these developments have for

[1] As indicated by this definition of GIScience and as discussed by Goodchild (2009), GIScience encompasses GIS, but it is not limited to it. This distinction is embraced in this dissertation and reflected in the careful usages of each term in appropriate contexts.

the field of GIScience. These are considered standalone projects, but they are united in their focus on student-centered learning.

The first project begins to assess the appropriateness of the flipped classroom technique for GIScience at a major research university by looking at first-time experiences flipping GIScience classes and inviting perspectives from both students and instructors. The second project investigates the potential for feedback from graduate students to contribute to ongoing discussions about curriculum revision and development. The third project tests the ability of free and open source software for GIS to facilitate substantial learning in GIS, specifically examining how well the QGIS software can facilitate a substantial learning experience for color as applied in cartography and visualization. Therefore, the key questions that this dissertation addresses are:

- How do instructors and students engage with first-time flipped classroom experiences in GIScience courses? How can these experiences inform future research into the appropriateness of the flipped classroom approach for teaching and learning GIScience? (Chapter 2)
- What are graduate students' reflections on their past and desired learning experiences in GIScience? How might their reflections contribute to curriculum revision and enhancement? (Chapter 3)
- Can free and open source software facilitate a substantial learning experience? Specifically, how well can the QGIS[2] software facilitate a substantial learning experience for color as applied in cartography and visualization? (Chapter 4)

Substantial and Student-Centered Learning

To be clear, throughout this dissertation the terms "substantial learning" and "student-centered learning" are used with particular understandings. In regard to the former concept, "substantial" learning is a renaming of Fink and Ganus (2009)'s term "significant" learning, which they describe as the result of learning experiences that are "powerful" (71), designed from

[2] QGIS was selected as the free and open source software of choice for this research, as it has been considered "the #1 free GIS software package" (see http://gisgeography.com/free-gis-software/, accessed July 11, 2016). It is becoming the software of choice in many contexts, including teaching, research, and other contexts, and its adoption is endorsed by the researcher based on the reasons discussed in this dissertation, particularly chapters 3 and 4.

a “learning-centered, integrated, systematic approach”, are “student-centered”, result in “critical thinking” (72), and have a “lasting impact” (78). The term “substantial” learning, as used throughout this dissertation, is meant to indicate the same concept; it is merely being renamed to avoid any confusion with statistical significance. In regard to the latter concept, “student-centered learning” will be discussed in light of José Bowen’s book, *Teaching Naked* (2012), and Barr and Tagg’s (1995) paper on the paradigm shift from instructor-centered teaching to student-centered learning.

In his book, Bowen (2012) makes the case that technology is changing the who, what, when, where, and how of learning. Bowen claims that unless higher education can capitalize on what makes a residential education different than other means of learning and worth the extra cost, higher education will begin to suffer as potential students seek alternative means of accomplishing the substantial learning needed to pursue their academic and career goals. Although lecturing has an appropriate time and place, the case has been made that lecturing was appropriate for the time when content was not as readily available and was more difficult to obtain. Due to rapid advancements in modern technology, lecturing is becoming increasingly less necessary for first exposure to content, because there are now a multitude of resources available to students via the Internet. Bowen claims that this has vast and critical implications, because higher education must refocus on creating substantial learning experiences in a student-centered environment or will struggle to survive in the face of change.

Bowen’s emphasis on being student-centered echoes Barr and Tagg (1995), who claim that there is a need to shift from instructor-centered teaching to student-centered learning. They provide a table (see Table 1.1) that compares these two paradigms, illuminating the variety of implications that must be addressed in such a shift.

Table 1.1 “Comparing Educational Paradigms” (Barr & Tagg, 1995, p. 17-19, selection).

THE INSTRUCTION PARADIGM	THE LEARNING PARADIGM
Mission and Purposes	**Mission and Purposes**
Provide/deliver instruction	Produce learning
Transfer knowledge from faculty to students	Elicit students’ discovery and construction knowledge
Improve the quality of instruction	Improve the quality of learning
Achieve access for diverse students	Achieve success for diverse students
Criteria for Success	**Criteria for Success**
Inputs, resources	Learning and student-success outcomes
Quality of entering students	Quality of existing students
Quantity and quality of resources	Quantity and quality of outcomes
Enrollment, revenue growth	Aggregate learning growth, efficiency
Teaching/Learning Structures	**Teaching/Learning Structures**
One teacher, one classroom	Whatever learning experience works
Independent disciplines, departments	Cross discipline/department
Covering material	Specified learning results
End-of-course assessment	Pre/during/post assessments
Grading within classes by instructors	External evaluations of learning
Degree equals accumulated credit hours	Degree equals demonstrated knowledge and skills
Learning Theory	**Learning Theory**
Knowledge exists “out there”	Knowledge exists in each person's mind and is shaped by individual experience
Knowledge comes in chunks and bits; delivered by instructors and gotten by students	Knowledge is constructed, created
Learning is cumulative and linear	Learning is a nesting and interacting of frameworks
The classroom and learning are competitive and individualistic	Learning environments and learning are cooperative, collaborative, and supportive
Productivity/Funding	**Productivity/Funding**
Definition of productivity: cost per hour of instruction per student	Definition of productivity: cost per unit of learning per student
Funding for hours of instruction	Funding for learning outcomes
Nature of Roles	**Nature of Roles**
Faculty are primarily lecturers	Faculty are primarily designers of learning methods and environments
Faculty and students act independent and in isolation	Faculty and students work in teams with each other and other staff
Teachers classify and sort students	Teachers develop every student's competencies and talents
Any expert can teach	Empowering learning is challenging and complex

Such a shift would address the “Seven Principles for Good Practice in Undergraduate Education” presented by Chickering and Gamson (1987), which include:

1. Encourages contacts between students and faculty
2. Develops reciprocity and cooperation among students
3. Uses active learning techniques
4. Gives prompt feedback
5. Emphasizes time on task
6. Communicates high expectations
7. Respects diverse talents and ways of learning

Research Frameworks and Designs

<u>Flipped Classroom Project (Chapter 2)</u>

How do instructors and students engage with first-time flipped classroom experiences in GIScience courses? How can these experiences inform future research into the appropriateness of the flipped classroom approach for teaching and learning GIScience?

The Department of Geography at the University of Georgia regularly offers a host of courses in GIScience and related fields such as remote sensing, etc., and like many academic programs across the United States and around the globe, there is a strong emphasis on the lecture/lab model for teaching and learning. The lectures are often heavy on content, and the lab is considered the primary active learning portion of the course. Because there has been evidence of substantial learning occurring from this model, it has continued for approximately a quarter of a century. But in light of rapid advancements in technology during this same time period and the consequent changes in the way teaching and learning occurs, investigating the means of embracing these advancements could achieve benefits for students, instructors, and the department as a whole, maintain the level of competitiveness with other academic programs that has been enjoyed for many years.

This research project aims to investigate the potential of the flipped classroom approach for teaching and learning to create substantial learning experiences for students in GIS courses. In "unflipped" (sometimes called "traditional") classrooms, first exposure to content happens in the classroom, and students engage with the material at home. But in the "flipped" classroom, first exposure to content happens at home, and students engage with the material in the classroom. The "flipped classroom" model, which is being widely adopted at all levels of education and across many subjects and disciplines, gives students more face-to-face time with teachers/instructors and creates an environment of discovery and teamwork that is more conducive to long-lasting, substantial learning. This type of learning experience echoes the characteristics of student-centered learning, as discussed earlier (Barr & Tagg, 1995; Chickering & Gamson, 1987). The goal of this research project is to determine the potential of the flipped classroom approach to contribute to the creation of substantial learning experiences in GIScience courses, pulling the content out of the classroom and creating more time for substantial learning to take place in the classroom, maximizing the utility of the limited face-to-face time that students have with their instructors that is currently being filled with lectures (Bowen, 2013).

Although there has been discussion of the flipped classroom and research on creating substantial learning experiences, there has been no research that puts the two together for GIS courses: utilizing the flipped classroom model to create substantial learning experiences in GIS courses, specifically. There is a significant amount of literature in the Scholarship of Teaching and Learning (SoTL), and there are several examples of SoTL research in geography and GIS, addressing problem- or activity-based learning (Drennon, 2005; King, 2008; Read, 2010; Srivastava & Tait, 2012), spatial thinking (Lee & Bednarz, 2009; Jo et al., 2012), web/distance learning and multimedia (Clarke et al., 2007; Elsner, 2005; Deadman et al., 2000), and highly creative, original course activities (Oyana, 2012; Mount & Priestnall, 2012; Songer, 2012). However, most of this existing literature follows the traditional SoTL method where the course instructor is the researcher performing research on the students in his/her course(s), utilizing some central question of inquiry related to teaching and learning. This research project separates the researcher from the course instructor in order to provide a more objective outsider perspective, which will provide a unique perspective from which to observe the implementation of the "flipped classroom" and gauge its appropriateness and effectiveness for teaching and learning GIS.

To address this project's research questions, the flipped classroom approach was implemented in existing GIScience courses at UGA with the cooperation of course instructors. To avoid introducing bias, any employment of the model in any course(s) taught by the researcher has not been included in the data collected for this project. The flipped classroom approach was employed for at least 1-2 (typically 2) class days per course; no entire course was flipped in this study. Only portions of course were flipped due to 1) the desire to gather instructors' and students' reactions to and reflections on the utilization of the flipped classroom model for teaching and learning in comparison to the traditional lecture/lab model and 2) the challenges associated with flipping for those instructors unaccustomed to the teaching and learning model. Nevertheless, instructors were encouraged to "flip" as much of their course as they were willing, to aid in gathering more data for the purposes of this research project. Flipping only one class per course per semester was discouraged, since it would not provide enough "samples" of utilizing the technique to reach an appropriate sample size from which to draw conclusions. The study's data were comprised of responses gathered from brief student surveys (using both closed- and open-ended questions) and the recording of brief after-the-fact interviews with course instructors. Additionally, the researcher was a non-participant observer, on both "non-flipped" (or "traditional") and "flipped" class days, gathering observations on the experiences.

Graduate Student Interviews Project (Chapter 3)

What are graduate students' reflections on their past and desired learning experiences in GIScience? How might their reflections contribute to curriculum revision and enhancement?

There have been numerous attempts to address curriculum concerns, which have materialized in the forms of the *Geographic Information Science and Technology (GIS&T) Body of Knowledge* and the *Geospatial Technology Competency Model* (*GTCM*) (DiBiase et al., 2006; DiBiase et al., 2010). It has been recommended that these two tools, the *GIS&T Body of Knowledge* (focusing on content)[3] and the *GTCM* (focusing on competencies, primarily for technicians)[4], be used in conjunction with one another for addressing curriculum revision and development.

This research project aims to show that there is another source of illumination for those attempting to address current curriculum concerns: the voices of graduate students. For the purposes of this research project, these graduate students are considered more "mature" learners than undergraduate students, as graduate students typically have a more cultivated understanding

[3] "Published by the Association of American Geographers (AAG) in 2006, the *Geographic Information Science and Technology Body of Knowledge* is an important reference work and classroom resource for teachers, students, and GIS&T professionals. It was produced as part of the Geographic Information Science and Technology Model Curricula initiative coordinated by the University Consortium for Geographic Information Science. It represents a comprehensive inventory of the GIS&T knowledge domain describing the conceptual foundations, analytical methods, visualization techniques and real-world applications. It is divided into 10 knowledge areas, 73 units and 330 topics, each of which is described in terms of formal educational objectives" (http://www.aag.org/cs/publications/special/gist, accessed July 12, 2016).

[4] "The Geospatial Technology Competency Model framework was developed through a collaborative effort involving the Employment and Training Administration (ETA), the GeoTech Center, and industry experts. "Over the course of 2013-2014, the GeoTech Center and industry subject matter experts updated the model with guidance from ETA to reflect the knowledge and skills needed by today's geospatial technology professionals" (http://www.careeronestop.org/competencymodel/competency-models/geospatial-technology.aspx, accessed July 12, 2016).

of their career aspirations and the kinds of learning experiences that they desire or require to accomplish their goals. This research project uses graduate students' reflections on their past and/or desired learning experiences in GIScience courses to inform curriculum enhancement efforts in geography departments at the University of Georgia and other educational institutions.

Courses in GIScience attract students of ever-increasing diversity, including those 1) specializing in GIS, 2) using GIS in other fields, and 3) whose education "could be enriched by awareness" of it (DiBiase et al., 2012), and this diversity is observable in graduate students taking GIScience courses as well. This diversity reflects the increasing diversity of the field as a whole, and curriculum development efforts may be well served by attempting to address this increasing diversity. There already exists evidence that there are deficiencies in current GIS programs; as Solem et al. (2008) observe, "many geographic and general skills are in high demand, yet the curriculum offered by academic departments may not producing those skills at a level required to satisfy that need" (370). Gathering the reflections that mature learners, such as graduate students, may have on these matters could be exceptionally illuminating and benefit curriculum enhancement efforts in GIScience. There are no existing studies of this particular nature, a qualitative study gathering the perspectives of graduate students' experiences and goals to inform curriculum revision and development in GIS.

The qualitative research method of gathering, transcribing, and analyzing one-on-one interviews, one of many "qualitative strategies in educational research" discussed in Wolcott (1992) and discussed in other writings on qualitative research (DeWalt & DeWalt, 2002; Emerson et al., 2001; Preissle & Grant, 2004), was utilized to address this study's research questions. Participants were drawn from graduate students at the University of Georgia who completed at least one GIScience course offered by the Department of Geography within the previous five years at the time of the interviews, which was the Spring semester of 2015. These graduate students discuss their past and desired learning experiences in GIS according to a flexible interview protocol, flexible in order to encourage thoughtful reflections and detailed responses. These perspectives are unique because there has been little engagement with the particular experiences of graduate students in the realm of academia and no engagement of this sort in the particular subfield of GIScience within geography. Results of this research project suggest that graduate students are a valuable resource of information for departments attempting to remain relevant and student-centered in their respective discipline-specific curricula.

<u>QGIS Workshops Project (Chapter 4)</u>

Can free and open source software facilitate a substantial learning experience? Specifically, how well can the QGIS software facilitate a substantial learning experience for color as applied in cartography and visualization?

An increasing number of employers are interested in hiring people with experience using free and open source software, and this is true for employers seeking to hire people for GIScience positions as well. This is because there is "growing global interest in and need for geographic information systems (GIS), especially among those with limited resources. Free and open source GIS software provides advanced management, visualization and analysis of geospatial data to those who cannot afford commercial GIS software licenses" (M. Madden, personal communication, July 5, 2016). These trends are leading toward greater democratization in the production and consumption of geospatial data, information, and knowledge. However, GIScience is rarely taught and learned using free and open source GIS software because some companies, such as ESRI, provide copies of their robust, yet closed-source, software to numerous academic institutions for free. Fortunately for those companies and unfortunately for the person without access to the software after graduation, a "lock-in" effect occurs, in which the person knows how to use only that particular software and has little to no experience with other software, such as free and open source software (Câmara et al., 2012). It is true that some skills are transferable among different GIS software, but there are still substantial learning curves to overcome when utilizing free and open source software alternatives. In the not-too-distant past, it was nearly impenetrable and difficult to use unless one was already entrenched in the development community, but quite recently, free and open source software alternatives are rapidly becoming more accessible and easier to use, particularly QGIS.

This research project addresses whether or not the free and open source software can facilitate a substantial learning experience, drawing from the scope of the *GIS&T Body of Knowledge*, which provides learning objectives that can be used in GIScience courses. However, as indicated by an examination of the learning objectives in the *GIS&T Body of Knowledge* against Bloom (1956)'s cognitive levels, which has since been updated by Anderson et al. (2001), DeMers (2009) indicates that the "average Bloom's level" varies by knowledge area and is "skewed toward lower learning levels" (S74-S75). Therefore, it would not be appropriate to gauge substantial learning by the explicit adherence to accomplishing the learning objective(s) listed in the *GIS&T Body of Knowledge*. Nevertheless, an examination of the learning objectives presented in the *GIS&T Body of Knowledge* would point toward appropriate content to be included in the creation of substantial learning experiences based on the *GIS&T Body of Knowledge*.

To address this project's research questions, a subsection of the *GIS&T Body of Knowledge* has been selected and reframed to meet the needs of facilitating substantial learning. The topic of choice selected was color for cartography and visualization, because the selection of color for maps and other visualizations is an issue faced by most, if not all, users of GIS attempting to communicate the results of their work. A standalone workshop was designed that utilized QGIS to facilitate a learning experience appropriate for novice and advanced users of GIS, familiar or not with concepts of color. This workshop was widely advertised, offered 10 times, and attracted over 200 participants, who completed pre- and post-workshop surveys. The pre-workshop survey contained questions about the participants themselves, and the post-workshop survey included questions about the learning experience of the workshop. Data were analyzed, and results were discussed, which were generally quite positive toward the experience, both quantitatively and qualitatively. Results suggest that substantial learning was achieved, that QGIS was beneficial for participants' learning, that QGIS can and should be incorporated into regular GIScience curriculum, and that concepts and software previously reserved for advanced courses can be taught to students in introductory courses.

These research projects create a body of new and original research on GIScience education. Directions for future research, inspired by each project, are explored at the end of each manuscript. The conclusion reviews how these projects are all related to one another, focusing on how each project has a student-centered focus. Other directions for future research in GIScience education are included in the conclusion.

CHAPTER 2

FLIPPING THE CLASSROOM IN GISCIENCE COURSES: PERSPECTIVES FROM STUDENTS AND INSTRUCTORS ON FIRST-TIME EXPERIENCES[5]

[5] Castellucci, E.S. and J.A. Knox. Submitted to *Journal of Geography in Higher Education*, 7/24/15.

Abstract

The flipped classroom strategy inverts when students are exposed to new information and where learning actually occurs. In this research study, the flipped classroom strategy is applied to the design of individual class days across five GIScience courses at a major research university. Data gathered on these first-time experiences include 24 class observations, 11 instructor interviews, and 66 student surveys. Results indicate that feelings are somewhat positive toward the flipped classroom but also highlight aspects of the designs that could be altered in the future for more beneficial experiences, such as more explicit, accessible instructions and more built-in accountability. The influence of "instructor-buy-in" is discussed for its influence on this study's results and importance for consideration in future studies.[6]

Introduction

Geographic information science (GIScience) is "an experimental research field that has geographic space as its object of study, geographic information as its means of representing knowledge and geographic information systems [GIS] as its disciplinary tool" (Painho et al., 2012). It is a rapidly evolving field, and there are numerous challenges that often arise when attempting to teach and learn it effectively, particularly staying up-to-date with the technology and best pedagogical practices as well as remaining relevant to students' needs. Compounding these challenges are simultaneous advancements in technology that are impacting teaching and learning, most notably when students are exposed to new information and where learning actually occurs. For example, Web 2.0 allows users to both download and upload content, providing opportunities for dynamic and active learning through learning management systems and virtual environments. Rising competitors to traditional residential education are online or

[6] This research study, which involves human subjects, was approved by the Institutional Review Board (IRB) of the Office of the Vice President for Research of the University of Georgia on August 28, 2014. This study's IRB identification number is STUDY00001223.

distance-learning courses or programs. Students now have a host of learning opportunities that they can pursue without physically leaving home. They can attend major universities that offer online courses and programs, which are often offered at a reduced rate in comparison to residential programs.

To justify its increasing cost, residential higher education does well to question what it offers that online education cannot. According to Bowen (2012), residential education offers "face-to-face time." When this is maximized through the use of teaching and learning strategies that invert the traditional in-class lecture and out-of-class homework model, what can result is substantial learning that online education still struggles to achieve (pp. ix-x). Inverting traditional class time and homework activities is known as the "flipped classroom." Popularized by high school teachers who want to revolutionize learning in their chemistry classrooms (Bergmann & Sams, 2012), the flipped classroom technique has become widespread in K-12 education and is increasingly popular for higher education. This paper begins to assess the appropriateness of the flipped classroom technique for GIScience at a major research university by looking at first-time experiences flipping GIScience classes and inviting perspectives from both students and instructors. The questions this research study attempts to answer are as follows:

1) How do instructors and students engage with first-time flipped classroom experiences in GIScience courses?
2) How can these experiences inform future research into the appropriateness of the flipped classroom approach for teaching and learning GIScience?

Literature Review

There is no extant peer-reviewed research on the appropriateness or effectiveness of the flipped classroom technique in GIScience courses. To provide a general overview of literature relevant to this study, two largely distinct areas are examined: 1) GIScience education literature and 2) flipped classroom literature, with connections drawn between the two as appropriate.

GIScience education literature

A sizable portion of GIScience education literature emphasizes curriculum concerns utilizing the *Geographic Information Science & Technology (GIS&T) Body of Knowledge* (DiBiase et al., 2006)[7] and/or other organizing approaches. The *GIS&T Body of Knowledge* has been used in several studies focusing generally on curriculum design, assessment, and evaluation (Demers, 2009; Hossain & Reinhardt, 2012; Prager, 2012; Prager & Plewe, 2009), and it has been used in conjunction with the *GTCM* to propose a more flexible framework for curriculum within GIScience higher education (Veenendaal, 2014). Other studies concerned with curriculum have considered Kolb's learning styles and learning cycle and proposed spiral course design (Foote, 2012a; Foote, 2012b; Healey & Jenkins, 2000; Kolb, 1984; Szablowska-Midor, 2012), taken an ontological-based approach to design (Painho et al., 2007; Painho & Curvelo, 2012), and focused on special curriculum concerns for online learning environments (Huang, 2011; Weibel et al., 2012).

Case studies compose a considerable portion of GIScience education literature. Many discuss individual classroom experiences and primarily include reflections from the instructor's point of view. Others include more data collection and analysis, utilizing both quantitative and qualitative methods. Increasingly popular are studies involving online learning (Clark et al., 2007; Mount & Priestnall, 2012; Songer, 2012) and problem-based learning (Giordano et al.,

[7] "Published by the Association of American Geographers (AAG) in 2006, the *Geographic Information Science and Technology Body of Knowledge* is an important reference work and classroom resource for teachers, students, and GIS&T professionals. It was produced as part of the Geographic Information Science and Technology Model Curricula initiative coordinated by the University Consortium for Geographic Information Science. It represents a comprehensive inventory of the GIS&T knowledge domain describing the conceptual foundations, analytical methods, visualization techniques and real-world applications. It is divided into 10 knowledge areas, 73 units and 330 topics, each of which is described in terms of formal educational objectives" (http://www.aag.org/cs/publications/special/gist, accessed July 12, 2016).

2007; King, 2008; Read, 2010). Particularly noteworthy are studies on spatial thinking (Lee & Bednarz, 2009; Jo et al., 2012), which contribute to the goals advocated in *Learning to Think Spatially* (National Research Council, 2006), as well as studies that emphasize active learning (Srivastava & Tait, 2012), which include many of those previously mentioned. Incorporating active learning strategies is encouraged as a means to deepening student learning (Schultz, 2012) and an opportunity to address troublesome knowledge, an area in GIScience education that still needs to be researched and addressed (Bampton, 2012). There have been several studies focused on active learning in the *Journal of Geography in Higher Education* in recent years (van der Horst et al., 2016; Cantor et al., 2015; Fagan & Sturm, 2015; Clark & Zeegers, 2015; Fuller & France, 2015; Marvell et al., 2015; Anderson, 2013; Pande et al., 2013; and Srivastava & Tait, 2012), but none has examined active learning within the context of the flipped classroom.

Closest in design to this research project is a study on education design research (EDR) for teaching and learning with geographic information systems (GIS) (Favier & van der Schee, 2012). EDR is described by the authors as interventionist, iterative, process-oriented, and utility-oriented. The experience discussed in Favier and van der Schee involved the cooperation of several teachers, presumably high school as indicated by students' ages. The researchers gathered 1) videos of lessons, 2) field notes, 3) interviews with students, 4) student work, 5) surveys of students, and 6) interviews with teachers. However, their work does not focus on the flipped classroom, which is the focus of this research study. Also, this study focuses on teaching GIScience itself, not teaching with GIS, which are two separate categories of research (Baker et al., 2012).

Flipped classroom literature

In a flipped classroom, students' exposure to new material

> "moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter" (Flipped Learning Network, 2014).

This approach increases the amount of in-class time that instructors can use active learning strategies, better achieving the third of the "Seven Principles for Good Practice in Undergraduate Education" (Chickering & Gamson, 1987):

1. encourages contact between students and faculty;
2. develops reciprocity and cooperation among students;
3. uses active learning techniques;
4. gives prompt feedback;
5. emphasizes time on task;
6. communicates high expectations; and
7. respects diverse talents and ways of learning.

Employment of the flipped classroom strategy may assist instructors in meeting all seven of these principles, because it may simultaneously allow for more up-to-date content and skills to be incorporated into current and future GIScience courses, while at the same time keeping the focus on student-centered learning rather than instructor-centered teaching (Barr & Tagg, 1995).

Common in the education literature that focuses on the flipped classroom are studies that compare flipped classes with "traditional" classes. One study that compared traditional and flipped versions of the same engineering course observed that it took about four weeks for students to grow accustomed to the flipped format (Mason et al., 2013). Another study that compared traditional and flipped versions of the same business course observed that students' feelings were mixed toward the flipped classroom (Findlay-Thompson & Mombourquette, 2014). Finally, another study on a flipped business course observed that students' responses changed from skeptical to favorable throughout the semester (Butt, 2014). It is noteworthy that in the examples above, the first two studies utilized video lectures, whereas the third did not. Although the more traditional means of "flipping" a class utilizes video lectures, the idea behind the flipped classroom strategy does not exclude other methods of exposing students to new information. These and other discussions on the flipped classroom (Tucker, 2012; Bishop & Verleger, 2013) or on successful flipped classroom experiences (Stoltzfus, 2014; Sullivan, 2014; Talley & Scherer, 2013) usually refer to experiences that utilize video lectures, but not always (Aronson & Arfstrom, 2013).

Unfortunately, there is little description in the literature of the specific activities completed in flipped classes. Bishop and Verleger (2013) recommend that "researchers clearly describe the activities used for both in-class and out-of-class activities (this was not always clear for studies we examined)" (p. 12). This research study meets this need with descriptions of both pre-class preparation and in-class activities for all flipped class days included in this study. This research study also contributes to the calls for more Scholarship of Teaching and Learning (SoTL) research in GIScience education (West, 2012; Solem et al., 2009; Jenkins, 2013).

Study Scope and Methods

At a major research university's geography department, four GIScience instructors teaching a total of five GIScience courses during the fall semester of 2014 were invited to participate in a study that 1) encouraged the design and implementation of flipped class days and 2) gathered instructors' and students' perspectives on these first-time experiences. The subjects of the five GIScience courses included a variety of introductory and advanced topics in GIScience, including GIS and remote sensing. One course was open only to undergraduate students, and the other four courses were open to both undergraduate and graduate students. A total of 69 students consented to participate in the study of the 107 students registered for these classes in total; this is a participation rate of approximately 64%. A variety of courses were chosen to increase sample size, providing opportunity to gauge the potential appropriateness and effectiveness of the flipped classroom strategy for teaching and learning GIScience in general.

It is important to note that unlike most SoTL literature, where the instructor and the researcher are the same person, this study separated the instructor from the researcher. This was done to address the potentially confounding variable of the combined instructor/researcher role on the study's results, where it may be unclear whether a method succeeds or fails due to the method itself or due to the teaching characteristics of the instructor/researcher. Therefore, for this study the researcher and instructors had to compromise how much their courses would be "flipped" for inclusion in this study. What makes GIScience courses unique for "flipping" is the fact that it is still frequently taught in separate lecture and lab sessions, and this research study focuses *only* applying the flipped classroom approach to the *lecture* sessions, exploring whether or not "flipping" the lecture sessions may enhance students' learning experience.

Instructors were encouraged to flip at least two lecture sessions over the entire semester because the instructors and students could have developed some familiarity with the flipped classroom approach from the initial experience to better engage with the second or following experiences. The researcher expected that responses to repeated attempts following the initial experience might generate more favorable results based on the findings by Mason et al. (2013). For those courses that met only once a week, instructors were provided with the option of flipping only a portion of their class, and for those instructors who took advantage of this option, it was usually half their class. The researcher investigated the instructors' familiarity with the flipped classroom and then brainstormed with them for appropriate pre-class preparation and in-class activities. The instructors were not required to conform to any particular style of flipped class, as long as they respected the general intention of the flipped classroom method, and the final design and implementation were the instructors' responsibility.

Three types of qualitative data were gathered in this study: class observation notes, surveys of students, and interviews with instructors. Class observations were scheduled for both traditional class days (before and/or following flipped class days) and all flipped class days. Observation notes were gathered by the researcher from the perspective of a non-participant observer; notes were taken on the activities being performed by both instructors and students, usually throughout the entire class period. After each flipped class day, students who consented to participate in the study received a request to complete a survey, which contained eight open-ended questions and three Likert-scale questions (see Appendix A). Additionally, after each flipped class day an interview was completed with the instructor; interviews were in-person, audio-recorded, and transcribed. All participants were assured that their responses would be shared anonymously in an attempt to encourage honesty and preserve the validity of this self-reported data.

Student surveys after flipped class days were analyzed in two parts. First, the Likert-scale responses were assigned numerical values, and their means were calculated. These means were used to determine overall favorably toward the flipped classroom, as well as in conjunction with the number of respondents per flipped class day to determine the "highest" and "lowest" rated experiences. Second, the open-ended questions were grouped according to the themes of the students' answers, and these answers were used to gain insight into why certain flipped class experiences were rated more or less favorably than others. Instructor interviews were analyzed by categorizing content into themes based on 1) teaching background and familiarity with the flipped classroom, 2) design considerations for each flipped classroom experience, 3) challenges encountered and suggestions for improvement, and 4) general observations. Students' and instructors' responses were combined where common themes were present, and their responses were compared to provide insight on using the flipped classroom strategy in GIScience courses.

Position Statement

As appropriate to qualitative research, it is important to note the researcher's background experience and expectations, as they influence the motivations and direction of this research study. The researcher, having taken many GIScience courses (10+), experienced many course designs featuring separate lecture session and lab sessions, resulting in what the researcher felt was a gap between the content covered in lecture and the application in lab. The researcher hoped that the flipped classroom, applied to students' learning experience in the lecture portion of the course, might help students' "bridge" the gap between lecture and lab and better understand how the two are connected and build upon one another. Additionally, as many of the lectures experienced during the researcher's coursework typically featured minimal engagement, between instructor and students and especially among students, it was additionally hoped that the flipped classroom approach might increase interaction and engagement in class.

Before the semester in which this study's data was gathered, the researcher had no personal experience with teaching using a flipped classroom approach. During this semester, the researcher had the opportunity to guest lecture. In this experience, the researcher provided lecture videos in advance of class and reserved class time for activities focused on students' learning. The researcher felt that the experience was a positive one and inspired further reflections on the flipped classroom approach as applied to GIScience courses.

Results

Throughout the course of this study, 13 traditional classes and 11 flipped classes were observed, 11 interviews with instructors were conducted at an average of ~35 minutes in length, and 66 surveys of students were collected with an overall response rate of 43%. Observation notes, survey responses, and interview transcriptions totaled 118,706 words (~220 pages) of raw data. In response to the call from Bishop and Verleger (2013) to provide more detail about pre-class preparation and in-class activities, these items have been collected for all 11 flipped classroom experiences and included in Table 2.1.[8]

Table 2.1 Pre-class preparation and in-class activities for each flipped class day.[9]

Flipped Classroom Experience	Pre-class Preparation	In-class Activities
Day 1	Read lecture slides.	Large group activity to complete a chart on the board. Individually search for data on lab computers and email instructor results.
Day 2	Read assigned text and lecture slides. Prepare question(s) or subtopic based on the readings to contribute to class discussion.	Small group discussions followed by large group discussion.
Day 3	None.	Tour valuable campus resource, relevant to course content. Answer questions provided by instructor in advance and email responses to instructor.
Day 4	Read lecture slides. Bring questions to class.	Instructor lets each student present questions and areas of concern. Lecturing.
Day 5*	Read provided material. Prepare presentation on material with small group of students to present in class.	Small group presentations.

[8] Topics of each flipped class day are not shared for anonymity purposes.
[9] Days 5 and 11 are two separate flipped classroom experiences despite their identical appearance here. (Different course content was covered on these days.)

Day 6	Read lecture slides.	Read handout provided in class. Small group tasks: create discussion questions and present questions to other small groups to answer. Large group question/answer session.
Day 7	Read assigned text and paper. Prepare to present in class.	Randomly selected student presentations, interspersed with short lectures. Small group discussions.
Day 8	Read and research provided materials. Be prepared to discuss in class.	Relay-style discussion as large group; all students must participate.
Day 9	None.	Online mapping exercise, completed individually.
Day 10	Read and research court case related to course content.	In class debates of court cases.
Day 11*	Read provided material. Prepare presentation on material with small group of students to present in class.	Small group presentations.

As shown in Table 2.1, instructors chose a variety of pre-class preparation tasks and in-class activities. This resulted in widely varying degrees of "flipped-ness", meaning that some classes were more "flipped" than others. The "flipped-ness" of each attempt at flipping a class is determined by both the activities performed before class and the activities performed during class. To gauge the degree to which classes were flipped, the following questions (and others) were considered:

- Are students expected to expose themselves to new information in preparation for class activities? (If no preparation is required, this is substantially less flipped.)
- How much lecturing takes place during class time? (If the instructor reverted to lecturing, it is less flipped according to how much lecturing took place.)
- Are lecture slides provided in advance, and if so, is it with or without narrative? (If lecture slides are posted without narrative, it is substantially less flipped.)

For example, Day 4 was the least flipped of all flipped class days included in this study, because the instructor provided the lecture slides in advance of class without narrative and, as a result, reverted to lecturing for the majority of the class time.

This was reflected in students' responses to Question 2 of the survey for this day, which rated Day 4 least different from a normal class day of all flipped class days included in this study. To be clear, Question 2 is not a measure of "flipped-ness." It is a measure of similarity/difference, asking, "How similar were the activities on this day to the activities on other days in this course?" Responses were Entirely Similar, Somewhat Similar, Somewhat Different, and Entirely Different. The researcher hoped that participants would rate flipped class days "entirely different," if the class had been taught primarily with lectures to that point. The other side of this, however, is that in a class that is already more interactive, participants might rate a flipped class as somewhat or entirely "similar," which is why Question 2 is not measure of "flipped-ness." Question 2 is a measure of similarity/difference. In the case of Day 4, this class was taught primarily with lectures, so its average rating of most similar, in comparison to all other flipped class days, indicates that participants felt the flipped class day was little different from the norm, primarily lecturing.

"Flipped-ness" is a relative concept in this study. These varying degrees of "flipped-ness" are considered acceptable for this study because it was flexible enough to encourage participation from instructors. Additionally, accepting that the flipped classroom experiences would be different provided for greater opportunity to investigate the nuances of instructors' and students' first-time experiences with the flipped classroom approach. In the end, all flipped class days observed in this study did incorporate at least some distinctively flipped elements (collaborative activities, active learning strategies, etc.).

Likert-scale responses

Looking at all flipped classroom experiences included in this study, students' overall responses indicate feelings that are somewhat positive toward the flipped classroom. In response to Question 7, which emphasizes engagement and perceived value, the overall mean was 3.48 (on a scale of 1-5, with 5 most engaging and valuable). For Question 10, emphasizing students' desire to see the design replicated in the future, the overall mean was 2.12 (on a scale of 1-3, with 3 most desirable).

To shed more light on the Likert-scale results for all flipped days included in this study, students' responses were divided into two groups corresponding with 1) initial attempts (first tries) and 2) repeated attempts (second, third, etc. tries). Of the 66 surveys submitted for the study, 37 responses were submitted after initial attempts, and 29 responses were submitted after repeated attempts. From initial attempts to repeated attempts, the mean for Question 7 increased from 3.42 to 3.55, and the mean for Question 10 increased from 2.05 to 2.21. These means were compared for statistical significance using t-tests, resulting in p-values of 0.6274 and 0.3973, respectively. Therefore, neither increase was found to be statistically significant at a significance threshold of $p \leq 0.05$. The researcher's hypothesis that students' feelings towards the flipped classroom approach may have become more favorable with repeated attempts cannot be confirmed from these results. Mason et al. (2013) found that it took at least four weeks for students to grow accustomed to a flipped classroom structure, so more favorable results might still have been obtained if more class days had been flipped in each course. However, an effort on the scale of Mason et al. (2013) was beyond the scope of this project.

Students' responses to Questions 7 and 10 of the survey also provide opportunity to 1) identify which flipped class experiences were more or less favorable than others and 2) inquire why the particular days rated most and least favorable were rated as such, potentially providing valuable information on using the flipped classroom strategy in these courses and in GIScience in general. Because the number of student respondents per each flipped class experience varied dramatically, ranging from 1 to 13, it was deemed desirable to omit those days for which the number of respondents was fewer than the mean number of respondents, which was 6. Therefore, only Days 2, 5, 7, 8, and 10 were included in the determination of highest and lowest rated flipped class day experiences (see Table 2.2).

Table 2.2 Means of student responses to Likert-scale survey questions. Higher ratings are more favorable, and lower ratings are less favorable.[10,11]

Category	Flipped Class Day(s)	Number of Respondents	Engagement/Value (Question 7) Scale of 1-5	Desirability (Question 10) Scale of 1-3	Rating
Single attempts*	Day 2	10	3.80	2.20	
	Day 5	8	3.00	2.00	
	Day 7	7	2.86	1.57	Lowest
	Day 8	13	3.00	1.92	
	Day 10	10	3.90	2.40	Highest
	Other days	18	3.89	2.33	
Initial / repeated attempts**	Initial	37	3.42	2.05	
	Repeated	29	3.55	2.21	
All attempts	ALL	66	3.48	2.12	

Day 10 ranked highest for both Question 7 (scale of 1 to 5) and Question 10 (scale of 1-3) with scores of 3.90 and 2.40, respectively, and Day 7 ranked lowest for both questions with scores of 2.86 and 1.57, respectively. These means were compared for statistical significance using t-tests, resulting in p-values of 0.02753 and 0.04509, respectively. Therefore, these differences between these flipped class days' means for Questions 7 and 10 are statistically significant at a significance threshold of $p \leq 0.05$. Students' responses to the corresponding open-ended

[10] Emphasizes days with greater than the mean number of respondents. Days with fewer than the mean number of respondents are grouped into "Other days". The mean number of respondents is 6.
[11] Compares initial (first) attempts with repeated (second, third, etc.) attempts. Note the increase in response to both questions in repeated attempts versus initial attempts.

questions provide insight regarding why Day 10 ranked most favorable and Day 7 ranked least favorable.

Highest rated: In-class debates (Day 10)

Day 10 featured in-class debates of court cases relevant to GIScience and was rated highest among students for being an engaging and valuable learning experience and for being a class structure that students would like to see again in the future. A close look at students' elaborations upon their Likert-scale answers reveals that students were highly engaged and their learning benefited from the experience. Students expressed that "it was engaging for nearly everyone in the team to act like a lawyer. And [the court cases] were very good examples… It was a fantastic experience that enhanced what we learned" (Student C2-3[12]) and "I learned about the trial in depth and how it relates to GIS… Being expected to be ready – this made me actually do the readings" (Student C2-7). However, despite the favorable responses of students due to the level of engagement experienced on this class day, there were a comparable number of responses that indicated students' concerns about the activity's relevance to course content and goals, e.g.:

> "I wouldn't say that it was a very educational experience. Definitely entertaining but not very educational because the aspects of the case that were discussed were not GIS related points… The debate was fun but I didn't take anything away that was actually useful to succeeding in the course" (Student C2-10).

Students' concerns about relevance were also echoed by the instructor, who stated,

[12] Responses from students are coded first by course (A, B, C, D, or E), second by flipped classroom attempt (first, second, etc.), and finally by the order in which the student's response was received (following a dash).

> "My expectation for them was to argue based on the knowledge or technology of GIS, which to be honest I didn't get a lot, but then again, this is the first time we run that, so maybe next time I will be more specific" (Instructor C[2] [13]).

This would directly address concerns voiced by students over the need for more direction: "[We need] better instructions for the project/better defined expectations for what each group was supposed to do in preparation. We just kind of read the article and winged it because there was so little guidance on what to do" (Student C2-5). Although rated highly for engagement, both students and instructors voiced concerns over the relevance of the discussion to the course content. Both parties expressed confidence that more specific directions might have helped the focus of the experience stay even more relevant to the course while maintaining a high level of engagement.

Lowest rated: Randomly selected student presentations (Day 7)

Day 7 featured randomly selected student presentations interspersed with short lectures and ending with small group discussions. This flipped day appears to be rated lowest primarily due to two factors: 1) ineffectiveness of randomly selected student presentations and 2) lack of explicit, accessible directions to guide student preparation and class activities. Students address the first factor almost unanimously in their responses to Question 6, e.g. "When students presented. I wasn't clearly able to follow their explanations and thus couldn't improve my understanding of the method" (Student E2-2). Although not explicitly stated, students' struggles were not necessarily with presenting but rather with learning the content. Students were expected to read and prepare from *new* materials, a factor that a student explicitly addresses in response to Question 9 saying, "Maybe it should be review material, as opposed to having

[13] Responses from instructors are coded by course (A, B, C, D, or E). The number following the course code is followed by a number in brackets which indicates flipped classroom attempt (first, second, etc.).

student introduce material that is completely new" (Student E2-5). Students were not assigned the portion(s) to present in advance of class; they were simply expected to be prepared to present on any portion of the new material. Additionally, the instructor neither lectured nor facilitated small group discussions in advance of students' presentations.

Indirectly addressed in the above responses are indicators of the second factor that likely contributed to the rating of this flipped class day as lowest, which was the lack of explicit, accessible directions. The instructor verbally announced the flipped class preparation and activities the week before but did not make accessible via hard copy, course website, or email any explicit directions to which students could refer while preparing at home. When asked whether or not an email would have helped accountability, the instructor responded, "Email probably was something in writing, but I didn't feel they forgot about what they supposed to do. They just didn't do it. Well, I can do the email. I just don't know whether or not that will help significantly" (Instructor E[2]). By contrast, students felt that such directions and reminders would have beneficially guided student preparation and class activities, e.g.:

> "Due to the fact that the class only meets once a week… it was difficult to recall exactly how we were supposed to prepare for the flipped classroom… Written instructions (perhaps hardcopy) of how we were supposed to prepare and perhaps a reminder email… would be greatly appreciated" (Student E2-1).

Although there were substantial challenges experienced with this flipped class day, some students' responses indicated feeling positive that if changes were made, the experience could be replicated in a way much more beneficial to learning.

Despite the discussion above of the challenges experienced with this flipped class day, participants did identify elements of the experience which were considered beneficial for helping students learn. As reflected in students' responses, the small group discussions were particularly beneficial, and achieving a balance among lecture, group discussions, and presentations would likely achieve an ideal balance for this flipped class experience.

> "In the second part of the class we broke into small groups to discuss application. This was more effective than student teaching but still less than the professor's lecturing… The most beneficial part was the teacher lecturing with some group discussion after. It is the most steady reliable way for me as a student to process and analyse new information" (Student E2-3).

Another student added, "Perhaps if it was ordered differently (lecture first before presentations)" (Student E2-2). As indicated in the responses following this particular experience, lecturing, group discussions, and presentations can each have a place and purpose in a flipped class.

<u>Other major trends observed</u>

Returning to all flipped class day experiences included in this study, other major trends were observed upon analysis of students' and instructors' responses as a whole.

Incorporating accountability measures

Instructor responses indicated the need for more accountability in the design of pre-class preparation and in-class activities.

> "I feel like a lot of them didn't really do the work… I think [the flipped classroom] is a great idea, but the success of it depends on two things, two ends. One is the classroom time; the other is really the learning time at home… I think I will try to find strategies to improve students' accountability to do their work at home" (Instructor C[2]).

Concerns regarding accountability were echoed by students. In their responses, some students included practical suggestions for how accountability measures could have been incorporated into the flipped classroom experiences they were reviewing, e.g.:

> "I think people could come into class with questions and discussion ideas about the topic and the groups could select or improve on one of those so that a more significant amount of time could be given to discussion rather than creating a question" (Student B3-2).

After flipped classroom activities that required students' preparation, students responded favorably to the built-in accountability measures, e.g. "I found that I was more engaged in the class because I knew participation was expected… This was beneficial because I learned the material well instead of procrastinating" (Student C1-5). As indicated by this response, accountability measures can result in more thorough attempts to learn new material before class and a more engaging class environment.

More generally, accountability also factors into helping students take control of their learning. However, two instructors had somewhat opposing opinions on the matter. One instructor commented, "They're more accountable for their learning… It benefits some students more than others, so there will be a large disparity among students" (Instructor 3[2]), but the second instructor observed,

> "They are in control or in larger degree of control, because it's up to them to what extent, to what degree they want to prepare… The minimum line is still the same, like whether they do traditional or flipped… I need to think of how to encourage them to do more, not just simply be satisfied with finish reading" (Instructor C[2]).

While the first instructor is concerned about great disparities among student learning, the second instructor recognizes an opportunity afforded by the flipped classroom strategy. The flipped classroom approach challenges instructors to encourage students to go beyond the minimum requirements to deepen and broaden learning, which the second instructor claims is difficult to do when exclusively lecturing.

Scheduling and subject matter

None of the instructors who participated in this study were exceptionally familiar with the flipped classroom, and none had explicitly incorporated the flipped classroom strategy into the design of their courses, though some class days contained various elements similar to those seen in flipped classrooms. Instructors opted to flip only a portion of their courses, rather than their entire courses as commonly seen in flipped classroom studies. As a result, there were comments from both instructors and students regarding which part(s) of semester would be most ideal for flipping.

Students responded in favor of using the flipped classroom strategy from the “beginning of the semester” and using it continuously “rather than just a few days” so that they could “settle into a routine” (Students E2-7 and E1-6). By contrast, instructors suggested teaching the first half of the semester with traditional face-to-face lectures and the second half with the flipped classroom approach, basing their concerns on the appropriateness of course content. They felt that the approach would be most appropriate for advanced topics or in “advanced courses” (Instructor D[1]). However, at least one student had a completely opposite opinion on the matter, responding to Question 10 saying that the flipped classroom activities would be more suitable “for some part of the class which has easier content” (Student E1-3).

<u>Comments on the use of videos</u>

Videos were never used in any of the flipped classroom experiences included in this study, despite the popular use of lecture videos in many flipped courses. Rather, most instructors provided their students with their lecture slides with no alterations or additional commentary. This was surprising, because although it is possible to give students lecture slides without lecturing, this typically requires substantial editing. The very nature of using slides is to be an *accompaniment* to a presentation, so to provide lecture slides without narration is ineffective for student learning. As a result, concerns were raised by students that were echoed by instructors. One student observed, "[The slides] didn't have any explanation so examples didn't make any sense… It might be handy if the lecture slides were better constructed for this format rather than just handed to us without additional context" (Student E1-8). Another student suggested, "This class could be improved by providing a lecture with voice-over / video in order to better learn the material so we can delve right into the activities" (Student B1-2). With respect to the uniqueness of teaching and learning GIScience, an instructor echoed this response saying, "If you just show the slides, they may not fully understand that, and video is a better way" (Instructor A[1]). Yet despite the additional benefits to be gained from including the commentary with the slides, instructors raised additional concerns regarding feeling self-conscious at being recorded and the amount of time and work involved in making videos.

Discussion

Participants' reactions to the highest and lowest rated flipped class day suggest that students may have preferences on the order of activities to promote an optimal learning experience. Of lecturing, group discussions, and presentations, students prefer those activities in that order. Student responses indicate that guided exposure to new material with instructor guidance, such as through lectures, is desirable as a first step to learning. Small group discussions are deemed an emotionally safe (as opposed to stressful) and appropriate second step for students to process this new material before venturing into the "riskier" world of presenting, especially if the presentations are randomly selected. Balancing these three elements so that a cyclical learning experience can occur could promote an optimal learning experience and could take multiple forms; e.g., lectures could be given virtually through the use of videos, and group discussions followed by presentations could be repeated throughout the duration of the class. Such a cyclical design of activities reflects Kolb's learning cycles (Kolb, 1984) as applied to GIScience education as discussed by Foote (2012b).

When implementing a flipped classroom course design, such as the one just described, students need to have had their first exposure to the material and have completed any necessary preparation to be an active participant in class. Therefore, what happens outside the classroom is just as important as what happens in the classroom, and accountability is essential to the success of the flipped classroom strategy. Many instructors' concerns about the flipped classroom and student preparation would likely be addressed by building accountability measures into pre-class preparation, such as having students complete low-stakes tasks. Accountability measures can also be established when students clearly understand how their upcoming class activities are dependent upon their pre-class preparation. Either way, accountability helps students learn to take control of their learning, and the opportunity that the flipped classroom method affords instructors is the chance to inspire students to go beyond what the course requires to deepen and broaden their learning.

Finally, the researcher observed that there seems to be some confusion in instructors' minds regarding whether or not lecturing is "allowed" in a flipped classroom experience, but the answer lies not in whether or not it is "allowed." The answer lies in where and how the lecturing takes place. In a flipped classroom setting lecturing can occur, but it usually takes place at home, using lecture videos. The commentary is important for students' understanding of the new material, and it is best included in an accessible format. Speaking of the lecture commentary, it was observed during the lectures on both non-flipped and flipped class days included in this study that very few students, if any at times, were taking notes during the lectures. Many students just listened to the lecture, and still others were distracted by activities on their computers or cell phones that were not related to class. Therefore, even in face-to-face lectures, a substantial portion of the instructors' commentaries are being lost. Altering these slides to include the commentary or providing voiceover or video for the slides could permanently attach the commentary for access at a later time, and these could be easily incorporated into a flipped classroom course design.

Instructor "Buy-In"

Observations of these first-time experiences reveal a substantial component of successful flipped classrooms: "instructor 'buy-in.'" It is expressed in the literature that student buy-in, helping students understand the purpose behind and commit to the flipped classroom approach, is important for successful flipped classrooms. Based on the experience of completing this study the researcher would argue that the same is true for instructors; it is critical that instructors "buy-in", i.e. understand the purpose behind and fully commit, to the flipped classroom approach in order to have a successful flipped classroom experience. This is also expressed in existing literature (McKinney & Chick, 2013; Roberts et al., 2014; Orlando, 2012). Instructors who are not fully committed to the flipped classroom approach may inadvertently foil attempts to gauge the actual appropriateness and effectiveness of this or any other pedagogical intervention. The researcher, from the perspective of the non-participant observer, feels that the flipped classroom experiences reflected in this study 1) are, at least in small part, partially the result of different levels of "buy-in" on the part of instructors and 2) are not representative of what flipped classroom experiences in GIScience could be. Therefore, the researcher would caution GIScience instructors from making any decisions regarding whether or not to adopt the flipped classroom approach based on these results. There is still much research to be done on flipping the GIScience classroom. Additionally, the flipped classroom approach to teaching and learning is not considered the answer to all teaching and learning related concerns. It may not be appropriate for all contexts, but engagement with flipped classroom approach does encourage instructors to question the effectiveness of the activities they choose for their students, both for pre-class preparation and in-class activities. Such an exercise is exceptionally valuable for instructors facilitating face-to-face learning experiences, as residential higher education seeks to remain relevant in a world of proliferating online education opportunities.

Conclusion

These first-time experiences flipping the GIScience classroom examined in this study yielded student survey and instructor interview responses that were somewhat positive toward the flipped classroom. These responses also highlight aspects of the designs that could be altered in the future for more beneficial experiences. Engagement seemed higher on flipped class days than normal class days based on observation and participant responses, and student learning appears to have benefited from the some of the experiences. Students noted that more explicit, accessible directions and clearer ties to course content and goals would have benefited their learning. Instructors noted possible benefits for future class days, including incorporating the flipped classroom into the course design and syllabus and building accountability into pre-class preparation and in-class activities. Students and instructors had different opinions about scheduling and designing flipped classroom experiences, as well as what content is most appropriate for flipped class days. Finally, the effective inclusion of lecture commentary during pre-class preparation remained elusive in this study, and the issue of "instructor 'buy-in'" was noted as an influence on results that needs to be addressed in future studies.

Future studies on using the flipped classroom strategy for GIScience could continue in several different directions from this study's examination of first-time experiences. One possible direction could be taking a closer look at using lecture videos in GIScience courses and the design of appropriate corresponding in-class activities. Another possible direction could be investigating the design, implementation, and effectiveness of various accountability measures to encourage the completion of pre-class preparation and participation in class. It is hoped that this research study will encourage more GIScience and geography instructors to consider 1) incorporating new teaching and learning strategies into their course designs, 2) turning their classrooms into research opportunities, and 3) contributing to the ongoing dialogue about effective teaching and learning practice in GIScience and geography education.

CHAPTER 3

GRADUATE STUDENT PERSPECTIVES ON GISCIENCE CURRICULUM: A CASE STUDY IN THE UNIVERSITY OF GEORGIA'S DEPARTMENT OF GEOGRAPHY[14]

[14] Castellucci, E.S. and J.A. Knox. To be submitted to *Research in Geographic Education*.

Abstract

The experiences of graduate students remain largely unexplored in GIScience curriculum research. Yet, as more 'mature' learners, graduate students have a more cultivated understanding of their career aspirations and the kinds of learning experiences that they desire or require to accomplish their goals, in contrast to many undergraduate students. Therefore, graduate students are a valuable resource for educators seeking to keep their GIScience curriculum relevant and student-centered. This qualitative research study explores 1) graduate students' reflections on their past and desired learning experiences in GIScience and 2) how these reflections may benefit curriculum revision and enhancement efforts. Thirty University of Georgia graduate students, who had completed GIScience courses in the university's geography department, were interviewed regarding department-level curriculum. Their feedback was analyzed according to GIScience course and according to overarching trends. Results indicate that graduate students in UGA's Department of Geography have substantive opinions on content and seek opportunities to develop skills through hands-on learning, specifically in regard to programming for GIScience. They are also concerned with being marketable and competitive when seeking a job. These and other results are discussed at length in this paper in the students' own words, along with directions for future research.[15]

Introduction

There have been numerous attempts to address curriculum concerns in Geographic Information Science (GIScience) education, most notably the *Geographic Information Science*

[15] This research study, which involves human subjects, was approved by the Institutional Review Board (IRB) of the Office of the Vice President for Research of the University of Georgia on November 22, 2014. This study's IRB identification number is STUDY00001426.

and Technology Body of Knowledge (GIS&T Body of Knowledge)[16], which focuses on content, and the *Geospatial Technology Competency Model* (*GTCM*)[17], which focuses on competencies (DiBiase et al., 2006; DiBiase et al., 2010). It has been recommended that these two tools be used in conjunction with one another for addressing curriculum revision and development (Veenendaal, 2014). However, these tools have quickly become out-of-date and are difficult to maintain in a sustainably timely fashion, considering how rapidly the discipline of GIScience grows and changes.[18] Additionally, these tools are quite general and idealistic in nature, speaking more to the discipline as a whole than to the specific needs of institutions or organizations that offer learning opportunities in GIScience, such as college and universities. Although this "big picture approach" is good for providing general direction for curriculum revision and enhancement, more focused and specific suggestions may more greatly benefit the immediate needs of GIScience educators. This research project posits that there are other sources of illumination for those attempting to address current curriculum concerns, namely the voices of graduate students, as explored in this work.

For the purposes of this research project, graduate students are considered more 'mature' learners, in contrast to undergraduate students, for example. This qualifier of maturity is

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[16] "Published by the Association of American Geographers (AAG) in 2006, the *Geographic Information Science and Technology Body of Knowledge* is an important reference work and classroom resource for teachers, students, and GIS&T professionals. It was produced as part of the Geographic Information Science and Technology Model Curricula initiative coordinated by the University Consortium for Geographic Information Science. It represents a comprehensive inventory of the GIS&T knowledge domain describing the conceptual foundations, analytical methods, visualization techniques and real-world applications. It is divided into 10 knowledge areas, 73 units and 330 topics, each of which is described in terms of formal educational objectives" (http://www.aag.org/cs/publications/special/gist, accessed July 12, 2016).

[17] "The Geospatial Technology Competency Model framework was developed through a collaborative effort involving the Employment and Training Administration (ETA), the GeoTech Center, and industry experts. "Over the course of 2013-2014, the GeoTech Center and industry subject matter experts updated the model with guidance from ETA to reflect the knowledge and skills needed by today's geospatial technology professionals" (http://www.careeronestop.org/competencymodel/competency-models/geospatial-technology.aspx, accessed July 12, 2016).

[18] There does exist an ongoing effort to update the Body of Knowledge; for more information, see http://gistbok.org/ (accessed July 12, 2016).

intended reflect graduate students' more cultivated understanding of their career aspirations and the kinds of learning experiences that they desire or require to accomplish their goals. Trained to be critical thinkers, graduate students are quite capable of deconstructing their learning experiences to examine the various components for merit and providing specific suggestions for enhancement. Additionally, many graduate students become faculty at other colleges and universities after graduation, and they will be making decisions affecting curriculum and the learning experiences of students at their institutions. As they will very soon be making these decisions, it would not be a far stretch to include graduate students in the ongoing curriculum revision efforts taking place in their department, and the department may greatly benefit from listening to their graduate students. Yet as discussed below, graduate students' reflections on their learning experiences remain almost entirely unexplored.

This research project addresses these questions: What are graduate students' reflections on their past and desired learning experiences in GIScience, and how might their reflections contribute to curriculum revision and enhancement? The focus of this paper is at the departmental level, particularly the Department of Geography at the University of Georgia. However, it is expected that geography departments in other colleges and universities and other providers of learning opportunities in GIScience may benefit from these graduate students' reflections. It is additionally hoped that this research will inspire disciplines other than geography to consider the voices of their graduate students as they undergo curriculum revision efforts. The structure of the remainder of this paper is as follows: Literature Review, Scope (and Subjectivity Statement), Data and Methods, Results (featuring graduate students' course-specific feedback), Discussion (featuring major trends in feedback), and Conclusion.

Literature Review

Courses in GIScience attract students of ever-increasing diversity, including those 1) specializing in GIScience, 2) using GIS in other fields, and 3) whose education "could be enriched by awareness" of it (DiBiase et al., 2012), and this diversity is observable in graduate students taking GIScience courses as well. This diversity reflects the increasing diversity of the field as a whole, and curriculum development efforts may be well served by attempting to address this diversity. There already exists evidence that there are deficiencies in current GIScience programs; as Solem et al. (2008) observe, "many geographic and general skills are in high demand, yet the curriculum offered by academic departments may not be producing those skills at a level required to satisfy that need" (370). Gathering the reflections that mature learners, such as graduate students, may have on these matters could be exceptionally illuminating and benefit curriculum enhancement efforts in GIS.

There are no existing studies of this particular nature, i.e. qualitative studies gathering the perspectives of mature learners' experiences and goals, and using this information to inform curriculum revision and enhancement in GIScience at a departmental level. There are only two past works that are remotely related to this idea. First, there is a chapter in *Teaching Geographic Information Science and Technology in Higher Education*, where McMaster and McMaster (2012) reflect on "a decade of experience in professional education," looking at the MGIS program at the University of Minnesota, and they include in their reflection the results of a student survey (177-179). They gathered information on students' GIScience interests, the perceived value of their courses, the "goodness" of their advising experiences, and their general satisfaction with the program as a whole. The survey appears to have been primarily composed of closed-ended questions utilizing Likert scales, and although the results of these types of questions are easily quantified, they are highly limited in the amount of useful information that they can yield. Additionally, measures of "satisfaction," which are commonly used in end-of-semester evaluations, can be misleading (Jenkins, 2013). As noted by DiBiase and Rademacher (2005), "student satisfaction does not equate with educational effectiveness" (156). It would be more beneficial to investigate and address the sources of mature learners' informed satisfaction and *dis*satisfaction, arising from their attempts to acquire substantial learning in GIScience.

Second, there is a symposium paper in the *Journal of Geography in Higher Education* in which Arrowsmith et al. (2011) investigate factors of "student employability," including "mixes of geographic knowledge, technical competencies, and personal attributes that graduates require," and the implications these factors have "on the design of geography curricula and learning practices" (365). They found that technical competencies (skills acquired from hands-on learning activities) give graduates "an edge in the marketplace" more than subject matter, and they found that employers prize personal attributes more highly than either technical competencies or subject matter (368). Arrowsmith et al. (2011) held interviews with only eight graduate students who were all graduated, and half of these had been graduated for five or more years. Additionally, these were not anonymous interviews; rather, names and occupations of the participants were shared. Finally, these graduate students' reflections were not the foci of the work, as they are in this research project.

This research project focuses on departmental curriculum revision. In contrast to the two antecedent works previously discussed, this project focuses on 1) the experiences of *current* graduate students, 2) the experiences of *more* graduate students, drawing a more complete picture of graduate students' educational experiences in GIScience, and 3) allows participants to remain *anonymous* in an attempt to encourage openness and honesty. While there is overlap with Arrowsmith et al. (2011) in discussing employability issues, this project represents the most comprehensive and scholarly analysis of department-level GIScience curriculum from the point of view of graduate students performed to date.

Scope

To gather graduate students' reflections on their past and desired learning experiences in GIScience courses, one-on-one interviews were conducted in the Spring of 2015. These interviews were both Master's and Ph.D. students from any department. To participate, they must have completed at least one GIScience course offered by the Department of Geography at the University of Georgia within the previous five years (2010-2014). Criteria for which GIScience courses were and were not discussed include the following:

1) GIScience courses completed during an undergraduate program were discussed, if they were offered by the geography department and completed in 2010-2014.
2) GIScience courses currently in progress at the time of the interview were not discussed, as any feedback regarding these courses was considered incomplete.
3) GIScience courses offered by other departments were not discussed; they were excluded from this study in order to focus on the geography department's GIScience curriculum.

Interviews were anticipated to take ~30 minutes, following the interview protocol written for this research study (see Appendix B). In the first part of the interview protocol, participants shared information about themselves, including their program, year, and focus (e.g. human geography, physical geography, techniques/GIScience, or some combination). Participants then discussed their research interests and goals, followed by identifying which techniques or GIS-based courses had been most relevant to them, with respect to their interests and goals. Participants' identification of which courses were most relevant helped to focus the discussion on particular courses of interest. For each of these relevant courses, participants were asked to compare their expectations going into the course with what they actually learned. They were guided to think critically about content, considering the merits of included and excluded topics, and the learning experience, both in terms of course design and class activities. Opportunity to identify and reflect upon other GIScience coursework was provided, including both courses taken and courses participants were unable to take for various reasons. This led into participants reflecting on topics that may be good to include in either currently offered courses or in new courses of their own. Finally, participants shared general opinions about the GIScience curriculum and program options in the Department of Geography at the University of Georgia. The interview protocol was open-ended by design in order to allow for further prompts and exploration based on participants' responses.

To avoid influencing results, the researcher asked all questions in a neutral fashion. Providing suggestions for talking points was avoided, unless specifically requested by the participant. Similarly, sharing opinions was avoided, unless the opinion was first provided by the participant. Only opinions in agreement with the participant were shared; if the researcher did not agree with the participant's opinion, the researcher maintained silence. This was done to build rapport with the participant in an attempt to promote an emotionally safe space for the participant to share opinions openly and honestly.

Subjectivity Statement

In the spirit of full disclosure, as appropriate to qualitative research, it is important to note the researcher's background experiences and expectations, as they influence the motivations and direction of this research study. At the time of the interviews, the researcher was a third-year Ph.D. student in UGA's Department of Geography (a fifth-year graduate student, due to completing a Master's degree in geography in the same department). The researcher completed more of the techniques/GIScience courses (10+) offered by the geography department than any participant in the research study, according to the information disclosed by participants during the interviews. Throughout the researcher's extensive course of study and other dissertation research regarding GIScience education, the researcher formulated her own opinions about the GIScience courses offered by UGA's Department of Geography and about GIScience curriculum, in general. This led to expectations regarding the results of this research study.

For example and most notably, the researcher expected that the acquisition of programming skills relevant to GIScience would be a substantial concern among graduate students who have taken GIScience courses. This expectation arose from the researcher's informal observations throughout graduate study that graduate students seem just as concerned with developing marketable skills for positions outside academia as they are with developing the skills they need for research, and it appears that an increasing number of postings for GIScience positions outside of academia require programming expertise. Therefore, the evaluation of graduate student demand and motivation for a regularly offered programming course and/or other opportunities to develop programming skills for GIScience applications was a primary motivator for this research study, particularly considering the fact that the geography department had offered their programming for GIScience course infrequently throughout the years examined in this study (once in the five years examined).

Aside from anticipating demand for opportunities to develop programming skills relevant to GIScience, the researcher also had other expectations regarding the possible results of this study. It was expected that graduate students may also be interested in free and open source software alternatives as well as in opportunities to learn about and gain experience with best practices in cartography and geovisualization. Aside from content-specific expectations, the researcher expected graduate students to provide feedback reflecting critical engagement with course design and learning activities, possibly citing a desire for more opportunities to practice hands-on application of the content covered in lectures. Finally, it was expected that graduate students, as more mature learners, may have innovative ideas that could benefit the GIScience curriculum both at the University of Georgia and beyond, but the researcher did not have any particular suspicions regarding what those ideas might be. It was simply expected that as a result of thinking more critically about their learning experiences, graduate students may have developed ideas that could have broad and beneficial implications for the discipline.

Data and Methods

A total of 30 graduate students participated in this research study. Of these 30 participants, 11 were Master's students and 19 were Ph.D. students. Additionally, eight participants were in the first year of their program; eight participants were in the second year of their program, and ten participants were in the third year or a later year of their program. The remaining four participants gave responses regarding their year that were ambiguous, or they had already graduated. Finally, participants self-identified or were identified as focusing in human geography, physical geography, or techniques/GIScience. Roughly evenly split among these categories, 7 participants focused on human geography (exclusively or in combination with techniques/GIScience), 12 participants focused on physical geography (exclusively or in combination with techniques/GIScience), and 11 participants focused on techniques/GIScience exclusively.

The average length of interviews was approximately 34 minutes; most interviews (19 of 30) were between 25 and 40 minutes. Of the shorter (6 of 30), the shortest was 16 minutes, and of the longer (5 of 30), the longest was 56 minutes. All 30 interviews were audio-recorded and transcribed. The totals of all transcriptions were approximately 150,000 words across 360 pages;

this is approximately 5,000 words across 12 pages per interview. Analysis of this substantial amount of data required a multi-step approach. First, each transcription was skimmed to identify which courses were discussed in each interview. Each course was labeled as either relevant or irrelevant, either GIScience or non-GIScience, or other based on participants' responses.[19] The total number of times courses were mentioned according to these labels was calculated, and this quantification was used to focus the analysis and results of this study as follows: The results primarily focus on those courses most frequently taken and most frequently identified as relevant for participants' research interests and goals. Specifically for this research study, the following cutoff values were chosen by looking for naturally occurring breaks in the quantification of participants' responses: courses that were taken by more than 10 participants and identified as relevant by more than 5 of those participants. These include the following courses (in order from lowest course number to highest course number):

- GEOG4330/6330 Aerial Photographs and Image Interpretation
- GEOG4350/6350 Remote Sensing of Environment
- GEOG4370/6370 Geographic Information Science
- GEOG4470/6470 Geospatial Analysis
- GEOG8570 Seminar in Geographic Information Science

The first four courses are split-level courses open to undergraduate and graduate students, and the last course is a graduate-only seminar. Participants completed a variety of other courses, and results secondarily focus on these other courses. A complete listing of all courses taken by participants can be found in Appendix C. Course descriptions from the UGA Bulletin are provided in Appendix D to give a general sense of what each course entails.

[19] Some participants identified as relevant and discussed courses that were not considered GIScience courses for the purposes of this study, but they are included for the sake of completeness. A few participants identified courses that were just outside the temporal scope of this study (ca. 2009), but they are also included for the sake of completeness. Some of the feedback provided for these non-GIScience and other courses is relevant to this discussion.

Second, all transcriptions were examined for substantive feedback regarding 1) specific courses and 2) suggestions for the GIScience curriculum in general. Trends and connections among participants' thoughts and ideas were identified and used to stitch together general impressions of participants' experiences in each course. Participants' experiences regarding the courses previously identified and listed are addressed in the first portion of the results section, and participants' experiences in other courses are addressed in the second portion of the results section. It is important to note that quantifiable results are not an objective of this research; rather, this research attempts to capture *qualitatively* the essences of recent graduate students' educational experiences in GIScience.

Finally, this study's course-specific results are analyzed for broader trends across all results as well as participants' general suggestions for GIScience curriculum with respect to coursework, career goals, personal interests, and other life experiences. These trends are featured in the discussion.

The results of this analysis represent only one way to understand and convey the results, and other researchers may have interpreted these graduate students' responses somewhat differently. Similarly, it is likely that feedback would have somewhat differed with a different group of participants. However, the overarching goal of this study is to identify generalizable trends in these graduate students' concerns, as these concerns can inform GIScience curriculum revision and enhancement, not only at the University of Georgia, but at other colleges and universities seeking to keep their programs up-to-date and relevant to students' needs. Therefore, these limitations are deemed acceptable, especially considering this is the first study of its kind. Numerous directions for future research inspired by this study are addressed in the conclusions.

Results

The first portion of this research study's results include the five courses most frequently complete by participants and most frequently identified as relevant to participants' research interests and goals. The second portion of the results includes participants' feedback regarding other courses. When considering these results, it is important to keep in mind that some of these courses were taught by different instructors from semester to semester, resulting in mixed feedback for the course.[20] The number of different instructors per course varies, and this number is not shared in an attempt to preserve as much anonymity as possible. Therefore, emphasized in the results are comments from which broader and more generalizable feedback may be discerned that are applicable to both the course at the University of Georgia and similar courses at other institutions. Participants' suggestions for GIScience curriculum that are not specific to any particular course are addressed in the discussion.

GEOG4330/6330 Aerial Photography and Image Interpretation

There were ten participants who took this course, and of these ten, six participants identified the course as relevant to their research interests and goals. Participants indicated appreciation that this course covered techniques used "before we got computers," as it helped students to "understand how computers are able to do it" (Participant 13). Participant 20 felt that the course is "a very good introductory level remote sensing and can give you the interesting points about these GIScience field… Every year I know [the instructor] will add something new in that, so that is what I appreciate." However, one participant remembers another individual involved with the course saying that the course was a "dinosaur" relative to remote sensing and GIScience and that the material was "obsolete." This participant said that the individual

[20] During one of the academic years encompassed within the time frame of this study, there was a visiting professor teaching some of the courses addressed in this study. Participants' comments about taking courses taught by this visiting professor were generally negative and may be considered to skew some of the results in a negative direction.

indicated strong feelings that "there's no purpose to this class anymore," and the participant noted, "That kind of stuck with me" (Participant 3). Nevertheless, Participant 3 clarified, "I actually really liked that class... I thought the labs were really good, and it's been really beneficial to me, I mean, for what I do especially." Participant 29 also indicated that the course's labs were beneficial noting, "They help a lot because they make you think about what you're doing." Feedback from Participant 16 was a blend of the previous comments, indicating preference for "emphasizing newer stuff a little bit more" and spending "more time on the new techniques that people use now, but I wouldn't lose the historical aspect." To accomplish this, Participant 16 suggested, "maybe a few less labs and having maybe two weeks to spend on some of the more difficult ones."

Participants' suggestions for newer topics or techniques to address in the course include unmanned aerial vehicles (UAVs) (Participants 26 and 27), structure from motion (Participant 29), and Map Warper and other free and open source tools (Participant 26). Regarding UAVs, Participant 26 felt that much of the current course content can be relatively easily geared toward UAVs since this is a modern form of traditional aerial photography. Participant 27 felt as though many people gathering aerial photography at other institutions and organizations have already switched to UAVs, and therefore, it is important to address to remain up-to-date. Regarding structure from motion, Participant 29 felt as though inclusion of structure from motion into the course is appropriate because it is "something that you can do with aerial photography" and "just mentioning that in the class could be something that can just improve the attention… draw broader audiences to the objects, because it's a very sexy topic." Finally, Participant 26 explained that Map Warper is "an online website that has been built to enable citizens using drones to build image mosaics themselves." This participant felt as though students' awareness of free and open source tools

> "can really empower them as well as not just for them to use the tools themselves but also to be cognizant if they have projects where cost is a limitation or people who are interested in learning these can teach themselves and more aware of these free and open source software solutions" (Participant 26).

Among other feedback for this class are Participants 16 and 29's appreciation for the scheduling of the course; it was a Monday, Wednesday, Friday course for these participants. There were 50 minute lectures on Mondays and Wednesdays, and the lab was on Fridays. Participant 16 appreciated how this "kept the PowerPoints to a minimum amount of time," and Participant 29 felt as though the schedule resulted in a "good mix between teaching and actually practicing. Other than this, there were mixed feelings regarding the group project; one participant felt it was weighed too heavily and underperforming group members were too great a detriment, but another participant had a more positive experience being grouped with "two other students that were more experienced than I was, so I was able to learn a lot from them." And finally, Participant 7 noted, "I had the wrong expectations, but I'm glad I took the class."

<u>GEOG4350/6350 Remote Sensing of the Environment</u>

There were twelve participants who took this course, and of these twelve, nine participants identified the course as relevant to their research interests and goals. Several participants indicated a desire that there been more emphasis on application. Participant 17 expected "to learn some very useful skills" but found that "only very basic concepts are covered in this class," and Participant 3 "felt like there was actually very little practical." Participant 28 suggested that there be "more about how to, how these kind of images can be applied to different fields. Similarly, Participant 6 suggested addressing "not only 'here's what you do' but 'here's why you should care' and 'here's how you could use this for your own research.'" Other participants were able to find “a way to make it more applicable” (Participant 23). Both Participants 23 and 8 were able to combine their work in the class with work in other classes to write professional papers; one participant wrote a conference paper, and the other participant was able to publish a paper.

Typical opportunities to delve into application in any GIScience course, such as this one, include projects and labs. Regarding projects, Participant 12 indicated that this was “an element that I kind of missed… A project instead of a paper I think would be especially useful for something like remote sensing.” Participant 23, who took the course in a different semester, indicated that projects were required of graduate students and optional for undergraduate students. Reflecting on this, Participant 23 stated,

> “I like that experience… because it gives me something that I can put my hands on and say that, ok, I have done this. I have a better understanding of it, and I think that is true with just about any course… It’s more meaningful to you. So the undergraduates who didn’t have the opportunity to do that or may not have something as in depth, may have missed something there.”

Regarding labs, another opportunity to engage with application to deepen learning, Participant 29 explained that “you can really tell whether you actually get the topic or not because you can actually put in practice what you learn from the class.” Because practice in labs is so important to student learning, this explains why Participants 28 and 18 both indicated the desire to capitalize on the learning experiences that labs can offer. Both expressed interest in having more labs than had been offered, approximately 7-8, and Participant 28 suggested 10-15 throughout the semester. Participant 18 suggested more labs to delve further into the software, as students had been exposed to multiple software options only briefly. Both Participants 7 and 17 appreciated the multiple software options, but Participant 17 expressed the desire to learn more than the basics. Finally, Participant 3 pointed out that simply increasing the number of labs was insufficient to increase the level of practical application in the course, noting that labs could still be “hard to understand” without “bigger application.” Supplying both a sufficient number of labs and clarifying general applicability of each lab are both important for addressing students concerns about being able to apply what they have learned.

In regard to content, participants identified several topics from the course that they felt were very important to continue including in future offerings of the course. These included “spectral analysis” specifically looking at “vegetation” (Participant 12 and 18), water remote sensing (Participant 18), and the nature of data, including what one can and cannot do with data, specifically “limitations” and “how to express those” (Participant 23). Identifying a topic not as well covered in the course, Participant 28 said, “I didn’t get exposed too much to the image processing field, so I would like to learn more about that.” More generally, Participant 3 felt there was a little too much focus on details of lesser importance relative to understanding broader concepts. Participant 3 continued to explain that this inverted focus was reflected in the exams saying,

> “It’s not that [the tests] are hard… It doesn’t actually test you over the big picture, because I think as grad students, when we go in to study, it’s big picture stuff. [The instructor] tested on the most [obscure] stuff… which I don’t really think covers what the material was… I do think the assignments and the tests could be geared more toward the content of the class and making it more cohesive.”

These concerns were echoed by Participants 5 and 6 who noted that the test required memorization, rather than understanding “broader connections between larger ideas or things funneled into each other” or “more applicable, applied things” (Participant 6).

Other feedback from participants included appreciation that the instructor provided the class with examples of “something [the instructor] learned from his own research,” giving the participant the impression that the course was “very updated” (Participant 5). However, although Participant 6 agreed that these examples from the instructor’s research interesting, it would have also “been interesting to see other approaches.” Finally, participant feedback regarding the teaching and learning experience of the course included concerns that the lectures were "very long" (Participant 12), as the lecture was one day a week for up to 3 hours. Participant 12 clarified, "I always thought that the point of a very long class like that was so that people could discuss things." This participant also proposed having a "mini-lab" during lecture, which would be possible because the class took place in a computer lab. However, although having the class in the computer lab was great for lab, it was actually distracting during lecture as the screens would "flash" with screensavers or because of other students performing activities on the computers while the instructor lectured (Participant 6). This negative impact of these computers on students learning during lecture reflects results founds by other researchers (Sana et al., 2012).

<u>GEOG4370/6370 Geographic Information Science</u>

"I felt like I couldn't graduate with a geography degree or call myself a geographer, if I didn't take at least intro GIS."

- *Participant 30*

There were fourteen participants who took this course, and of these fourteen, twelve participants identified the course as relevant to their research interests and goals. This split-level course, like most techniques/GIScience split-level courses, contained lecture and lab components. Regarding lectures, a couple of participants felt that the lectures were a little too content-heavy (Participant 11) and "tiring" (Participant 27), noting that "if you can participate it's good, but if you cannot, that kind of very tiring… I learn more when I am doing something than when I am listening" (Participant 27). However, introducing discussions was not necessarily recommended: "I don't think more discussion based classes would be too useful, because it's intro level" (Participant 21). Rather, it was suggested by a couple of participants that the lectures include "in-class demo" (Participant 15) or just "have GIS running and maybe show real examples" (Participant 30). This may require that instructors "eliminate [excessive content] and expect [students] to just pick up the pieces that they don't know" (Participant 11), but this was deemed an acceptable compromise because the "hands-on practical is so powerful" (Participant 3).

In fact, some participants explained that their expectations for the class were to "become a bit more technically proficient," but

> "at the end of it, there was maybe 50/50 focus on techniques versus theory… that I wasn't expecting when I signed up for the course… It was a little disappointing because I'd hoped to be able to have just more technical chops" (Participant 11).

This response would easily explain why another participant suggested that GIScience courses "play up the labs even more than they do, because I feel like that's the way people learn that type of stuff" (Participant 12). Participant 24 went even further with this idea, suggesting that the course "should be lab based." When asked to clarify what being "lab-based" means, Participant 24 continued, explaining that a lab-based course would mean

> "more hands-on, activity-based exercise or learning and a lower percentage of actual lecture… Lecture material could be presented either through readings or online, actually listening to a lecture outside of the class time and that the class time is spent on hands on. It is the flip classroom kind of idea."

Participant 3 echoed these sentiments, suggesting "maybe a short lecture… more time could be spent developing those skills." Participant 3 continued to say, "If we're talking about theory but we're not having the application, that's not really helping us." To be clear, no participant actually took this course without any applied, hands-on component; participants are simply requesting more practical, skill-building opportunities.

To accomplish this, several participants suggested more complete integration of lecture and lab. Participant 3 stated, "I look at [the GIScience course] like it was two classes. You had the lab, and you had the lecture," and Participant 30 also noted that the lecture and lab were completely separated. Participant 30 explained that this was very different than past experiences, specifically, "In my undergrad [which was *not* at the University of Georgia]… it was really tightly integrated between what you are doing in lecture and what you are doing in lab," and another participant, who also had a more integrated experience "in a different department," explained that this other course was "totally integrated. There is no separation between lecture and lab… There is no sort of abstraction of concepts from the actual application itself" (Participant 11). With a contrary opinion, Participant 12 expressed concern about having lecture and lab "on the same day because people would probably pass out," but this was not the experience of Participant 15, who took this course during a May semester (lecture and lab every day, Monday through Friday, for three weeks). This participant reflected,

> "What I really liked about that class, and I don't know if it's just because I did the Maymester, I really loved the way the lecture dovetailed with the assignment. Even though the lecture was long… I really liked that flow from the classroom to the workstation… You actually get to do what we talked about, and you don't have to wait a week to do it. I really liked that. That was super useful I thought… I felt like I had a really good experience from it, but that's tempered with the fact that I was in that compact environment. We really did have the benefit of we had lab every day, so definitely felt like I got a lot out of it skill-wise" (Participant 15).

This participant's only particular critique about this experience was "I almost wish that we had just, it had all just been based in the lab classroom," offering even more immediate opportunity to engage with the content of the lecture via a hands-on activity.

Better integration of lecture and lab may address other related concerns. Participants 21 and 23 both explained that the separation of lecture and lab led to an effect that labs could be ahead of or behind lecture, resulting in an inversion of the intended learning experience, where students are exposed to new content before working with it during lecture. Sometimes students found themselves completing lab before, rather than after, the corresponding lecture. Additionally, a more integrated experience may address Participant 11's concerns: "I never really had the feeling from week to week that I was building on something that I had previously done… The whole point of what you're doing is sometimes kind of lost." A more integrated class may help students see the connections, not only between lecture and lab but also in everything they are learning throughout the semester.

Among participants' other concerns regarding the course is the assumption of computer literacy skills among students:

> "There's I think a level of assumption about technical proficiency like just computer literacy that is maybe a false assumption to make even though in today's day and age most people are relatively computer literate. When it comes down to things like making sure that you're putting the right drive location in or you're saving it to the right folder… a set of best practices would also
>
> be really helpful, and that's kind of a just a nuts and bolts of how to use your software" (Participant 11).[21]

Knowing about computers is only one of three things that Participant 29 claims students in GIScience need know: "GIS means also knowing a lot about maybe statistics, math, and computers in general… You have to learn it, because there's no way around it." Students can easily feel "overwhelmed" (Participant 11) and find themselves spending a substantial amount of time completing their lab work (Participant 30). To ameliorate these issues, students may benefit from practical tips, such as how to understand and handle problems with file paths (Participant 11), and more generally, how to use Google to their benefit:

> "I know as the teacher you don't want to be like, 'If you have a problem, go look it up on Google.' …You don't want them learning the wrong thing from that, but I think it should be emphasized somehow, even if it's just… tips and tricks on how to be a little more self-sufficient" (Participant 30).

Helping students develop self-sufficiency would benefit them because "it's never going to be as nice as it is in your lab"; rather it is very likely that they'll find themselves with "real messy just frustratingly bad datasets" (Participant 19), and they will need the confidence and skill to figure out how to deal with them. Both Participants 7 and 30 felt as though they came out of the class

[21] From the researcher's teaching experience, it can be confirmed that this is indeed an issue for many students: simply understanding where one is saving files. There have been many students who accept the default save settings when completing work in GIS software, and later, these students do not know where their data are saved. Sometimes students lose their work simply because they cannot find it. The problem is at least two-fold: 1) Students do not understand the organizational structures of files on computers, and 2) students underestimate the necessity of creating an organized and sustainable approach to saving their work. Instructors need to consider helping their students become more mindful and knowledgeable regarding data structures and saving their work.

with the ability to "search it and have an idea of what it is I'm looking for" (Participant 7) or "ask the right people" (Participant 30) for assistance when they run into problems. However, not all participants felt this way, as it was expressed, "Only taking that class is not enough… You should take advanced, more advanced courses" (Participant 29).

The need for "more advanced courses" may be a result of specialized needs, and some subjects, such as programming, may be beyond the scope of the course and reserved for more advanced courses. However, it is worthwhile to consider the subjects that participants identified as important or desirable to include in this course. These include the following: open source options, specifically QGIS (Participants 7, 10, 11, 21, and 24), GRASS (Participant 21), and OpenStreetMap (Participant 24); programming, automating, and model building (Participants 2, 15, and 23); data, database, and geodatabase management (Participant 7, 11, and 24); cartography and visualization (Participant 15, 24, and 27); careers in GIScience (Participants 10 and 30); raster analysis (Participants 11 and 15); critical and qualitative GIS (Participant 21); digitizing (Participant 7); georeferencing (Participant 27); map projections (Participant 12); and suitability analysis (Participant 27). Obviously the most frequently cited topic of interest is open source options, particularly QGIS, which does not appear to be included in the course at all to date.

Participants cite several reasons why open source options are important, despite the fact that "so much in the academic instruction of GIS right now is biased towards ESRI products" (Participant 24). Participant 21 claims it is important to have

> "more intentional, explicit engagement with [other software options], rather than being so acquiescent to the prevailing architecture of the institution, in the sense that [ArcGIS] is all you learn and you have no idea what QGIS is or how to use it."

Rather than accepting the status quo, which is a high dependency on ESRI products, such as ArcGIS for Desktop, using these open source alternatives "break[s] down institution barriers between people, taking academia into field practice and engaging community members in the creation of knowledge" (Participant 11). As Participant 7 observed, "Students who work with [non-governmental organizations (NGOs)] or have stakeholders in other countries who can't afford the latest version of GIS or work on some pirate version of GIS, they've started to rely more on open source version of that software." This is echoed by Participant 21 who notes, "Open source or free, at least, software is really critical for working in some of these places," mentioning friends and colleagues that work in developing nations. More participants cited the need for more learning opportunities for free and open source GIS in their general suggestions for GIScience curriculum, which will be addressed in the discussion.

Other comments about the Geographic Information Science course address class size, not surprising since this is the largest of the GIScience courses offered by UGA's geography department (~40 students). Participant 10 suggested breaking the class into two classes, and Participant 11 noted that the size problem may be partially due to the split-level nature of the course. However, not only is it popular among both undergraduate and graduate students, it is also popular among both geographers and non-geographers, because many see taking the course as a "résumé booster." For example, Participant 19 observed, "I've gotten on certain projects because of my GIS skill set, in just having that on a résumé." In short, it may be worthwhile to consider the impact of changing ratios of undergraduate to graduate students and geography to non-geography students in future offerings of the course. Splitting the class to suit the needs of these different groups may be needed.

<u>GEOG4470/6470 Geospatial Analysis</u>

There were sixteen participants who took this course, and of these sixteen, eleven participants identified the course as relevant to their research interests and goals. Several participants indicated interest in a more project-based approach to the course to emphasize "real applications" (Participant 5). Participant 9 suggested "Maybe more project-based stuff than just labs. I felt like some of the labs were just like kind of click through and I don't know if I really – how much I retained I guess." At least one semester did incorporate a project, according to Participant 28, but it was "kind of short period of time, so we don't have a long time to dig into certain topics." This ties into at least a couple of participants' mindsets toward such projects: "Any project that I do in any course should have, should be big enough where you can grow into some of it or be a part of something else" (Participant 23), such as "dissertation project" (Participant 9). Additionally, Participant 9 indicated hope that such projects might help students better understand what they are learning:

> "I think that anytime you have a chance to work on a real problem without real answers and you have to make decision that have positive and negatives and you have to weight all those, I think those are super valuable learning experiences" (Participant 9).

Participant 9 additionally explained that this is important for understanding how what is being learned in the course translates to the real world when students are seeking jobs:

> "The one thing I guess I struggle with is thinking about applying to a career and taking the skills that I learned in that class, marketing them, and saying, 'Hey, I know how to do this... but does anyone care? …If you go and look at GIS job postings or things, I mean a lot of them aren't 'we want you to come and do this great analysis.' It's like, 'We want to you to *build* these different things,' and how do you link what we learn in this class or any GIS class to the skills that employers want? …It seems like a lot of GIS people want GIS *developers*" (emphasis added)

in contrast with GIS analysts, per se. Another participant echoed these sentiments, wanting

> "a little more of 'ok what are, how is this being applied in either the real world job market' or 'what is some of the more recent research being done? Why does this matter?' I think that's always the question I like to have, and I feel like it was not answered fully" (Participant 1).

All of these participants' comments contribute to understanding why many participants wanted "more hands on time" and explained why participants felt that "it's all about hands on time" (Participant 24).

Participants' feedback regarding course content further contributes to understanding what skills that participants desire, as several participants cited wanting more programming skills in general and more experience with R, a popular programming language for statistical applications. "I want to learn some programming… which might be helpful for my future career" (Participant 2). Participants 9 and 23 also wanted more opportunities to develop programming skills, and specifically R was cited by Participant 9, who stated, "We used R one week but there was really no introduction or background into how to use R and how to do those things." This was echoed by Participant 18 who explained that the "teacher give you handout and we just copied." Exposure to different programs, such as R Studio and GEODA was identified as important for inclusion in future semesters, but students prefer that more emphasis be placed on their acquisition of skill using these software (Participants 9 and 17). Among other topics to continue including were spatial autocorrelation and spatial-temporal analysis (Participant 8), pattern analysis and hotspot/coldspot analysis (Participant 17), and spatial dependence and spatial allocation statistics (Participant 23).

Aside from comments regarding application and content, participants also spoke to the teaching and learning environment and activities of the course. A couple of participants spoke to the division of scheduled class time between lecture and lab, suggesting that "the time could be split up differently" (Participant 9), as it was a class that met for a two-hour lecture once a week and a two-hour lab once a week, and the lecture and lab were on different days. Additionally, according to Participant 9, the lab "sometime relates and sometimes doesn't," an issue that Participant 10 claimed to result in a "gap between the application and the lecture." Participant 4, when asked to describe an ideal schedule for this and other GIScience courses, suggested splitting the two-hour lecture into two 50-minute sessions, such as on a Monday and Wednesday.

This was deemed beneficial because it would allow students "to leave, let it marinate, and come back [to have] the next little packet," and "you'd be able to see the professor a little more often" (Participant 4). Regarding seeing the professor more often, Participant 9 felt that "it will be helpful if [the instructor] was in the lab… More chance to engage with [the instructor] as we were working through the problems would be helpful." This may result in the additional benefit of "intermixing lecture and lab" (Participant 4), bridging a "gap" perceived by some students between lecture and lab (Participants 9 and 10).

Other comments regarding lecture specifically include an appreciation for opportunities to interact. "[The instructor] asked us a lot of questions… That definitely made me pay a bit more attention... I always pay more attention to the question and answer section" (Participant 12). Participant 10 also indicated a preference for "interaction" and "questions," and Participant 5 reflected on how a classroom that encourages asking and answering questions promotes creativity: "You were asked to [ask and answer questions], and I think that will help you be more creative." However, as Participant 18 observed, an active classroom requires that students prepare, which did not always happen: "[The students] didn't prepare enough. So if they didn't prepare enough, it [was] inactive practice." The address this issue, the participant suggested incorporating some accountability method so that students "pay more attention" and "prepare better" (Participant 18). An existing accountability measure in the course design, weekly quizzes, was met with mixed opinions. While one participant liked the quizzes, because "it can encourage you to review" (Participant 5), another participant disliked the quizzes:

> "It's such a undergraduate thing… I understand as a teacher why you would put quizzes in there, because you want to have some kind of ability to make sure that everyone is keeping pace… As a graduate student, you are held at a higher level, so it is not your teacher's responsibility to make sure you are on top of your stuff" (Participant 23).

In an attempt to propose a solution, Participant 23 suggested, "I think that quizzes could have been much less frequent, or maybe instead of quizzes, maybe it could have been four homework assignments or something like that." Such homework assignments might have been an opportunity to pose problems and address students' struggles with more broadly applying what they have learned to the real world.

GEOG8570 Seminar in Geographic Information Science

There were sixteen participants who took this course, and of these sixteen, ten participants identified the course as relevant to their research interests and goals. Only one person expressed explicit uncertainty regarding course goals: "I didn't know if it would be more of hands-on application learning or if we would be doing literature review" (Participant 13), but this may explain why several people noted wanting more hands-on activity. Participant 2 indicated desiring to learn "practical skill, but… we just read what someone else did." Although some learning of the methods could be learned from reading, "the papers sometimes are clear, sometimes they're not" (Participant 27), and "for certain papers, there wasn't much emphasis placed on making sure that the students really understood the methods very well" (Participant 19). As noted by Participant 19, there was an occasional "hands-on lab-based component, and those were always really fun…to practice some of the concepts that we've been talking about" (Participant 19), but some participants still desired "a little bit more methods than what I learned" (Participant 27). To learn these methods, Participant 22 felt "[students] need to take another course… to learn the method." This is not necessarily a weakness of the course; students' experiences in the course may simply benefit from having clearer expectations regarding what to expect and what not to expect from the course, and this is true for all courses, regardless of discipline.

Because this course was more based in literature review and discussion, it is not surprising that the majority of student feedback for this course was in regard to the content of the course. Participants identified 1) topics that *were* covered in the course and would be good to cover in future semesters of the course, and/or 2) topics that were *not* covered in the course but would be good to cover in future semester of the course. These include the following: big data, both mining and analysis (Participants 19, 21, 22, and 27); health GIS (Participant 10, 12, and 14); participatory GIS (Participants 12 and 21); GIS for urban issues (Participant 10); social media (Participant 13); foundational GIS papers (Participant 14); careers in GIS, specifically examining job sectors and job listings/requirements (Participant 14); space-time GIS (Participant 19); GIS work being performed in other disciplines (Participant 18); volunteered GIS (Participant 21); critical GIS (Participant 21); visualization (Participant 22); and GIS for physical geography (Participant 27).

Some participants provided elaboration regarding why they felt their topic(s) of choice were important. Participant 13 felt that discussing privacy and surveillance are important for examining the "problems with using this technology" and that the "discussion about social media should be kept, especially since it seems like it continues to be relevant" (Participant 13). Participant 4 noted in a different portion of the interview that "a lot of people are really interested in [social media]." Participant 19 identified space-time GIS as "something that's going to be very important especially as we enter the big data era," and Participant 14 was interested in talking about careers and discussing job listings, reading their requirements and asking, "Are those requirements being met? Am I taking the right courses?" This participant continues to explain that in the course is "a group of people who are passionate about GIS getting together to talk about GIS, and jobs are a huge part of it" (Participant 14). Regarding participatory GIS and health GIS, Participant 12 felt that being sure to include such topics could "attract maybe more people from outside of the techniques specialty." Finally, the most common response regarding content was simply a desire for newer material (Participants 1, 18, 19, and 22). To make room for students' preferences, Participant 1 suggested giving students opportunity to vote for preferred topics.

Returning to Participant 12's comment about attracting "people from outside of the techniques specialty," the seminar did attract people from other geographic specialties as well as non-geographers, which participants deemed both advantageous and disadvantageous for the class discussions. These students were able to provide alternative perspectives (Participant 5), but "not everybody had had the same level of exposure to GIS techniques, and so sometimes the discussions weren't too terribly engaging" (Participant 26). A possible solution might be "to have two people be the discussion leaders instead of one," as Participant 12 found that these students' "discussions about the questions before class, end up coming up with better questions and thinking through things more deeply than if it was just them by themselves writing up some questions."

Other comments about the seminar included Participant 21's appreciation that the seminar was "very reading and discussion heavy" as "it seemed like that was something that was missing from the model so far," referring to the other GIScience courses, which had been exclusively situated in the lecture-lab paradigm until the seminar. In the seminar, Participant 27 appreciated the encouragement and prompting of instructors that everyone participate and talk, sharing their thoughts. However, Participant 10 did say that for non-native English speakers, it was difficult to participate, as other students might more quickly share a similar opinion. A possible solution, despite the fact that the class size of the seminar is already small, is to further subdivide into smaller groups of two to four. Frist, students can share their thoughts with each other, and second, the small groups could then share their thoughts with the class. More students would be able to participate during the scheduled class time, and language limitations would be less of an issue, as there would be more opportunity to speak in a smaller group.

Another opportunity for more equitable participation is the “mini-conference” discussed by Participant 23. This class activity was viewed quite favorably by this participant; however, it was announced with short notice, resulting in little time to prepare. Advance notice of these and other expectations might have also addressed other miscommunications about the course. For example, one participant, a student from another department expected the seminar to be an

> “environment to [ask] questions that people in a different setting wouldn’t want to ask because they would be afraid to embarrass themselves or embarrass their intelligence and stuff like that. What I found was that it was a very intense class for something being labeled as a seminar” (Participant 19).

This participant’s disenchantment with the course design and learning environment was the result of departmental differences, which can be easily addressed with clearer explanation of all expectations. This would benefit not only this seminar and not only GIScience courses; students’ experiences in a multitude of other courses and other learning experiences may be aided by clearer expectations.

Other Courses

Participants completed numerous other techniques/GIScience courses. These other courses account for 23.64% of all participants’ coursework (26 of 110 courses), whereas the courses previously discussed account for 61.82% of all participants’ coursework (68 of 110 courses). Each of the other courses, taken by fewer participants than those courses previously discussed, will be discussed in brief.[22] Any comments from participants judged to be substantive are provided.

GEOG2011 Introduction to Geographic Information Science. There were two participants who took this course, and of these two, both participants identified the course as relevant to their research interests and goals. However, both of these participants took this course just outside of the time window of this study; nevertheless, they are mentioned here because participants identified this course as relevant and important to the participants' growth as geographers. Participant 19, who took this course while completing an undergraduate degree at UGA, explained, "It was incredible. By the end of the class, I felt like I had missed out being a geography undergrad, geography major," and Participant 4 cited the benefits of having taken the course prior to GEOG4370/6370 Geographic Information Science, stating, "It was a huge advantage for me to have that kind of in my back pocket… The first exposure is always going to be tough, so to have that, just get that out of the way as quick as possible before going into a cross-listed class, that helped me a lot."

GEOG3510 Cartography and Graphics. There were three participants who took this course, and of these three, all three participants identified the course as relevant to their research

[22] There are several courses that were discussed in the interviews that will not be covered in this section.

- GEOG4300/6300 Spatial Analysis (2 participants, both relevant), GEOG8300 Multivariate Techniques in Geography (2 participants, 1 relevant), and GEOG8910 Seminar in Geographic Thought and Methods (2 participants, 1 relevant) are not discussed because they are not considered GIScience courses for the purposes of this research study.
- GEOG4430/6430 Advanced Image Analysis and Photogrammetry and GEOG8350 Advanced Remote Sensing are not discussed, because there was ambiguity among participants' responses regarding the course number for what they frequently referred to as the "LiDAR course." There were approximately nine participants who took one of these courses, and of these nine, five participants identified the "LiDAR course" as relevant to their research interests and goals. The main findings from these participants' comments are that 1) it was a positive experience to learn about LiDAR (for some that was the draw of the course) and 2) LiDAR is important to include in GIScience curriculum.
- GEOG8590 Directed Problems in Geographic Techniques (1 participant, relevant) is not discussed because it is not a traditional course, being more self-directed in nature.

These omitted courses account for 14.55% of all participants' coursework (16 of 110 courses).

interests and goals. [23]Participant 14 says that although cartography was previously geared towards printed maps, now

> "it's all online, but even still, the things that I learned in cartography still apply… At the end, there's that last step of telling the story, and a lot of people miss out on that, telling the story aspect of GIS."

Participant 19 also speaks to the relevance of cartography, noting that cartography was "the best class that really encompasses everything about the work that I do." Stressing the importance of cartography, Participant 14 observed, "We're graduating these students, and they're putting out works that have pretty much UGA's name behind it. If we make bad maps, it looks bad for UGA geography." Because of this, Participant 14 feels as though cartography coursework should be required for anyone working with GIS.

GEOG4380/6380 Transportation Modeling and GIS. There were five participants who took this course, and of these five, three participants identified the course as relevant to their research interests and goals. Regarding content, Participant 1 wanted to see "more modes of transportation"; Participant 17 was interested in learning more about traffic; and Participant 14 observed that since network datasets are so important to the content of the course, it might be good to expose students to "online options like ArcGIS online." Additionally, Participants 17 and 18 also wanted more opportunities to practice skill-building, both in lab (Participant 17) or via a "practical project" (Participant 18). Practicality was also an issue for Participant 1, who noted, "For me it's all about practicality and why does this matter? …What we did learn was interesting, but maybe just a little more practical application." This was at least partially accomplished through reading articles and presenting, since Participant 14 explained, "What I really liked…was having to read articles, and we got real world examples how transportation

[23] Similar to the previous course, there was one participant who took this course just outside of the time window of this study; nevertheless, this participant's response is included here for the same reasons previously discussed.

GIS is evolving and what people are doing in other fields." However, although Participant 14 appreciated the student presentations, an additional suggestion was provided: "Maybe some more video or guest lectures, people in the field, coming in to talk, maybe even a field trip" (Participant 14). This may address Participant 1's concerns with the content-heavy, lecture-centric nature of the course:

> "This has been a theme through pretty much all my GIS classes… It's a lot of just information being thrown at you and read to you from PowerPoints… I think there are better ways to get about things, and that's not to say it's all just been reading from a [PowerPoint], there was explanation too."

These and other students may appreciate diversity in their learning experiences, not only in this class but in others as well.

GEOG4460/6460 Field Methods in Remote Sensing. There were four participants who took this course, and of these four, two participants identified the course as relevant to their research interests and goals. Specific to this course, participants indicated appreciation for the following: 1) for the opportunity to "play around with the sensor, looking at the data, and everything else… [I] expected to learn more about the physics behind the sensor, and I did, so that was great" (Participant 7); 2) for stopping to "ask some of those basic questions about what is it to do research" and to do a substantive project leading to publishable results (Participant 19); 3) for an engaged "TA that's there to help with the fieldwork and getting used to the software that may be new for us and that kind of thing. That was just really helpful" (Participant 16); 4) for the tests, because "as much as I would [want] to say there is no need for tests, I think that it was definitely warranted" because "it does provide a time where you have to take a step back and you have to go back… and make sure that you stop and know what you're talking about" (Participant 19); 5) for the labs, the project, and the lectures (Participant 16); and 6) for "the theoretical part" (Participant 20). Participants' suggestions for the course include addressing the "long PowerPoints"; Participant 16 suggested no longer than 40 minutes. Participant 20 suggested giving students more "opportunity to speak," specifically in during project development: "[Students] mainly discuss with teaching assistant and [the instructor], but I think maybe we can have some students talk, discuss their ideas with each other." Also providing feedback about the project, Participant 19 suggested a little more time between the exam and the project due date, in order to make it less "crazy at the end."

GEOG4570/6570 Advanced Geographic Information Science. There was one participant who took this course, and this participant identified the course as relevant to their research interests and goals. Participant 24 provided several pieces of substantive feedback, having taken the course with the objective of developing "a working literacy that could then develop independently." First and foremost, Participant 24 emphasized "the most important thing is really the dearth of "critical GIS," which is important because

> "GIS are not purely quantitative, and they are certainly not absolute representations of whatever the data or the information is being represented. There should be a constant process of self-critique, as one is working with the information… about why you are choosing it, how you are choosing to represent it, and that is something that could be highlighted more throughout the course."

Second, the participant suggests doing "a type of skill maybe multiple times but has different iterations of it so that you learn that skill better ideally than just maybe completing it once along a certain exercise line." Third, the participant recommended reserving more class time for hands-on activities during which the instructor can be present and provide feedback; this can be accomplished if the instructor were to "have the lecture have been presented online beforehand." Finally, the participant felt that the course could delve into alterative GIS software, such as QGIS.

GEOG4590/6590 Programming for Geographic Information Science. There were four participants who took this course, and of these four, all four participants identified the course as relevant to their research interests and goals. Most participants commented on the importance of this course, making statements such as “I know that programming was something that I needed to take or that I wanted to take based off looking at jobs” (Participant 14), and “I need a lot of programming techniques in my research” (Participant 8). Participant 4 suggested that the course be required, “just based on how useful it’s been to me.”

In regard to the content, both Participants 14 and 26 expressed the specific desire to have more experience and skill with programming for online applications. “Programming GIS is a really important area,” says Participant 26,

> “And it’s an area I wish I currently know more about, particularly as it goes to building and using GIS-based applications on the internet… I wish that that course though had maybe included things on web mapping and learning how to work with web mapping APIs and how to build a basic slippy map using the Google Maps API.”

Participant 26 goes on to suggest that these topics might be appropriate for a second course, a position with which Participant 14 agrees:

> “I wish I knew Java script or had programming for GIS in terms of online capability, like web maps or story maps or online cartographic visualizations of the code that goes behind that… Companies require that you know coding or at least a little bit… CSS, HTML, python, Java script, those are the ones that I’m trying to learn now… There needs to be a python course, just python, and in another course there needs to be cartographic visualization using CSS, Java script, and HTML… It’d be called introduction to online visualization.”

In regard to the learning environment of the course, it was suggested that lecture and lab could be intermixed better, “like having a class that’s hybrid” (Participant 4). This may provide opportunities for “more one-on-one guidance,” which Participant 14 suggested because “it’s a really difficult course.” Speaking of the course’s difficulty, Participant 14 impressed the importance of being stricter about requiring an introductory programming course, because without such a course, a participant may find himself/herself “completely lost.” However, because getting “lost” can happen anyway, regardless of experience, Participant 14 suggested “going a little bit slower and not assuming that students know.”

GEOG8450 Geospatial Techniques in Landscape Analysis. There were five participants who took this course, and of these five, one participant identified the course as relevant to their research interests and goals. Participants' comments about this course indicate confusion regarding their expectations for the course, both in regard to "landscape" analysis itself and in regard to the balance of reading and discussion versus application. Regarding the former, Participant 27 stated, "I got confused even with the name of the class" and suggested more readings on theory, because "if we had more theories, we would have more deeper discussions." Regarding the latter, Participant 13 expected that the class would be "more analytical that it actually ended up being… My impression was that we were going to have more real case study work, that we might have taken a specific landscape and done some sort of analysis on it." However, when discussing expectations with Participant 29, this participant described an applied project that did take place in that course: "Structure from motion was one of the main topics that I wanted to learn about… We actually did a project using structure from motion." Another participant also had a hands-on experience in the course using software called eCognition; however, this participant expressed that since taking the course, "I've kind of flipped my opinion about eCognition… It just doesn't seem to be living up to that hype." Based on these participants' response, it may be appropriate to delve more into clarifying students' understanding of what landscape analysis *is* and how it is accomplished.

GEOG8510 Seminar in Cartography and Visualization. There were two participants who took this course, and of these two, one participant identified the course as relevant to their research interests and goals. Participants' feedback regarding this course was entirely based in content. Participant 13 was interested in gaining more understanding of and skill in both ArcScene and Google Sketchup and desired less emphasis on Visual Nature Studio. Specifically discussing ArcScene, the participant explained, "For people who are familiar with ArcMap, it's sort of a simple introduction to 3D modeling and animation that works pretty intuitively" (Participant 13). Participant 27 was interested in exploring open source software alternatives to these proprietary options.

Discussion

Examination of graduate students' feedback of all of these GIScience-related courses, in combination with their non-course-specific feedback, reveals several themes. First, graduate students have particular concerns regarding *content*. Popular responses for content interests include programming, cartography, free and open source GIS, and critical GIS. Graduate students' comments on these topics will each be discussed in turn. Second, graduate students are concerned with *application*, both understanding how what they are learning applies to their future careers and also gaining practice with the necessary skills required to become a skilled GIScientist or user of GIS. Third, graduate students expressed a desire for better *support* of GIScience education, desiring more instructor involvement/engagement and suggesting practical ways that departments can help their GIScience students.

<u>GIScience Course Content</u>

Participants cited a wide variety of interests and ideas for 1) courses and 2) topics to include in courses. The focus of this section will be on the four courses/topics in which participants most frequently indicated interest: programming, cartography, free and open source GIS, and critical GIS. Included in Appendix E are 1) other existing courses of interest, including both courses that participants have taken and recommend and courses that participants are interested in taking; 2) other topics that participants would like to see featured more in existing or new courses; and 3) participants' ideas for other new courses.

Programming for GIS

A substantial portion of participants indicated interest in taking the programming for GIScience course: 18 (60%) of the 30 total participants. However, several participants indicated that they have been unable to take the course because the instructor was unavailable to teach it (Participants 1, 9, 10, 23, and 27). "I don't think that students should have to necessarily wait two years, or in my case, never even have the chance to take that class here," says Participant 1, who feels, along with several other participants, that programming skills are increasingly necessary for getting a job (Participants 1, 2, 7, 18, 21, and 28). As Participant 21 observes, not only are students' skills in programming important for getting a job, such skills are also important for the geography program at UGA: "We need an edge in the market. We need a way to actually say that the GIScience Certificate or getting a Ph.D. from Georgia in GIS is more meaningful."

An introductory programming course used to be a prerequisite for UGA's GIScience certificate, but it was frequently waived. Participant 21 expressed disagreement with this action, stating, "The programming class *should* be one of the core requirements" (emphasis added). This prerequisite has recently been removed, and it is now possible to complete the certificate without any programming experience whatsoever. Such a deprioritization of programming may eventually undermine the UGA GIScience certificate's critical acclaim, as some "don't think there is any reason if you're doing GIS in 2015 you should not also be taking some computational science courses. It's just crazy to me" (Participant 25). Among some of the top geography programs in the nation,[24] at least one computer science course is typically listed as a prerequisite for GIScience-intensive majors.[25]

Participants expressed a desire that the programming for GIScience course be offered more frequently. At the time of this writing, this course was not offered for the past four academic years, meaning that three cohorts of two-year Master's students and one cohort of four-year Ph.D. students had no opportunity to take this course. The last time the course was offered was Spring 2012, and this was the only offering of this course during the time period of this research study. Other universities have offered a programming for GIScience more recently than this.[26] However, the geography department at UGA is planning to offer their programming for GIScience course again this coming fall.

Participants' responses indicated preference that a programming course be offered at least once a year (Participants 1, 14, 17, 20, and 22). One participant expressed that "it should be ok if [the department] didn't offer it so frequently" (Participant 8), due to the availability of online courses (non-UGA). However, Participant 23 made a substantive case for benefits of a face-to-face class, explaining,

> "I really wanted to have the structure of the time period... to like mingle minds with people who are also trying to work this coding stuff... It is one of the things that I guess you just have to continue play with yourself, but it would have been nice to have the environment to nurture it."

José Bowen, author of *Teaching Naked* (2012), argues that residential education needs to capitalize on its face-to-face time in order to remain competitive in a world of proliferating online educational opportunities. He would likely argue that this mingling of minds and

[24] Ranking obtained from http://www.justinholman.com/2015/01/13/2015-rankings-top-graduate-geography-programs-for-spatial-careers/ (accessed June 20, 2016).

[25] Universities with geography programs that require at least one computer science course include University of California Santa Barbara, The Ohio State University, Pennsylvania State University, University of Wisconsin-Madison, Arizona State University, etc.

[26] For example, Pennsylvania State University just offered a programming course this past spring. The Ohio State University is offering a programming course this coming fall, and it is required for geography majors.

nurturing environment needs to be embraced. Such a course has the opportunity to facilitate substantial learning in programming for GIScience that greatly surpasses students' attempts to learn programming from online courses that are isolating and not GIScience-specific.

Based on the demand for a programming course for GIScience among UGA's graduate students, it is recommended that geography departments at other universities poll their students on a regular basis (e.g. each semester or year) to determine 1) whether or not a demand exists among their university's graduate students to offer a programming for GIScience course and 2) whether or not students' feel their needs are being met in the course, making changes accordingly. Graduate students at different universities have different needs, but it appears programming skills are becoming something that many students need after they complete their formal education. Addressing these needs will reflect positively on the departments and universities from which these graduates obtained their degree.

Cartography

"There has been debate about whether a cartography class is needed. I would want to reinforce that as a really important subject area."

- Participant 26

Several participants expressed the need for a separate cartography course, *not* assuming that any mapping skills picked up in a GIScience course are sufficient: "So many people are learning GIS [saying,] 'I'm going to take a class, and I'm a GIS expert,' and that worries me to some extent… The maps you see are just really poorly done and are getting an A." It appears that map design skills are "something that many take for granted," which is dangerous because "every kind of scientist should know how to make a map, but if you don't, you should go to geographers, who should know" (Participant 29). However, many graduate students in the geography department at UGA come from different fields: "Some of us, by the time we get to this level, a lot of people aren't geographers… I've seen many a map that could use some help" (Participant 3). Considering the interdisciplinary nature of geography, it is likely that geography departments at other universities experience a "melting pot" of graduate students who completed their undergraduate degrees in other departments. These graduate students, in particular, may benefit from a cartography and geovisualization course. This may explain why cartography continues to be taught in the top geography programs in the nation.[27]

Participants stressed the needed for learning opportunities in cartography and visualization to learn how to "communicate their research" (Participant 29). Cartography is important for learning how to "successfully showcase what you're trying to say… It's one thing to know how to do GIS and how to run the software but if you can't portray it well on a map…" then one's work is undermined by one's inability to communicate (Participant 6). Participants 6 and 12 expressed interest in a 4000/6000-level cartography course, and if relevance is still a concern, Participant 26 suggests,

> "I would say making maps for the web is important… not just data processing on the web but also what are the design considerations for making maps that are going to be displayed on a screen or, even more recently, mobile device. I think those things are really important, and I don't think are really covered at all"

in UGA's existing GIScience courses.[28] Therefore, it is surprising that for the first time in at least several years, the geography department at UGA is not offering *any* cartography course this coming fall.

Free and Open Source GIS

Several participants were interested in learning more about and gaining skills with free and open source software alternatives for GIS, such as QGIS, and a couple of participants held

[27] The University of California Santa Barbara, The Ohio State University, and Pennsylvania State University, just to name a few, all offered at least one cartography course this past spring.
[28] An appropriate textbook for such a course could be *Web Cartography*: *Map Design for Interactive and Mobile Devices* by Ian Muehlenhaus (2013).

particularly passionate opinions about the learning and use of free and open source GIS. They note the sustainability of free and open source solutions for certain groups and organizations that are unable to afford proprietary software, such as ESRI's ArcGIS. If "you're working with different NGOs or any other kind of groups…you [want to] have a long lasting impact so whenever your project's done… they can continue to do it on their own," which is a more easily attainable goal if one utilizes free and open source software (Participant 7). Similarly and speaking from personal experience, Participant 26 explains,

> "I was asked to provide training on GIS… I had to make a decision: Do I want to train them in ArcGIS software, which I actually had with me, but I had a limited number of licenses, and I knew the licenses were going to expire in 6 months, or do I train them on open source software that I didn't know quite as well? …I chose the open source software from a sustainability perspective and [for] job skills… I felt like training them on open source software was going to enable them to take this skill with them to other jobs and potentially last a lifetime… I was effective in being able to train these folks…There's no reason today that they should have to learn ArcGIS or that they should be expected to bill out the hundred dollars for ArcGIS just so that they can learn… At the end of the day, now people have a skill they can use anytime they want, and share with anybody… It's something I really feel strongly about."

Free and open source software enables users in unique circumstances to continue working despite the established structures that limit access to knowledge and restrict agency in the production of knowledge.

The free and open source software used by Participant 26 was QGIS, who added that "QGIS has matured to a point that I think an introductory GIS class can be as effectively taught with QGIS as it can with even ArcGIS, and that's what everyone's been impressed with." The geography department at UGA and geography departments in other universities may wish to consider teaching a course or portions of existing courses using free and open source software, particularly if graduates from their programs have found or may find the use of such software beneficial for their job or career goals. Contacting recent graduates or polling current graduate students regarding their experiences or perceptions of need would be a great way to determine how much to incorporate free and open source software, such as QGIS, into the existing curriculum.

Critical GIS

At least seven participants were interested in critical GIS as something that should be included in current courses and/or in a separate course. It is hoped that such a course could examine "some of the ways that GIS helps to reinforce certain social constructs and can also help to tear down others" (Participant 13). According to Participant 21, "we actually need to think about all the things we're doing very critically and carefully and recognize the implications of all the knowledge we're putting off." It is important enough that, in Participant 24's opinion, "the critical geography course should not only be offered but should be a part of the core requirements." Such a course could dedicate a couple of hours to reading and discussion in a seminar style, and "then you have lab another day where you actually engage with how do to [volunteered GIS (VGIS)] or what VGIS is or you engage with open street mapping or qualitative GIS, which no one ever talks about" (Participant 21).

An alternative course option, suggested by Participant 6, could be

> "a health and medical geography course… That falls under critical GIS because medical geography is very quantitative, and it's GIS applied to public health data… Whereas health geography is a little bit more of the vulnerability side, which can be quantitative, but it can also be very qualitative, and more of a critical GIS approach to health and disease."

Addressing critical GIS could be done directly, via a separate course as suggested first, or indirectly, via a specialized course as suggested second. Either way, participants indicated that critical GIS was important to include in the curriculum somewhere and perhaps sooner than rather than later: "I have never heard of critical GIS until our Geography Thoughts and Methods" (Participant 6), an 8000-level course required for Ph.D. students. Both Participants 6 and 21 referenced a critical GIS reading group that was started among graduate students, but considering its perceived importance, it is worth considering more intentionally incorporating critical GIS into the GIScience curriculum. This could help bridge the divide perceived by Participants 3, 6, 9, and 29 between human geography and techniques/GIScience.[29]

GIScience Course Applicability

At least a couple of participants felt that "the way GIS is taught is pretty focused and blinding at times to the demands of what's going on in the technology and business community" (Participant 26), yet "there are lots of students who come to get a university education because they want to be marketable" (Participant 25). Participant 25 explained that

> "They want hard techniques skills, and they want good soft people skills to go and get a certain kind of job that they think they want. What I have heard from everybody here… is 'Oh, well that stuff is you just learn it as you go,' and most people who learn as they do, do a [terrible] job. They are really, really bad at it. [Therefore,] I think it would be really good to have some more business oriented courses"

because currently, "no one ever deals with management. They touch on it in all the geography courses, but there's no database or server administration course. There's no project manager or sort of business management course." Because of this, Participant 25 "challenge[s] anyone to show me how they are fundamentally that much more marketable then they were when they came" into academia. To elaborate, "I want to be clear that I don't mean just churn out drones to work on a GIS production line. You do want people with really big critical skills and conceptual skills, but I think we completely ignore" the fact that many undergraduates, some Master's, and a few Ph.D.'s do "go into production GIS, and if you have people who aren't prepared for that then they do become drones." Geography departments should consider their students' motivations for

[29] A phenomenon of fracturing in the discipline has been observed since the 1950s when human and physical geography "largely parted ways" (Tadaki et al., 2012). Participant 23's suggestion to offer a seminar on transportation GIS with an emphasis on climate could be an opportunity to pull together human geographers, physical geographers, and GIScientists. Participant 23 explains, "If we think back last year to snow jam or 'snowmageddon,' whatever you want to call it in Atlanta, that's a perfect blend of a GIS transportation climate problem amongst other social and political elements." It could be a great case study to fully delve into the interconnectedness of the discipline and encourage collaboration among students.

obtaining degrees in geography and address their students' needs for both academic *and* non-academic careers.

As a partial solution to address these needs, a few participants suggested emphasizing internship opportunities (Participant 14, 17, and 18).[30] Participant 14 explains how this contributes to finding a job, observing based on personal experience that an internship

> "gives you an idea of how GIS is used in the real world, and it teaches you soft skills as well: how to work on a team, how to work with people of different beliefs or ages… teaches you how to be responsible and on time and how to prioritize… how to have a conversation about work, how to present your ideas."

For these reasons, Participants 14 and 17 suggest that an internship be a requirement for every student, which is possible because

> "there are enough local opportunities, but what [the geography department] can do is create partnerships… There's the public works department, the planning department. There's nonprofit, and Georgia Bikes! is local… I'm sure there's a lot that we could do… GIS is related to
>
> everything. You could even work with your local store owner and plan out their advertising using local demographics" (Participant 14).

The University of Georgia is not a very large city (population ~120,000), especially in comparison to metro Atlanta (>5 million); if graduate students can find internships in Athens, then it is reasonable to assume that students attending colleges and universities in larger cities might have even more opportunities for internships. If departments could provide better support for facilitating internships and required their students to take advantage of these opportunities, this would be a great benefit to students seeking careers outside academia.

Supporting GIScience Education

Participants discussed a couple of means by which geography departments could better support GIScience education: 1) more involvement/engagement from instructors and 2) providing events/resources relevant to students' needs.

[30] An internship is an option for UGA's GIScience Certificate, but it is not currently a requirement.

In regard to the former, emerging from a disparate group of participants' comments was a desire that instructors be more involved in the classroom and engaged with students' learning. For example, Participant 1 also expressed that

> "for the lab part of [of the course], the professor's never there. It's always the TA the whole time, which is fine. That's their job, but I think it would be useful sometimes for the professor to be there a few times."

Additionally, Participant 3 wished that instructors could be more involved in organizing group discussions, because "when you're just talking randomly about different things, I don't really feel like you're developing." Finally, Participant 13's comment regarding instructor involvement revolved around online learning experiences:

> "I've heard some horror stories from undergraduates that have tried to take a GIS online course, and I think that there were some problems, not at this institution but elsewhere, with the instructor not being as accessible as they should have been."

Although this comment does reference a learning experience that did not take place at UGA, it is worth remembering for future learning experiences, both in traditional face-to-face courses and in online courses. Opportunities for one-on-one interaction with instructors is what makes residential education different from other educational opportunities (e.g. taking self-guided online course), and it is good for instructors in all departments to consider what they offer to students that students cannot receive anywhere else, such as personalized guidance, connections with other professionals in the field, etc.

In regard to the latter, providing events/resources relevant to students' needs, several participants indicated struggles with finding relevant courses to complete their certificate or program of study: "We don't have that many choices for classes… We emphasize less GIS side" (Participant 10). As pointed out by Participants 3 and 27, this results in "waiting" for relevant courses to be offered. These struggles could be partially ameliorated by ensuring that "courses could be offered more regularly" (Participant 17) and offering "a more diverse applications oriented array of classes" (Participant 11).[31] Another thing that would benefit geography students is helping students be more aware of courses being offered, both inside and outside geography, as well as what those courses entail beyond their course name and number. Participants expressed the desire that there was more communication between geography and other departments so that students could more readily be informed of relevant GIS courses (Participants 6 and 15). Also, ensuring that relevant courses are cross-listed was an idea presented by Participant 15. More broadly, however, Participant 21 suggests, "Maybe it's just a question of marketing?"

A practical suggestion for improving students' experiences, based on the responses collected in these interviews, is to market, advertise, or otherwise increase the awareness of course offerings. The department could consider offering an exposition of upcoming course offerings, a "Geography Expo," so to speak. On a dedicated date and time once a semester, the department could feature the course offerings for the upcoming semester. Instructors for each course could take a few minutes to talk about what they intend to cover in their upcoming course and their general plan.[32] Although GIScience *career* fairs are common in geography departments, it does not appear that events similar to this proposed exposition, which focus on the teaching and learning taking place in the department, are commonly hosted in any geography department, if at all. Nevertheless, it is still worth the effort to find out whether or not such an exposition provides substantial benefits to students, instructors, advisors, and the department.

[31] If each semester's collection of course offerings could include both 2-3 regularly offered courses and 1-2 themed GIScience courses that change every semester, this could be a huge benefit to those seeking to satisfy their course requirements within geography.

[32] Instructors could bring a flyer, PowerPoint slide, PDF, or other sharable item. Primary divisions of the time could be based on undergraduate-only courses, split-level courses, and graduate-only courses, and secondary divisions could be based on foci in human geography, physical geography, and techniques/GIScience. Such an exposition could be widely advertised both within and without geography to increase awareness and interest in geography courses, and it would be an opportunity for interested students to ask questions of instructors and advisors. This could streamline the process of tailoring their program of study to suit their research interests and goals.

Another practical suggestion based on participants' responses is to take the once-a-semester "GIS Help Day" (Participant 30) and expand it into a "dedicated GIS lab," as experienced at another university by Participant 27. Students in GIScience courses and students/faculty performing research using GIS could have a regular location at which they could receive assistance, and it could be available university-wide and perhaps even to non-academics as well, rather than remain exclusive to geography. This would be a great way to increase the transparency of the geography department and to encourage collaborative interdisciplinary projects and research. Such a dedicated GIS lab could be a great benefit to the department, the university, and the community. Such labs exist at other universities, sometimes hosted by the university libraries.[33]

Conclusion

As shown in this research study, graduate students do have substantive feedback regarding the GIScience curriculum of UGA's Department of Geography. Their responses show that they engage critically with the teaching and learning environment of each course and identify what does and does not benefit their and other students' learning. For GIScience specifically, they tend to feel that hands-on activities that build skills are exceptionally important and that this is something that could be emphasized more. They question the status quo, recognizing that just because something has always been, this does not mean that it is best to continue to be. Although many GIScience courses have been taught with separate lecture and lab components, graduate students are willing to question this and propose alternative solutions,

[33] For example, there are dedicated GIS labs at the University of Washington (see http://www.lib.washington.edu/about/hours/gislab, accessed June 20, 2016), the University of Miami (see http://sp.library.miami.edu/subjects/gis, accessed June 20, 2016), the University of California, Santa Cruz (see http://gis.ucsc.edu/, accessed June 20, 2016), and others.

going as far to suggest tilting the 50/50 balance between lecture and lab to favor lab time with the instructor present or more thoroughly integrating lecture and lab.

Additionally, graduate students are also forward thinking, meaning that they try to anticipate and address their needs for the future jobs they hope to acquire. For many this means gaining programming skills to be marketable and competitive. For others, this means acquiring experience with free and open source software alternatives for GIS, such as QGIS. Graduate students' justification for free and open source software also shows that they care about the long-term impact of their choices. They are willing to take a potentially more challenging path for the benefit of the greater good, hoping that more people can be geographically informed through the use of free and open source GIS. Last but not least, graduate students have innovative ideas for new topics and new courses for the department, including courses that may help return human geography, physical geography, and techniques/GIScience to a unified discipline.

This research study sought to answer, "What are graduate students' reflections on their past and desired learning experiences in GIScience, and how might their reflections contribute to curriculum revision and enhancement?" Their reflections were expounded in the results and discussion. It is hoped that their feedback has been summarized and presented in such a way that the participants of this research study may speak for themselves; after all, giving a voice to graduate students, who have been so thoroughly ignored in education research to date, was also an objective for this research. To respond to the latter question, graduate students' reflections contribute to curriculum revision and enhancement by ensuring that the GIScience curriculum remains student-centered and relevant. Unlike many faculty, graduate students and recent graduates are not far removed from the simultaneous experiences of being a student and job-hunting in hopes of beginning a career, and therefore, their thoughts on their learning experiences and the curriculum are based on immediate and pressing needs. This is a valuable source of information that departments could better utilize.

Directions for Future Research

There are multiple directions for future research inspired by this study, which include the following:

- *Research studies that involve more regular participation.* In UGA's geography department, there have recently been approximately 100 graduate students each year, and graduate students change each year as new students are admitted and other students graduate. This research study involved a substantial number of the students from the 2014-2015 academic year. Ideally, future studies would interview graduate students on a yearly basis to better capture the change in participants' feedback over time.
- *Research studies that streamline the process of data gathering and analysis.* This research study utilized one-on-one interviews exclusively. Ways to gather and analyze more feedback more efficiently and simultaneously maintain the quality of responses could include requesting that participants complete a pre-interview survey. This research could also develop repeatable and sustainable methodology for gathering and utilizing graduate students' feedback in curriculum revision.
- *Research studies that compare one-on-one interviews with focus groups.* In this research study, participants were interviewed one-on-one for their thoughts and opinions, and they did not build upon other participants' feedback. This was beneficial for lending credence to any quantifiable results, but future research could investigate whether or not any substantive difference exists between one-on-one interviews and focus groups. Additionally, a means of enriching focus groups could be to have one-on-one interviews first and then focus groups second.
- *Research studies that consider the temporality of participants' responses.* Graduate students' opinions may differ based on the timing of participation relative to the learning experience being discussed. In other words, responses may differ when interviewing a participant a week versus a year after a student finishes a course. Future research studies may want to emphasize interviewing participants sooner, while their learning experience is still fresh in their minds.
- *Research studies that evaluate the benefits of changes made based on feedback.* Ideally, changes will be made based on graduate students' feedback. A follow-up study could examine the impact of these changes. Such a study would need to evaluate how well the changes succeeded or failed to address students' concerns, as well as whether or not the resulting changes benefitted students' learning experiences.
- *Research studies that investigate barriers to curriculum revision.* Researchers can gather graduate students' feedback, streamline the methods of data collection and analysis, and provide summaries of this feedback on a regular and timely basis, but there may still be barriers to change. It would be worthwhile to investigate the

process of curriculum revision to better understand the process and to identify any barriers that slow or inhibit the process, investigating possible solutions.

GIScience is constantly evolving, and it is important for educational institutions to prioritize how to stay up-to-date and relevant to students' needs both inside and outside the classroom.

CHAPTER 4

SUBSTANTIAL LEARNING OF COLOR FOR CARTOGRAPHIC APPLICATION: WORKSHOPS USING FREE AND OPEN SOURCE QGIS[34]

[34] Castellucci, E.S. and J.A. Knox. To be submitted to *Cartographica*.

Abstract

This research study investigated how well QGIS, a free and open source software for GIS, can facilitate a substantial learning experience for color as applied in cartography and visualization. To accomplish this, a workshop focused on cartographic color concepts was created using QGIS as the software of choice and offered ten times. A total of 234 undergraduate and graduate students with and without GIS experience (QGIS and ArcGIS) and/or relevant coursework and with various levels of familiarity with cartographic color concepts participated in the study. Quantitative and qualitative methods were used to analyze participants' responses to the workshop surveys. Results indicate that 1) participants agreed that the experience resulted in substantial learning of color, and the use of QGIS was considered a benefit to participants' learning; 2) several participants felt that free and open source software alternatives for GIS, particularly QGIS, should be incorporated into regular GIS curriculum to provide a more equitable learning experience, to address needs outside of academia, and to capitalize on the social implications of using free and open source software; and 3) concepts and software previously reserved for more advanced courses can be taught to freshmen and sophomores, making a case for offering more lower-level GIS courses.[35]

Introduction

Free and open source software options for geographic information systems (GIS), such as the popular QGIS software (see QGIS.org), are becoming increasingly competitive with proprietary software. A prime example of proprietary, i.e. closed source and frequently expensive, software is ESRI's ArcGIS software, an established software of choice within many educational contexts. As free and open source software has matured in recent years, it is being

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[35] This research study, which involves human subjects, was approved by the Institutional Review Board (IRB) of the Office of the Vice President for Research of the University of Georgia on March 22, 2016. This study's IRB identification number is STUDY00003257.

more and more frequently adopted for various reasons, including cost considerations and platform limitations. QGIS is a popular GIS software choice among small companies, nonprofits, users, users of operating systems that do not support ArcGIS (e.g. Mac OS X, Linux, etc.), and particularly users in developing nations (Câmara & Onsrud, 2004; Chen et al., 2010; Goodchild, 2007; Kabo-bah et al., 2012; Neteler et al., 2012; Rocchini et al., 2012; and Schweik et al., 2009). Because of its popularity, more graduates find that they benefit or would benefit from an education that explicitly incorporates QGIS into the regular GIS curriculum, because having knowledge and skill with QGIS would increase their marketability and employment options compared to having experience only with ArcGIS.

This research study investigates how well the QGIS software can facilitate a substantial learning experience for color as applied in cartography and visualization. A focus on color, specifically as applied in cartography and visualization, was selected because most, if not all, GIS users will need to make a map at some point in their work with GIS, and questions of color are something that all map designers must answer. Unfortunately, there exists a stigma against cartography, as some consider it a dying or already "dead" field (Wood, 2003). Thankfully, there have been multiple responses, including one that asserts that cartography is, in fact, still "alive" (Carter, 2004), and according to Goodchild (2004), there has even been "a resurgence of interest in such topics as cartography (and its generalization in GIS visualization)" (301).

The simple fact remains that GIS are still maturing, and users still need to intervene to make design decisions. Most, if not all, GIS still randomly apply colors to newly imported data, and users must make decisions regarding how that data should appear. Without training in best practices in cartography and map design, GIS users typically default to personal preference, but as Robinson states in his classic work, *The Look of Maps* (1985),

> "There seem to prevail among otherwise logical thinkers the curious notions that a) what the individual himself likes another will also, and b) if someone likes a technique it is therefore good.
>
> If ever means and ends were confused it is in these reactions to color use... Except within the broadest limits personal preferences should play a small role in the choice of colors."

It is insufficient to choose what one "likes," as what one likes may not be good, i.e. effective for communication with others. Cartography is an art of visual communication, and it must be intentionally learned to both communicate effectively with others and also to critically engage with others' work and map designs. A poorly designed map can, in fact, result in *mis*communication and direct a reader to conclusions that were never intended by the map designer.

To evaluate how well the QGIS software can facilitate a substantial learning experience for color as applied in cartography and visualization, a workshop was designed that specifically uses QGIS to help participants learn about color. Color concepts were chosen through a comparative analysis of the color concepts included in the *Geographic Information Science and Technology (GIS&T) Body of Knowledge* (DiBiase et al., 2006) against seven cartography textbooks. A revised list of learning objectives related to color was created as a result of this comparative analysis (see Literature Review for more details). The workshop was designed to alternate between presentations and hands-on exercises, and it was bookended by pre- and post-workshop surveys (see Scope and Design for more details). Data from the workshop, which was offered ten times, were analyzed using quantitative and qualitative methods (see Methods). Findings from the quantitative analysis are included in the Results section, and the results from the qualitative analysis are used in the Discussion section to explain the quantitative results and provide insight on the use of free and open source software alternatives for GIS. The Conclusions summarize the overall results and provide suggestions for future research.

Literature Review

An increasing number of employers is interested in hiring people with experience using free and open source software, and this is true for employers seeking to hire people for GIS positions as well. However, GIS is rarely taught and learned using free and open source software for GIS, because some companies, such as ESRI, provide copies of their robust, yet closed-source, software to several academic institutions at reduced cost. Fortunately for those companies and unfortunately for the person without access to the software after graduation, a lock-in effect occurs, in which the person knows how to use only that particular software and has little to no experience with other software, such as free and open source software (Câmara et al., 2012). For GIS, it is true that some skills are transferable among different GIS software, but there are still substantial learning curves to overcome when utilizing free and open source software for GIS. In the not-too-distant past, free and open source software for GIS were difficult to access and utilize, due to their steep learning curves, lack of training materials, and limited functionality. Recently, however, free and open source software for GIS are rapidly becoming more accessible and easier to use, participating in and complying with the efforts and standards of the Open Geospatial Consortium (OGC) (see http://www.opengeospatial.org/, accessed July 12, 2016).

There has been little substantive research on teaching and learning with free and open source software for GIS. Of general works, Tsou and Smith (2011) published a white paper via the GeoTech Center in which they provide an introduction to free and open source software for teachers and students getting started with it. It only outlines available free and open source software and some basic considerations. Similarly, Donnelly (2010) wrote about adopting open source software for GIS in libraries, providing a thorough discussion on map making with free and open source software, which was relevant to ongoing discussions on the benefits/challenges of teaching and learning with free and open source software. Other works do not delve deeply into the issues, such as Singhai et al. (2011) and Gomasathit et al. (2011) who published papers on using free and open source software for geomatics/GIS education. They only scratch the surface of the issues relevant to adopting free and open source software for teaching and learning GIS. Scholz et al. (2011) discussed using gvSIG versus QGIS for teaching GIS but only "in terms of 'ease of use' and suitability for teaching." Menke (2011) merely reflected on the experience of teaching a course in free and open source GIS. Also writing reflectively, Brandalize and Antunes (2009) discussed the practical issues that arose when attempting to teach GIS in Brazil with an open source software known as SPRING.

A few papers have been written regarding online experiences with free and open source software. For example, Turton (2009) wrote about using open source software to teach GIS, but the focus was on web mapping; however this is not comparable with this research project, because this project focuses on free and open source desktop software for GIS. Schweik et al. (2009) reflected on an attempt to teach an online GIS course using open source software, but they admit that "when we began this effort and designed this course, we did so without fully reviewing existing research and knowledge about online and distance learning. In retrospect this was a mistake" (127). Finally, Hubeau et al. (2012) wrote a promising paper on the specific issue of software-independent and software-specific tutorials, but due to the small number of students in each group the significance of their results and conclusions is questionable.

Teaching and learning GIS using free and open source software is growing in importance, and the general trend appears to be adoption of free and open source software, such as QGIS, but this has come largely without focused research into its merits and faults, its unique advantages and disadvantages. This research study is unique in that it is designed to examine what none of this past research has addressed: potential for free and open source software for GIS to facilitate *substantial learning*. "Substantial" learning is a renaming of Fink and Ganus (2009)'s term "significant" learning, which they describe as the result of learning experiences that are "powerful" (71), designed from a "learning-centered, integrated, systematic approach," are "student-centered", result in "critical thinking" (72), and have a "lasting impact" (78). The term "substantial" learning, as used in this work, is meant to indicate the same concept; it is merely being renamed to avoid any confusion with statistical significance. Additionally, this research is unique in its learning context, a workshop, and its specific focus on cartographic color concepts.

New Learning Objectives for Color

In the *GIS&T Body of Knowledge* (DiBiase et al., 2006), very few learning objectives are explicitly dedicated to concepts of color. Only the Knowledge Area of Cartography and Visualization (CV) includes such learning objectives. In Unit CV3 Principles of Map Design (core unit), one finds the only Topic exclusively dedicated to color, Topic CV3-3 Color for Cartography and Visualization (pp. 72-73). This topic includes 13 learning objectives. There is one other topic in this unit that contains one learning objective related to color, Topic CV3-4 Typography for Cartography and Visualization, which addresses color for map labels. Three other units contain topics with learning objectives related to color. These include the following:

- Unit CV4 Graphic Representation Techniques
    - Topic CV-4 Representing Terrain (1 learning objective)
- Unit CV5 Map Production
    - Topic CV5-2 Map Production (5 learning objectives)
    - Topic CV5-3 Map Reproduction (3 learning objectives)
- Unit CV5 Map Use and Evaluation
    - Topic CV6-2 Map Reading (2 learning objectives)

In total, there are 25 learning objectives in the *GIS&T Body of Knowledge* that relate to color. Each of these learning objectives were categorized according to the revised version of Bloom's taxonomy of learning objectives (Krathwohl, 2000; Bloom et al., 1956), which include the following, from lower to higher order thinking skills:

- Remember – 2 learning objectives, each assigned a value of 1
- Understand – 11 learning objectives, each assigned a value of 2
- Apply – 9 learning objectives, each assigned a value of 3
- Analyze – 0 learning objectives, which would have been assigned value of 4
- Evaluate – 0 learning objectives, which would have been assigned value of 5
- Create – 3 learning objectives, each assigned a value of 6

The "average Bloom's level" for the learning objectives related to color in the *GIS&T Body of Knowledge* was calculated and found to be 2.76, echoing findings by DeMers (2009) that the "average Bloom's level" in the *GIS&T Body of Knowledge* varies by knowledge area but typically hovers around a 3, and there is a "skew toward lower learning levels" (S74-S75). This is not necessarily a problem, as "curricula should not be so tightly linked to this philosophical model," as some things could be unnecessarily overemphasized (S72). However, for concepts of color as related to cartography and visualization, the learning objectives included in the *GIS&T Body of Knowledge* indicate an overemphasis on understanding and very basic application, whereas the task of map design is inherently one of creation including cycles of revision characterized by analysis and evaluation.

Therefore, these learning objectives regarding color from the *GIS&T Body of Knowledge* needed to be revised if they were to be used as the basis of designing a workshop experience focused on color. To accomplish this, the following texts were compared according to the contents of their chapter(s) focused on color:

- *Cartography: Thematic Map Design* (Chapter 14) by Dent et al. (2009)
- *Thematic Cartography and Geovisualization* (Chapter 10) by Slocum et al. (2009)
- *Principles of Map Design* (Chapter 4) by Tyner (2010)

- *Web Cartography: Map Design for Interactive and Mobile Devices* (Chapter 5) by Muehlenhaus (2014)
- *GIS Cartography: A Guide to Effective Map Design* (Chapter 5) by Peterson (2014)
- *Designing Better Maps: A Guide for GIS Users* (Chapters 4 and 5) by Brewer (2005)
- *Making Maps: A Visual Guide to Map Design for GIS* (Chapter 11) by Krygier and Wood (2011)

The results of this comparison are shown in Table F.1 of Appendix F. As shown in the table, some concepts were commonly included in all texts evaluated; however, authors differed on which concepts were of secondary, tertiary, etc. importance. This variation was taken into consideration in choosing which concepts would be included in the revised learning objectives with respect to the concepts covered in the original learning objectives. The new learning objectives are listed in Appendix G. The Bloom's levels of these learning objectives differ from the original learning objectives as follows:

- Remember – 1 learning objectives, each assigned a value of 1
- Understand – 10 learning objectives, each assigned a value of 2
- Apply – 4 learning objectives, each assigned a value of 3
- Analyze – 1 learning objective, each assigned value of 4
- Evaluate – 1 learning objective, each assigned value of 5
- Create – 7 learning objectives, each assigned a value of 6

The "average Bloom's level" for the new learning objectives is 3.50. Although the majority of learning objectives are still skewed toward the lower order thinking skills, the revised list contains more learning objectives that require higher order thinking skills. In particular, the Analyze and Evaluate objectives were added to address these gaps in the original learning objectives; these new Analyze and Evaluate objectives are as follows, respectively:

- Compare and contrast the overall color harmony of multiple maps attempting to achieve similar purpose, commenting on specific color choices in component parts.
- Provide a critical evaluation of a map design, specifically noting good/bad color choices and providing specific suggestions for enhancement when/where necessary.

These learning objectives were drawn from real-life teaching experience rather than either the *GIS&T Body of Knowledge* or the textbooks included in the textual analysis. They were included because they represented a noteworthy gap in the learning objectives: there were none that required students to analyze or evaluate color in map design. Such skills are necessary for cultivating producers and consumers of maps who are able to turn a critical eye to design.

Scope and Design

The workshop was designed with consideration of the new learning objectives, but the driving forces guiding the design of the workshop were as follows:

- *Time limitation*. The workshop was limited to 2-3 hours, which put a restriction on how much could be accomplished during that span of time.
- *Desired structure*. The format of the workshop was intended to be short presentations followed by hands-on activities. The presentations were to be short to maintain participants' attention as new information was introduced. Activities were to follow each short presentation, giving students the opportunity to immediately apply what was learned.
- *Anticipated audience*. It was anticipated that many of the participants were going to be new to GIS and mapping, and the experience was designed to be suited for beginners with optional, additional goals for more advanced users.

Because of these factors, it was deemed unreasonable to attempt to achieve all of the new learning objectives. Rather, a selection was considered which generally corresponded with concepts frequently addressed in the evaluated texts. The color concepts addressed in the final workshop design include the following:

- Color in the Electromagnetic Spectrum
- Perceiving Color with the Human eye
- Color Blindness
- Additive Color Theory and the RGB Color Model
- Subtractive Color Theory and the CMYK Color Model
- Perceptual Dimensions: Hue, Saturation, and Value
- Color Mixing
- Color Preferences and Connotations
- Color Conventions
- Sequential vs. Diverging Color Schemes
- Color Contrast
- Figure-Ground Relationship

Concepts that were frequently mentioned, yet not included in this workshop experience, include black and white or grayscale color schemes, color interactions, Commission Internationale de l'Eclairage (CIE) LAB specifications, HSB/HSL color models, and the Munsell color model. Concepts that were not frequently mentioned yet included in this workshop experience include palettes/ramps, color mixing, and contrast.

Black and white or greyscale color schemes were omitted on the basis of relevance to modern map design and dissemination; black and white maps are less common in the world of digital and online map-making and map sharing. Color interactions, such as simultaneous contrast and successive contrast, were omitted since they have subtle effects on map color and require a more advanced understanding of color to understand. The CIE LAB, HSB/HSL, and Munsell color models were omitted in favor spending more time on more common color models: HSV, RGB, and CMYK. Additionally, QGIS supports color mixing only in the HSV and RGB color models. Palettes/ramps were included since qualitative and quantitative color conventions are easier to teach when providing palette and ramp examples for the respective concepts. Teaching and practicing color mixing complements and reinforces students' learning of color models. Finally, contrast was included because figure-ground relationship, sometimes known as object-background relationship, is easier to learn with an existing foundation of good/bad color contrast.

Materials

The workshop was designed so that no experience was required to participate, and everything needed to participate was provided. Upon arrival, all participants received a slip of paper containing a link to all workshop materials and an access code to be entered at the beginning of both the pre- and post-workshop surveys. The link gave students access to the following materials:

- Pre-Workshop Survey (See Appendix H.)
- Instructions Packet (PDF) (See Appendix I.)
- Data Files (ZIP) (See Appendix J.)
- PowerPoint Presentation (PPTX) (See Appendix K.)
- Post-Workshop Survey (See Appendix L.)

The access code was a randomly generated six-digit number. The purpose of the access code at the beginning of the pre- and post-workshop surveys was to make it possible to re-associate the two surveys as attributable to one participant, after the data collection was complete. Along with these workshop materials, QGIS 2.14 Essen was already installed on each of the computers in this lab.

Surveys

The pre- and post-workshop surveys were both collected online via Google Forms, which allow the administrator to download all responses in an analysis-ready Excel spreadsheet. The pre-workshop survey collected information about the participant including gender, undergraduate versus graduate and related information, previous GIS experience and coursework, and familiarity with color concepts as applied to maps. The post-workshop survey collected information from participants regarding their experience participating in the workshop, particularly the level of substantial learning achieved, both in general and per color concept. The format of questions in the post-workshop survey included Likert-scale questions, Yes/(Maybe)/No questions, and open-ended questions to encourage elaboration. All Likert-scale questions used the following response options:

Strongly Agree   Agree   Neutral   Disagree   Strongly Disagree

The first set of questions (Likert-scale and yes/no) specifically addressed participants' reflections on the level of substantial learning achieved in general. The substantial learning questions included the following:[36]

- Please indicate your level of agreement with the following statements:
  - This workshop was focused on participants' learning. (Likert-scale)
  - This workshop stimulated my critical thinking. (Likert-scale)
  - This workshop has changed the way I think about map color. (Likert-scale)
- Would you be able to apply what you have learned in this workshop, if you needed to make a map in the future?
  - Yes (If yes, how do you imagine you would use what you have learned?)
  - No (If no, why not?)

The second and third set of questions (both Likert-scale) addressed participants' learning of color concepts. They differ in that the first set asks students to respond to the statement, "*As a result of this workshop, I better understand* the following concepts related to color," and the second set asks students to respond to the statement, "*Using the QGIS software was beneficial for helping me learn* about the following concepts related to color" (emphases added). These statements are followed by the twelve color concepts covered in the workshop, and the purpose of these two separate sets is to distinguish between students' learning as a result of the workshop in general and students' learning as impacted by use of the QGIS software. The remaining questions in the post-workshop survey address whether or not QGIS was a benefit or inhibitor of participants' learning; participants' interest in taking a course that primarily utilizes QGIS; and participants' opinions, if any, on free and open source software for GIS.

[36] Participants' responses to the following yes/no statement were omitted from analysis: "QGIS was an appropriate software choice for this workshop." Many participants indicated that they were unsure how to answer this question, because they had no experience with any other GIS software. Nevertheless, most participants responded "yes." This was likely the result of a combination of two factors: 1) A response was required before moving to the next section of the survey, and 2) participants had a generally positive learning experience, so a response of "yes" made more sense to them than "no." Additionally, the "appropriateness" of the software begs the question of *more* or *less* appropriate than *what*? And this was not clear.

Presentations and Exercises

The majority of the workshop was dedicated to a series of presentations and exercises. The first presentation was entitled "What is 'GIS'?" and introduced basic concepts of geographic information and GIS (including layers and feature components) to participants who never heard of GIS before the workshop.[37] ArcGIS by ESRI and QGIS were introduced as Desktop GIS options, and the difference between proprietary and open source software was explained. Participants then completed the first exercise, entitled "Looking around QGIS," which was a general introduction to QGIS and its basic functions. With this exercise, students were provided with data to explore, which included shapefiles of the county boundary, roads, and pizza restaurants of Athens – Clarke County, GA.

The second presentation was entitled, "How do map designers think about color?" In this presentation, colors are discussed in the context of the electromagnetic spectrum and the ability of the human eye to perceive light and color, followed by an introduction to colorblindness. Additive and subtractive color theories were introduced, along with their respective color models, RGB and CMYK, and finally, the perceptual dimensions of color are discussed: hue, saturation, and value, the components of the HSV color model. Mixing colors using the HSV color model is demonstrated, which participants practice in their second exercise, entitled "Mixing Colors in QGIS." Participants who finished quickly were encouraged to practice mixing colors using the RGB model.[38]

The third presentation was entitled, "Which colors do I choose?" Color preferences, connotations (both generic and cultural), and conventions were differentiated. Established

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[37] At the beginning of each workshop, participants were informally asked if they had even heard of GIS before this workshop. In every workshop, a majority of participants indicated having never heard of GIS before the workshop.
[38] Participants were unable to practice mixing colors in QGIS using the CMYK model, because the CMYK model is not currently supported in QGIS.

conventions were exemplified using Google Maps, Bing Maps, and MapQuest maps of South Carolina. The exercise, entitled "Conventional Colors in QGIS", guided participants through the process of editing the colors of provided South Carolina data. This data was provided in the random colors generated by QGIS automatically, which were quite garish and used as an object lesson in never simply accepting the default colors generated by a GIS. This exercise ended up taking the longest for participants to complete.[39]

The fourth presentation, entitled "How do I color quantitative data?", emphasized the proper use of sequential and diverging color schemes for quantitative data. Additionally, participants were introduced to Color Brewer (colorbrewer2.org), which offers reliable sequential and diverging (and qualitative) color schemes that have already been included in the QGIS software. In the corresponding exercise for this section, "Color Ramps in QGIS," participants were given a shapefile of Georgia counties containing population density values, as well as a calculated field showing percent greater/less than the average population density. Participants applied a sequential color scheme to the former and a diverging color scheme to the latter.

Finally, the fifth presentation, "Which color tip is most important?", provided participants with general tips for combining colors, yet it emphasized the importance of establishing effective figure-ground (sometimes known as object-background) relationship. Establishing good color contrast, particularly of saturation or value, was emphasized as a critical component of effective figure-ground relationship. No exercise was provided for this section; rather, the previous exercises were reviewed. This provided an opportunity to show participants where the

[39] This was partially due to the fact that relative pathnames were not stored for this particular QGIS project file, so participants were presented with an error message that the instructions did not address. Although this was not originally intended, it was intentionally left unfixed, because it ended up serving a very beneficial purpose of forcing participants to wait and allow others to catch up. Participants were not instructed on how to fix this problem until Exercise 3 officially began.

instructions guided them to color features according to good color contrast and figure-ground relationship, even though it was not explicitly mentioned at the time.

Consistency

As it was necessary to offer the same workshop multiple times, a substantial effort was made to ensure that the experiences were as identical as possible. However, there were a few differences between the first 2-3 workshops and the rest, due to the workshops taking a little time to settle into a "rhythm."

First, it was quickly observed that participants were not waiting to complete the post-workshop survey. Rather, after finishing the fourth exercise but before the final presentation, which covered contrast and figure-ground relationship, participants were completing the post-workshop survey. This was problematic, because there were a couple of questions that explicitly addressed topics not yet covered. Therefore, for following workshops, the post-workshop survey was rendered inactive until its appointed time.

Second, determining how long to spend on each exercise was tricky, because each participant and each group of participants per workshop worked at a different pace from one another. Eventually, a pattern was settled that worked for every workshop. Participants were asked to raise one finger when finished with Exercise 1, two fingers when finished with Exercise 2, etc. until noticed by the facilitator. The facilitator would then keep a mental tally of how many were finished with the current exercise until a majority was reached, and when a majority was reached, the facilitator would move onto the next presentation. Participants were encouraged not to worry if not yet finished with the exercise, as they could finish the exercise at the beginning of the next. There was also time at the end of the workshop to complete exercises, as the workshop ended up taking ~2.5 hours for most participants to complete, rather than the scheduled 3 hours.

Third, the PowerPoint was slightly altered. The slide entitled “Quantitative Conventions” showed sequential and diverging color schemes side by side to emphasize their visual differences, and it was originally placed as the first slide in the fourth presentation. However, the facilitator quickly noticed that it was much easier to explain the concepts after discussing a sequential example and a diverging example, so it was moved to third position, before introducing Color Brewer. This did not appear to have any substantial effect on the overall workshop results.

The content of the surveys, instructions, and data were not altered.[40]

Participants

The workshop took place in the largest computer lab of the UGA Geography/Geology building, which contains 24 computers. Because of space limitations, the same workshop was offered 10 times during the Spring 2016 semester. Interested persons were expected to register in advance, choosing their desired date/time on the event website, but because there were also 10 additional seats without computers in the room, up to 10 extra persons were able to participate on the workshop on a “first come, first served” basis, as long as they brought their own computer with QGIS already installed. This helped to offset the number of “no-shows” among the number of registered workshop participants.

Across all workshops combined, the number of participants who attended and completed both the pre- and post-workshop surveys totaled 234.[41] In terms of gender, 160 (68.38%)

[40] Even the only typo, which directed participants to symbolize land as water in Exercise 3, was not corrected.
[41] Only a small handful of participants completed one survey but not the other. Four participants completed the pre-workshop survey and not the post-workshop survey. Two participants completed the post-workshop survey but not

identified as female and 73 (31.20%) identified as male.[42] Undergraduate students numbered 198 (84.62%), and graduate students numbered 36 (15.38%). As shown in Figure 4.1, the majority of participants were undergraduates in their freshman or sophomore year.

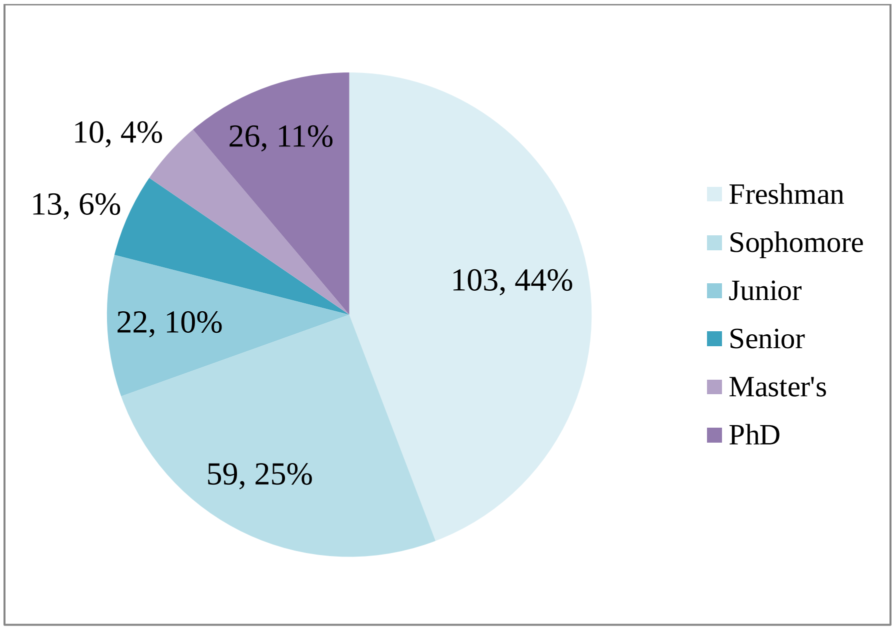

Figure 4.1 Breakdown of undergraduate and graduate student participants.

In terms of GIS experience, 12 (5.13%) of the participants indicated having QGIS experience, and 29 (12.39%) of the participants indicated having ArcGIS experience. However, because all participants with QGIS experience *also* had ArcGIS experience, the indicator of ArcGIS experience was able to represent students with *any* GIS experience (QGIS and/or ArcGIS). Therefore, for the purposes of this workshop, 29 (12.39%) of the participants had previous GIS experience. In terms of GIS or cartography-related coursework, 26 (11.11%) of the participants indicated having taken at least one GIS or cartography-related course.

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the pre-workshop survey. Only one participant was not a student. These incomplete responses and the non-student response are not considered in the data analysis.

[42] One participant (0.43%) identified as “other”.

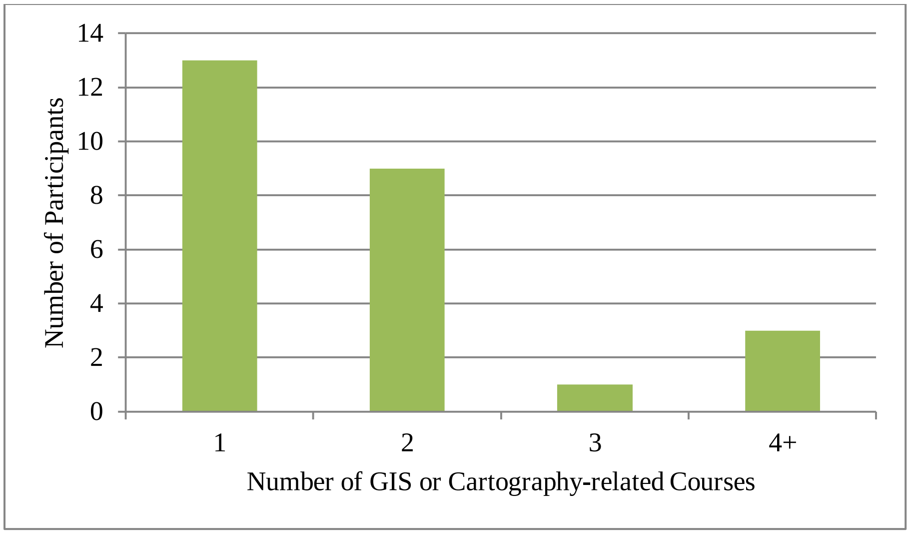

Figure 4.2 Number of participants with at least one GIS or cartography-related course experience.

Finally, participants gauged their familiarity with concepts of color as applied to maps on a scale of 1 ("Not at all familiar.") to 5 ("Entirely familiar."), and their responses are shown in Figure 4.3.

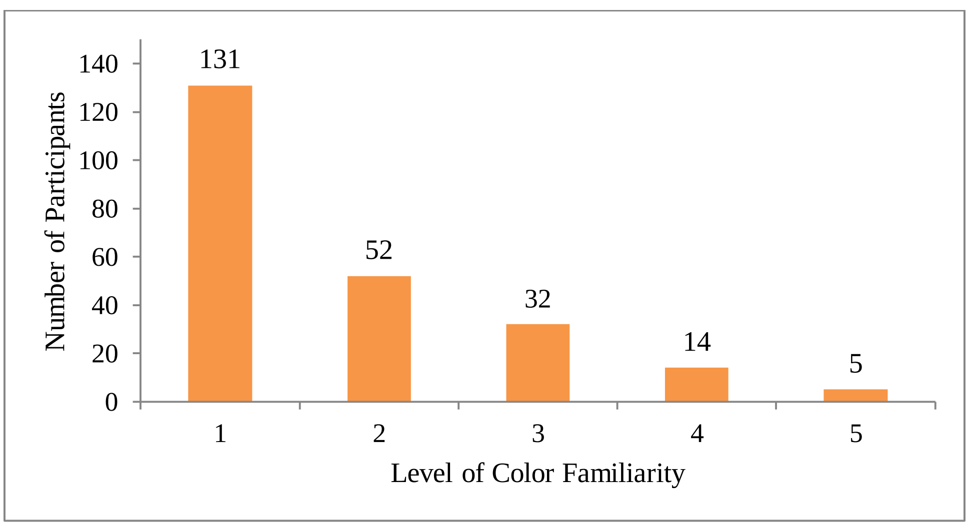

Figure 4.3 Participants' familiarity with color concepts applied to maps.

As seen in Figure 4.3, a majority (131, 55.98%) of participants indicated having no familiarity with color concepts as applied to maps. Participants who indicated having at least a little familiarity or more (Levels 2-5) numbered 105 (44.02%) in total. For an analysis of all of these categories in combination, please see Appendix M.

After estimating their own familiarity with concepts of color, participants had the opportunity to elaborate upon their response. Many who rated their familiarity at 1 merely confirmed that they were unfamiliar or basically had "no clue" (Participant 1). Those who rated their familiarity at 2 and above frequently cited the ability to read a map, the use of color to distinguish features, specific color concepts, and various degrees of relevant experience. Of particular interest is the response of Participant 104, who stated that "[Color] is probably one of the most neglected topics in GIS. It always seems to be mentioned as an afterthought." Despite having experience with QGIS and ArcGIS and relevant GIS and/or cartography-related coursework, this individual selected 1 for color familiarity, indicating feelings that GIS experience does not necessarily equate to confidence in one's understanding and skill at applying color.

Methods

Responses from the post-workshop survey were scaled as follows:[43]

- Likert-scale questions
  - Strongly Agree = 5
  - Agree = 4
  - Neutral = 3
  - Disagree = 2
  - Strongly Disagree = 1

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[43] Additionally, Participant 93's responses were recoded based on context. Although this participant selected "strongly disagree" for all Likert-scale statements, this participant's comments were explicitly positive. Therefore, based on these positive comments, Participant 93's responses were recoded to "strongly agree." Similarly, two other participants, Participants 9 and 39, selected "strongly disagree" for all Likert-scale statements in the first section of the post-workshop survey, but they provided no comments to explain their responses. Therefore, their responses remained unchanged.

- Yes/(Maybe)/No questions
    - Yes = 1
    - Maybe = 0
    - No = -1

<u>Quantitative Analysis</u>

Means were calculated for all Likert-scale and Yes/(Maybe)/No questions from the post-workshop survey. This includes means for all participants and means according to the participant information provided in the pre-workshop survey (e.g. according to gender, undergraduate vs. graduate, GIS experience, etc.). Simple two-tailed t-tests were run to compare mean responses among these different categories of participants to determine whether any significant difference exists between mean responses according to participant information. Similarly, chi-squared tests were run to compare patterns of responses among these different categories of participants to determine whether any statistical dependence exists among participant information and observed responses. However, to reduce the number of categories for more reliable results from the chi-squared tests, the Likert-scale responses were re-scaled to 5, 4, and 3-and-below. Color familiarity was re-scaled for both the chi-squared and the t-tests to 1 (131, 55.98%) versus 2, 3, 4, and 5 combined (103, 44.02%). This re-scaling of color familiarity was deemed acceptable because it would compare participants with no experience whatsoever versus participants with any experience. The significance threshold for these tests and others in this research is $p \leq 0.05$.

Comparing Measures of Substantial Learning

There were three Likert-scale questions that specifically addressed concerns related to substantial learning. These included the following statements to which participants indicated their level of agreement:

- This workshop was focused on participants' learning.
- This workshop stimulated my critical thinking.
- This workshop has changed the way I think about map color.

Simple t-tests were run to compare the means of all participants' responses to these statements. This was done to see if any statistically significant difference exists in participants' responses to these statements. The Yes/No question, "Would you be able to apply what you have learned in this workshop, if you needed to make a map in the future?" was also related to substantial learning, but it is not included in this comparison, since it is a different type of question.

Evaluating the Influence of QGIS

To evaluate overall learning of the 12 color concepts covered in the workshop, two more sets of t-tests were run. The first set of t-tests compared participants' responses to corresponding color concepts between the following two Likert-scale questions, which were each followed by a list of the 12 color concepts (same concepts, listed in the same order):

- As a result of this workshop, I better understand the following concepts related to color.
- Using the QGIS software was beneficial for helping me learn about the following concepts related to color.

For example, participants' mean response to "As a result of this workshop, I better understand color mixing" is compared to participants' mean response to "Using the QGIS software was beneficial for helping me learn about color mixing." The purpose behind asking participants to answer these two questions about each color concept is to differentiate participants' learning as a result of attending in the workshop versus using QGIS. In this case, statistically significant differences and statistically significant similarities are both important; it was expected that some color concepts would be rated low, because they were not explicitly included in the exercises. For example, it was expected that participants would agree that they better understand all color concepts as a result of participating in the workshop, but it was expected that participants would *not* agree that the QGIS software was beneficial for helping them learn about subtractive color theory and the CMYK model, because QGIS does not support CMYK. A statistically significant difference is expected here. On the other hand, it was expected that students would agree that the QGIS software was beneficial for helping them learn about the perceptual dimensions of color (hue, saturation, and value), because they were covered so thoroughly in the color mixing exercise in QGIS. A statistically significant similarity is expected here.

Comparing Color Concepts

The second set of t-tests compared participants' mean responses among different color concepts. For example, the mean response for color blindness is compared with the mean response for sequential/diverging color schemes. All possible pairings are compared among color concepts in the section, "As a result of this workshop, I better understand the following concepts related to color," and then all possible pairings are compared among color concepts in the section, "Using the QGIS software was beneficial for helping me learn about color mixing." The purpose behind these tests is to determine which concepts participants rated significantly higher/lower than other concepts. It is expected that there will be more statistically significant differences among responses to "Using the QGIS software was beneficial for helping me learn about the following concepts related to color" since not all concepts were equally addressed in the exercises as they were in the workshop as a whole.

<u>Qualitative Analysis</u>

Throughout the pre- and post-workshop surveys, participants were presented with multiple opportunities to elaborate upon their responses. Of particular interest are participants' elaborations on the questions related to substantial learning, their learning as a result of participating in the workshop, their learning as benefitted by using QGIS, and any opinions they have on the use of free and open source software alternatives to QGIS. These open-ended responses were evaluated by using a qualitative analysis strategy known as *coding for content*. Many participants' responses could be summarized in a few key words, and trends among participants' responses can be detected. In addition to coding for content, responses that provided additional, substantive insight to the participants' experience or opinions relevant to color and QGIS were noted. The coded content and notable responses were referenced to address the results observed from the quantitative analysis and to understand the learning experience as a whole.

Results

In general, participants responded very positively to the learning experience of the workshop. The mean of all participants' responses to all Likert-scale questions was 4.43, indicating that most participants would likely agree that 1) the workshop was a substantial learning experience on the basis of being focused on participants' learning, stimulating critical thinking, and changing the way participants thought about map color; 2) participants better understand the twelve emphasized color concepts as a result of participating in the workshop; and 3) the QGIS software was beneficial for helping participants learn. In response to the question, "Overall, did the use of QGIS benefit or inhibit your learning of the content covered in this workshop?", a supermajority (232, 99.15%) indicated that using QGIS benefitted their learning, while only 2 (0.85%) of the participants indicated that using it inhibited their learning. Similarly, in response to "Would you be able to apply what you have learned in this workshop, if you needed to make a map in the future?", a supermajority (229, 97.86%) responded yes, and only 5 (2.14%) responded no.

Influence of Participants' Characteristics and Background Experience

The mean responses for the different categories of participants' characteristics and background experience were calculated and included in Tables N.1-N.3 of Appendix N. These means were compared among categories using t-tests, and the resulting p-values from the t-tests are included in Tables O.1, O.3, and O.5 of Appendix O. The patterns of participants' responses were compared among categories using chi-squared tests, and the resulting p-values from the chi-squared tests are included in Tables O.2, O.4, and O.6 of Appendix O. With a significance threshold of $p \leq 0.05$, both the t-tests and chi-squared tests indicate that the most influential variables affecting the likelihood of observing certain responses include the following:

- Whether or not the participant is an undergraduate student or a graduate student.
- Whether or not the participant has any previous GIS experience.
- Whether or not the participant has taken a relevant GIS or cartography-related course.
- Whether or not the participant has any familiarity with concepts of color as applied to maps, or none at all.

Undergraduates vs. Graduates, GIS Experience, and Relevant Coursework

There were three participant characteristics that led to nearly identical patterns of responses: whether or not the participant 1) is an undergraduate student or a graduate student, 2) has any previous GIS experience, or 3) has taken a relevant GIS or cartography-related course. An examination of the mean responses from these groups indicates that graduate students, participants *with* previous GIS experience, and participants who *have* taken a relevant GIS or cartography-related course rated the following color concepts significantly *lower* than undergraduate students, participants *without* GIS experience, and participants who have *not* taken a relevant GIS or cartography-related course:

- "As a result of this workshop, I better understand…"
    - Color in the Electromagnetic Spectrum (all categories)
    - Perceiving Color with the Human Eye (categories 1 and 3 only)
    - Color Conventions (category 3 only)

- "Using the QGIS software was beneficial for helping me learn…"
    - Color in the Electromagnetic Spectrum (all categories)
    - Perceiving Color with the Human Eye (all categories)
    - Color Blindness (all categories)
    - Color Mixing (category 1 only)
    - Color Preferences and Connotations (category 3 only)

Similarly, graduate students, participants *with* previous GIS experience, and participants who *have* taken a relevant GIS or cartography-related course responded significantly more frequently that they were interested in taking a class that utilized QGIS as its primary software of choice (see Figure 4.4) and that they had general opinions on the use of free and open source software for GIS (see Figure 4.5).

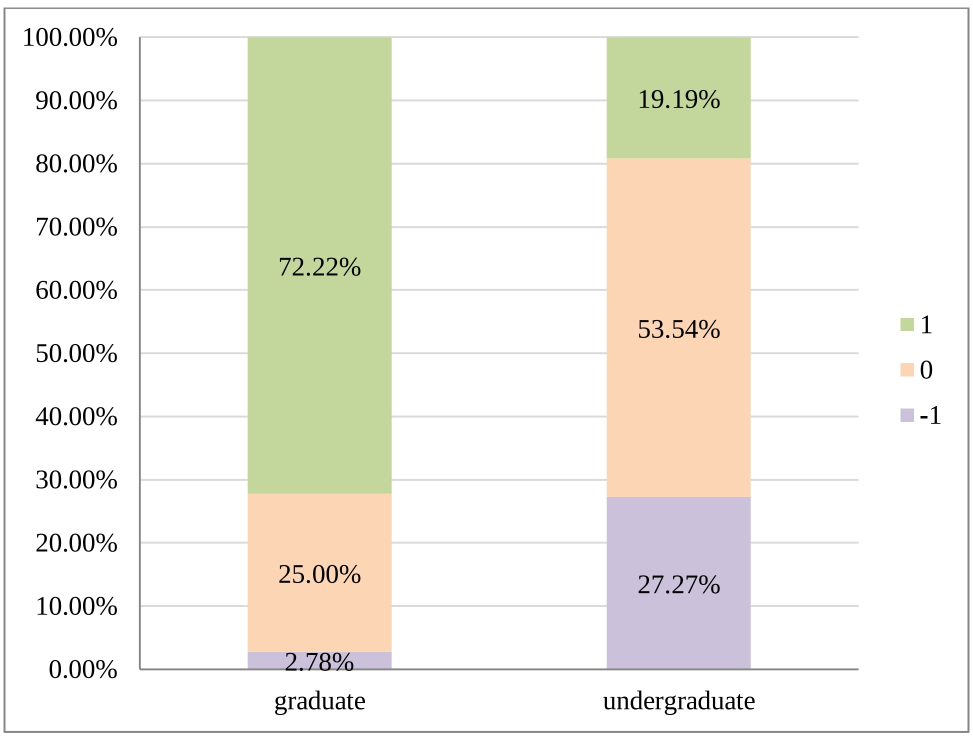

Figure 4.4 Participants' interest in taking a class that utilizes QGIS as its primary software of choice (-1, no; 0, maybe; 1, yes).

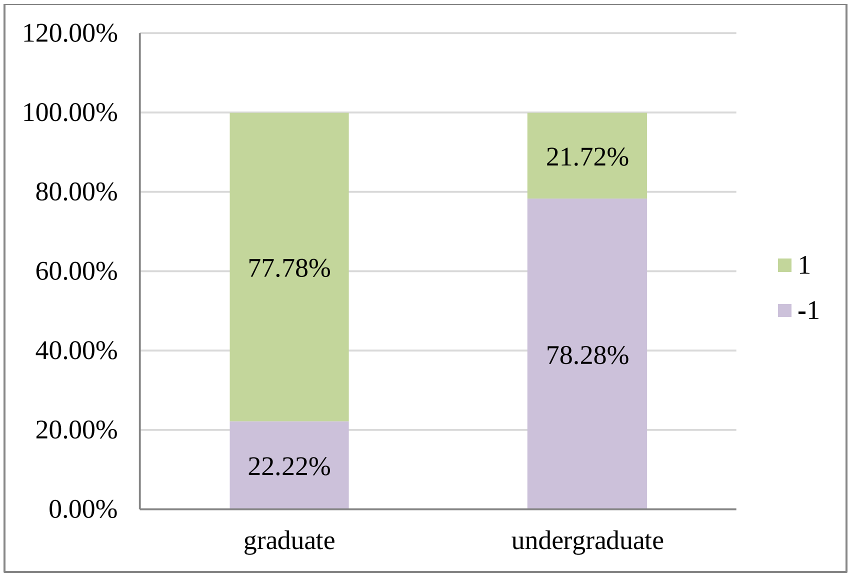

Figure 4.5 Participants with/without opinions on free and open source software for QGIS (-1, no, without opinion; 1, yes, with opinion).

Color Familiarity

Whether or not the participant had any familiarity with concepts of color as applied to maps, or none at all, resulted in statistically significant differences between means among participants' responses to certain questions. Participants with a color familiarity of 1 (no familiarity) rated the substantial learning statements "This workshop was focused on participants' learning" and "This workshop stimulated my critical thinking" significantly higher than participants with a color familiarity of 2 or greater. Participants with a color familiarity of 1 also rated certain color concept questions significantly higher than participants with a color familiarity of 2 or greater. These particular color concepts include the following:

- As a result of this workshop, I better understand…
    - Color in the Electromagnetic Spectrum
    - Perceiving Color with the Human Eye
    - Color Preferences and Connotations
    - Color Conventions

- Using the QGIS software was beneficial for helping me learn about…
    - Color in the Electromagnetic Spectrum
    - Color Mixing
    - Color Contrast

Finally, participants with a color familiarity of 1 responded significantly *less* frequently that they had general opinions on the use of free and open source software for GIS than participants with a color familiarity 2 or greater.

Comparing Measures of Substantial Learning

Three Likert-scale questions were focused on substantial learning. Participants were requested to indicate their level of agreement with the following statements:

- This workshop was focused on participants' learning (plearning).
- This workshop stimulated my critical thinking (cthinking).
- This workshop has changed the way I think about map color (changethink).

The distribution of participants' responses to these statements is shown in Figure 4.6.

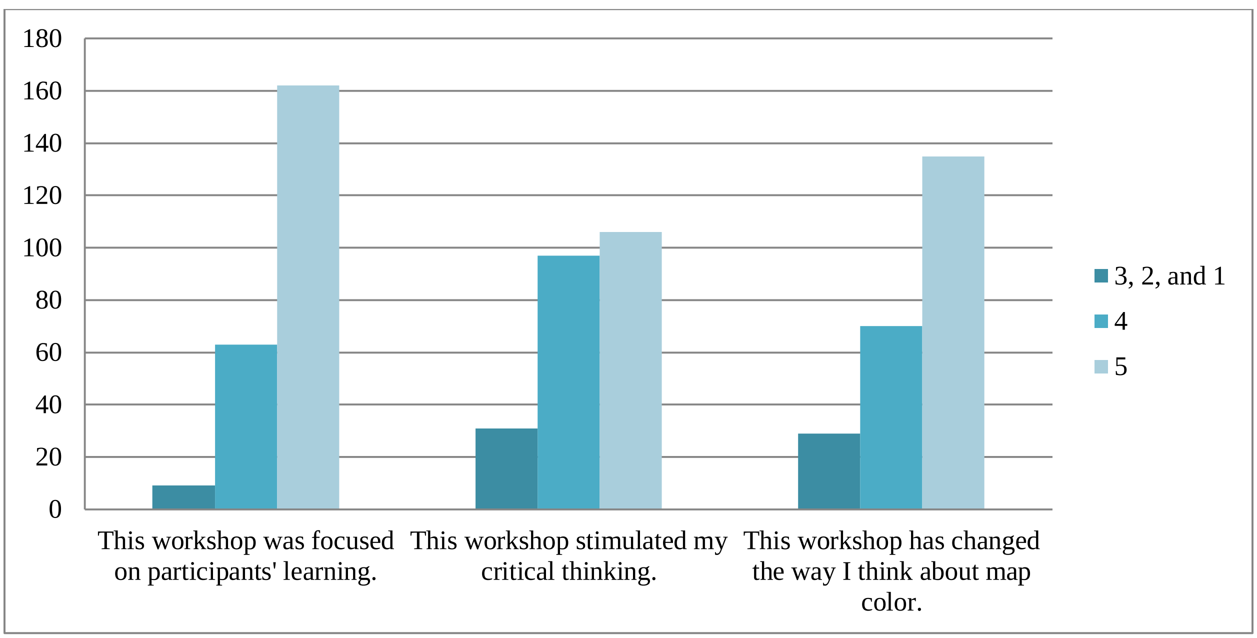

Figure 4.6 Participants' responses to Likert-scale statements on substantial learning (5, strongly agree; 4, agree; 3, neutral; 2, disagree; 1, strongly disagree).

The means of all possible pairings of these statements were compared using t-tests to look for statistically significant differences, and the means and p-values are shown in Table 4.1.

Table 4.1 Comparing participants' mean responses to Likert-scale questions regarding substantial learning; shading indicates statistically significant difference ($p \leq 0.05$).

Statement 1	**Mean 1**	**Statement 2**	**Mean 2**	**p-value**
plearning	4.64	cthinking	4.28	0.0000001388
plearning	4.64	changethink	4.41	0.0010380000
cthinking	4.28	changethink	4.41	0.0693600000

Most notably, these results show that 1) participants rated the workshop's focus on participant learning most highly, as its mean was significantly greater than either of the other two categories' means, and 2) participants rated critical thinking lowest. The mean for "cthinking" was most significantly lower than "plearning," but it was *not* significantly lower than "changethink."

Evaluating the Influence of QGIS

While it was expected that participants would rate highly all color concepts under "As a result of this workshop, I better understand…", it was also expected that participants could rate some color concepts significantly lower under "Using the QGIS software was beneficial for helping me learn about…" based on which concepts were or were not explicitly addressed in the hands-on exercises.

Concepts that were explicitly *addressed in the hands-on exercises included (green):*

- Perceptual Dimensions: Hue, Saturation, and Value
- Color Mixing
- Additive Color Theory and the RGB color Model
- Color Conventions
- Sequential vs. Diverging Color Schemes

Concepts that were addressed in the hands-on exercises, but not *explicitly, included (blue):*

- Color Blindness
- Color Contrast
- Figure-Ground Relationship

Concepts that were not *addressed in the hands-on exercises included (pink):*

- Perceiving Color with the Human Eye
- Color Preferences and Connotations
- Color in the Electromagnetic Spectrum
- Subtractive Color Theory and the CMYK Color Model

It was expected that the mean responses for the concepts listed in this last category would be significantly different, since these concepts were not addressed in the hands-on exercises. Actual results of using t-tests to compare the mean response are shown in Table 4.2.

Table 4.2 Results of evaluating the influence of QGIS. Shading of p-values indicates statistically significant difference ($p \leq 0.05$).

Concepts Related to Color	**As a result of this workshop, I better understand…**	**Using the QGIS software was beneficial for helping me learn about…**	**p-value**
Color Blindness	4.37	4.13	0.0022
Perceiving Color with the Human Eye	4.36	4.21	0.0385
Color Preferences and Connotations	4.53	4.41	0.0528
Color in the Electromagnetic Spectrum	4.29	4.24	0.4082
Color Conventions	4.44	4.39	0.4130
Figure-Ground Relationship	4.36	4.41	0.4885
Perceptual Dimensions: Hue, Saturation, and Value	4.56	4.53	0.5834
Color Mixing	4.49	4.50	0.7668
Subtractive Color Theory and the CMYK Color Model	4.32	4.33	0.8508
Sequential vs. Diverging Color Schemes	4.60	4.59	0.8735
Additive Color Theory and the RGB Color Model	4.36	4.37	0.9479
Color Contrast	4.53	4.53	1.0000

As shown by these results, the only color concepts with means that were significantly different were Color Blindness and Receiving Color with the Human Eye. However, it is worth noting that an examination of the means shows that the last five color concepts listed have exceptionally similar means, within ~0.01 of one another. Surprisingly, this includes Subtractive Color Theory and the CMYK Color Model, which was *not* addressed in the hands-on exercises, since QGIS does not support the CMYK color model.

Comparing Color Concepts

The means of participants' responses for all color concepts were ranked from highest to lowest, and t-tests were used to compare the means of every possible pairing to see which concepts participants rated significantly higher/lower than others. This was done for participants' responses for both "As a result of this workshop, I better understand…" and "Using the QGIS software was beneficial for helping me learn about…" The full results are included in Tables P.1 and P.2 in Appendix P. As shown in the full results, there are substantial differences in means, resulting in much smaller p-values than previous results, so the significance threshold for this result will be examined for those p-values that are smaller than 0.001.

In response to "As a result of this workshop I better understand…", participants rated 4 color concepts significantly higher than 6 other concepts. Means ranged from 4.60 to 4.29. In response to "Using the QGIS software was beneficial for helping me learn about…", participants rated 7 concepts significantly higher than 5 other concepts. Means ranged from 4.59 to 4.13. In both categories, the difference between the numbers of color concepts significantly higher/lower than others is due to the range of means.

There were similarities between which concepts' means were significantly higher/lower than others. In both categories, Sequential vs. Diverging Color Schemes was rated significantly *higher* than the following:

- Color Blindness
- Additive Color Theory and the RGB Color Model
- Perceiving Color with the Human Eye
- Subtractive Color Theory and the CMYK Color Model
- Color in the Electromagnetic Spectrum

Similarly, Perceptual Dimensions: Hue, Saturation, and Value was rated significantly *higher* than the following:

- Perceiving Color with the Human Eye
- Color in the Electromagnetic Spectrum

In addition to these lists, from which one may also infer the inverse, Color in the Electromagnetic Spectrum was rated significantly *lower* than Color Contrast, again in both categories. These similarities indicate that the hands-on exercises played a substantial role in how participants rated their learning of the color concepts as a result of participating in the workshop. This would help to explain why there were very few significant differences between corresponding color concepts from participants' responses to "As a result of this workshop, I better understand…" and "Using the QGIS software was beneficial for helping me learn about…"

Discussion

Participants were provided with multiple opportunities to elaborate upon their responses in the post-workshop survey. Within participants' feedback is qualitative information that helps 1) to explain the pattern of participants' responses and the results of the qualitative analysis, 2) to as understand the overall conclusions that that may be drawn from this research study, and 3) considerations for future research. The first aspect will be discussed in this section, and the second and third will be discussed in the conclusions.

Elaborations on Yes/No and Likert-Scale Questions

In the post-workshop survey, participants were able to elaborate upon the following:

- Their responses to questions relevant to the overall substantial learning experience of the workshop, including both 1) their responses to the relevant Likert-scale questions (coded plearning, cthinking, and changethink) and 2) their yes/no responses to whether or not they would be able to apply what they learned in the workshop, if they need to make a map in the future.
- Their Likert-scale responses that reflect their learning of the color concepts covered, both resulting from participating from the workshop and specifically resulting from using the QGIS software.
- Their yes/no response to whether or not QGIS benefitted or inhibited their learning of the content covered in the workshop.
- Their yes/maybe/no response reflecting interest in taking a class that utilizes QGIS as its primary software of choice.
- Their yes/no response indicating having general opinions on the use of free and open source software for GIS.

Each of these will be discussed in turn.

Substantial Learning

Overall participants' responses to questions regarding substantial learning were overwhelmingly positive. For example,

> "I've been taking GIS courses for the past three years and I feel like the way this workshop was organized really helped drive home the importance of color consideration and how to examine and use color better than any course I have had so far. I also loved and really appreciated the use of QGIS. I just this year was exposed to QGIS this year and all I could think was why haven't we been working with this all along" (Participant 17).

Participants also had positive feedback to share that was relevant to the particular metrics used to evaluate substantial learning in the workshop. First, in response to the workshop's focus on participant learning, Participant 21 stated, "I feel like the teacher of this course was *focused on us learning* how to use QGIS software to make a map" (emphasis added). Similarly, "The teacher wanted all of the students to understand and she took time to answer questions and walk around" (Participant 118). These responses indicate that an experience focused on student learning begins with the instructor shifting the focus from herself/himself and turn the focus to students' needs. Second, in response to the workshop's stimulation of critical thinking, Participant 33 stated,

> "Within the software, you have to decide what types of colors and schemes you want to use on the map in order to portray the data most effectively and efficiently. These decisions incorporated critical thinking. I never really thought much about the color schemes of a map but this workshop has unearthed their importance. The software was user friendly and efficient."

This response indicates that one form of critical thinking involves weighing multiple options against multiple criteria to make a decision when there is no perfect answer. Third, in response to the participant's thought about color having changed since participating in the workshop, Participant 5 stated, "*I now look at map colors differently* because I am now aware that they are chosen to suit the user" (emphasis added). Throughout participants' responses to the post-workshop survey, there were many participants who echoed this sentiment, noting that they learned a substantial amount about things that they had never before considered.

Some participants' elaborations were a mixture of positive and negative, or negative. Several whose responses were mixed indicated feelings that the pace of the workshop was a "bit rushed" (Participant 175). Another participant with a mixed response stated that although the workshop was focused on participants' learning, "I didn't really have to think critically because there were step by step instructions" (Participant 223). Similarly, Participant 128 stated, "Although the workshop definitely got me thinking, the lack of discussion and rapid pace somewhat stymied the critical thinking process." These responses echo a participant with a negative response who said, "More exploration and less attention to completing the pre-selected tasks would likely encourage more 'critical thinking'" (Participant 206). Participant 20 also noted that he "just followed the instructions." Solutions posed by participants included more exploration as noted above as well as more "conversation" (Participant 200). These responses clarify why some participants rated the workshop's level of critical thinking lower than the other metrics of substantial learning.

Being able to apply what one has learned later is another way to evaluate substantial learning. An overwhelming majority of participants responded positively that they would be able to use what they learned from this workshop if they needed to make a map in the future, including Participant 125 who stated, "Yes, because the information was presented in a memorable way and I would be able to remember it if I were to make a map in the future. When asked how, most (120 participants) gave responses reflecting general application to geographic maps. However, others (33 participants) cited applications of what they learned in fields other than geography, and others (17 participants) gave responses reflecting general applications of color, not necessarily to maps. These responses indicate that many participants were able to transfer their learning to applications beyond what was covered in the workshop, a desirable outcome from a substantial learning experience.

Of particular interest among participants' elaborations to these substantial learning questions is Participant 11's elaboration on her "yes" response, which was simply, "To critique future maps." Though brief, this is important to note, because it indicates that one of the new learning objectives was inadvertently accomplished by at least one student. The new learning objective that this participant felt could be accomplished as a result of participating in this workshop was "Provide a critical evaluation of a map design, specifically noting good/bad color choices and providing specific suggestions for enhancement when/where necessary." This learning objective, which emphasizes evaluation, requires higher order thinking skills.

Finally, there was a small handful of participants who felt that they would not be able to apply what they learned if they needed to make a map in the future. Two of these participants indicated feeling like the needed more practice (Participants 107 and 227). Other participants' elaborations were vague among those who responded negatively in regard to application.

Learning Color Concepts

Participants were asked two sets of questions in an attempt to differentiate their learning of the color concepts as a result of the workshop from using the QGIS software. Many participants' feedback reflects this difference, but not all do. Many participants gave identical responses to both sets of Likert-scale questions; at least 13 participants gave qualitative feedback that was identical or reflected a similar approach at answering both sets of questions. However, there are still many more participants' responses that contribute to the research goals.

Participants' feedback on their responses to the first set of questions regarding color concepts was generally very positive. For example, Participant 17 stated,

> "Because I have taken GIS classes I have heard these concepts before but again I feel that the organization of this workshop and the way the lesson was linked to the activities further solidified my comprehension of these concepts. This workshop better explained this information and dealt with this information than I have ever experienced before."

This comment suggests that possibly cursory treatment in past GIS courses of the topics covered in this workshop was insufficient to gain a solid grounding in them. Focusing exclusively on principles of color in cartography and visualization was beneficial to this more experienced GIS user. Other positive feedback written by participants reflecting on their learning of color concepts resulting from the workshop as a whole include Participant 80's comments, "Going into the many websites to see how the colors worked really helped me understand the many variations of colors, also the PowerPoints were very visually intriguing to further my understanding." This participant was one of many that made positive comments about the PowerPoint presentations and the selected websites, particularly including ColorBrewer (colorbrewer2.org).

Among a few comments from participants that were a mixture of positive and negative feedback is Participant 231's comment,

> "Although I felt like I did learn a great deal about color, it was difficult to retain all of the information since it was a lot of content in a short amount of time to be able to remember it all."

Because this workshop was designed to be a controlled experiment, compromises had to be made, and participants generally differed on whether there was too little or too much content, whether the length of the workshop was too long or to short, etc. To specifically address the previous comment, in an ideal scenario participants would have had more time to process the new concepts outside of the structure learning experience.

There were a few negative comments, which pointed out which color concepts the participants felt were not covered as well as others in the workshop. These partially explain color concepts rated less than Agree or Strongly Agree. However, they only partially explain participants' low ratings for particular color concepts because participants' feedback revealed an unintended effect resulting from the phrasing of the guiding statement, "As a result of this workshop, I better understand…" Specifically, "as a result" forced participants to consider how much their understanding of a concept changed as a result of participating in the workshop. However, as some participants indicated in their feedback, some came to the workshop with experience in one or more of the color concepts covered. Therefore, a participant might not better understand a concept, if the workshop did not cover it in more detail than they were already familiar, and as a result of this, a few participants noted selecting lower ratings because of their existing knowledge. For example, Participant 206 noted, "I've taken optics in both intro and designated optics-based physics classes, and also covered it in human models via neurobiology and cognitive neuroscience, hence the 'strongly disagree's."

Participants' feedback on their responses to the second set of questions regarding color concepts was also generally very positive. Many participants did note the difference between the two sets of questions and provide comments that particularly were reflective on the experience of using QGIS. Among positive comments regarding the use of the software was Participant 123's comment, "Hands on learning such as using this software helped me better understand what was being taught." Several participants, like Participant 123, noted that it was beneficial to their learning to apply what they learned. Others noted specific concepts that QGIS was more or less beneficial with helping them learn. For example, Participant 82 explained, "QGIS was especially useful for learning about HSV; the color diagrams in the software were very helpful for visualizing the relationship between the concepts." QGIS provided multiple ways of color mixing using hue, saturation, and value, and this particular participant noted that these were beneficial for helping him learn.

A few participants emphasized that it was the step-by-step instructions provided for the exercises that contributed to the software being easy to use. Participant 127 noted, "With the help of detailed instructions, it made the program straight-forward to use and solidified the information presented in the presentation." The overall tone of this participants' feedback would indicate positive feelings toward QGIS, despite the need for instructions, whereas the tone of Participant 224's feedback regarding the software is negative: "The software *only* makes sense if explained by someone who is proficient in the QGIS" (emphasis added). Other participants' comments that could be construed as more negative toward QGIS include those who considered their learning as a result of listening to the presentations rather than completing the exercises. Participant 54 stated, "The QGIS software didn't teach me about the first 3 [color concepts] because I learned that from the lecture." In this context, that participant could be referring to being "taught" or "learning" as the first exposure to new material only. Therefore, Participant 124's comment that "applying the information was helpful, but not as helpful as the instruction beforehand" may provide a more well-rounded view that the exercises helped to solidify participants' learning, even if participants' first exposure to new material felt as though more learning was occurring.

These quotes show that there may be an inverse relationship between one's perceived level of learning and one's level of lasting learning. One may more easily perceive that learning is occurring when exposed to something new, but this does not equate to lasting learning, where one will be able to remember and use what one has learned at some later time. Lasting learning requires reinforcement of material that is no longer new, such as through activities that require higher-order thinking skills. Although more lasting learning is taking place, it may feel as though less learning is occurring, because nothing new is being covered. It is possible that this phenomenon affected participants' feedback. Although the exercises were designed to reinforce their learning of the new material in the lectures, it may not have been obvious to some participants that this reinforcement was intended to promote more *lasting* learning, which is a more substantial form of learning than simply hearing and comprehending new information.

QGIS Benefiting or Inhibiting Learning

Continuing in the focus on using QGIS, a supermajority (232 of 234, 99.15%) of participants indicated that using the QGIS software benefitted, rather than inhibited, their learning. Of the 85 who elaborated upon why using QGIS benefitted their learning, a majority (56 of 85, 65.88%) made comments indicating that being able to apply what the learned from the presentations enhanced their learning of the new material. For example, "Not only was I able to listen and observe, but I was able to immediately apply this knowledge with feedback and on-the-spot guidance from [the workshop facilitator]" (Participant 104). Similarly, Participant 54 felt that "without applying it using the software, I would have been confused about certain aspects of the [presentations], especially color mixing and hue/saturation/value." According to Participant 54, using the QGIS software was not only beneficial, but it was also necessary for her learning of the new material.

Of the two that responded "no" to whether QGIS was a benefit or inhibitor to their learning, only one provided feedback. This participant's explanation was "I didn't listen as much to the lecture because I was preoccupied with the exercises" (Participant 118). It was neither intended that participants work on exercises during presentations nor was it necessary. Therefore, this participant's feedback is irrelevant to this analysis.

Interest in Taking a Course with QGIS

All participants were required to indicate their interest in taking a class that utilized QGIS as its primary software of choice. Of the 234 total participants, 64 (27.35%) said Yes, 115 (49.15%) said Maybe, and 55 (23.5%) said No.

Of those that responded "No," many simply explained by saying that they were simply "not interested." Other cited that they did not need such a course for their major, and a few others felt that they neither used maps frequently nor expected to do much with them.

Of those who responded "Maybe," a few said similar things as those who responded No, but they were much more likely to express mild interest, and their reasons for interest varied. For example, Participant 66 expressed willingness to consider taking a course using QGIS if it might be beneficial to his course of study: "I am not a geography major, but if a course was offered that used QGIS software, I would strongly consider taking it if it helped me fulfill my requirements," and Participant 4 found his interest in taking a course increased by what he learned in the workshop: “Now that I have somewhat of an idea what this is, I could see myself taking another course on it” (Participant 4). Another participant who responded “Maybe” expressed interest in learning other types of software as well: “If I were to take a class that was based around this workshop, I'd be interested in using the QGIS as the primary software in class, however I would also love to study other types of software as well” (Participant 26). Finally, other participants’ comments indicated hesitancy. For example, one participant who had ArcGIS experience found QGIS “not as intuitive as ArcGIS” (Participant 50) and provided no further explanation, but another participant’s response counters this opinion as he found QGIS “easy to use once accustomed to the tools” (Participant 31).

Of those that responded “Yes,” participants provided many different reasons why they were interested in taking a course featuring QGIS. For example, for Participant 204, the experience of using QGIS was sufficient to garner this participant interest; she states, “[QGIS] was surprisingly user friendly, very gratifying, seemed to encourage critical thinking skills.” Particularly noteworthy among the comments from those interested in taking a course that utilizes QGIS is Participant 75, who stated, “I would like to see if I want to pursue a career in GIS.” This was a pleasing outcome, as it had been hoped that one or more participants might consider getting more involved in geography and GIS as a result of participating in the workshop.

Many of those who provided substantive elaborations on why they would be interested in taking a course that uses QGIS specifically cited benefits of QGIS. For those participants with ArcGIS experience, they specifically cited benefits of QGIS over ArcGIS. These comments will be discussed in the next section.

Opinions on Free and Open Source GIS

In the post-workshop survey, participants were explicitly asked if they had any opinions to share on the use of free and open source software for GIS, and if so, participants were requested to share them. Approximately a quarter (57 of 234, 24.36%) of participants shared opinions here, but there were many opinions and comments provided using free and open source software and/or QGIS, sometimes even in contrast to ArcGIS, that participants provided in different free response sections throughout the post-workshop survey. All responses relevant to the use of free and open source software for GIS will be discussed here.

Participants' opinions toward free and open source software alternatives for GIS, especially QGIS as an alternative for ArcGIS, were favorable toward QGIS. Only two participants explicitly favored ArcGIS over QGIS, including Participant 50 (quoted earlier) and Participant 30, who stated, "I appreciate the use of GIS but I still like ArcGIS better," yet did not provide further elaboration. Participants 145 and 16 held opposite opinions, stating "QGIS was a much better choice to use in this activity than ArcGIS would have been" (Participant 145) and "QGIS is a bit more user friendly and easier to access than ArcGIS" (Participant 16). These participants also did not provide further elaboration. The truly substantive responses came from other participants whose opinions fall into three critical categories: 1) using free and open source can create a more equitable learning experience, 2) using free and open source software is increasingly needed outside of academia, and 3) the use of free and open source software has important social implications. Particularly notable responses from participants that fall into each of these categories are included in Table 4.3.

Table 4.3 Participants' opinions on the use of QGIS or other free and open source software alternatives for GIS.

Equitable Educational Experience	"As an open source software, QGIS is definitely a good choice and it can be utilized in a Mac compared to ArcGIS" (Participant 201). "Open source software has increased mobility for me, and I can get work done anywhere that I can bring my laptop. Otherwise, for some programs my work time is limited to a university computer" (Participant 19). "It also allows them to explore the software on their own, with their own computers, without relying on campus facilities alone. I've certainly found this to be very helpful with the statistical software R, and I would expect the same to be true for QGIS" (Participant 105).
Needed outside Academia	"Using ArcGIS is unrealistic outside of the academy, and knowing QGIS would allow my skills to travel further in the real world" (Participant 200). "I am very supportive of using free/open-source software in classrooms. Training students in the most commonly used and openly available software makes them more prepared for real world jobs" (Participant 105). "While ArcGIS will likely be the gold-standard for the foreseeable future, QGIS should likely be the wave of the future for those who are dealing with organizations that need GIS but who cannot afford the price or platforms that restrict the use of ArcGIS" (Participant 208). "I definitely want to explore QGIS more, especially since I am graduating and wanting to work with non-profits to make maps, so QGIS is a great tool for this" (Participant 17). "QGIS is an open source software as opposed to ArcGIS, which is what is predominantly used (at least at this institution) in GIS courses. Yet if one ends up at a smaller institution, non-profit, etc. the funds may not be there to use ArcGIS. I think being at least co-trained in both open-source and proprietary GIS software options increases the competitiveness of students on the job market" (Participant 103).
Social Implications	"I much prefer the use of free/open source software. It is more available to people and groups who do not have the resources for proprietary software, and as a result does not help to consolidate power and access to knowledge in the way that proprietary software can" (Participant 103). "I appreciate the great price (free!), transparency, customizability, and socially leveling aspects of it" (Participant 128). "If QGIS can do everything ArcGIS can, there is no reason not to use it, as it makes cartography more open and democratic" (Participant 200). "GIS are tools that can benefit so many groups who need to use geographic information. A more democratized and more geographically literate group of people would be better able to make critical decisions if GIS were more widespread, and this is more likely to happen with free and open source software. While some aspects of QGIS are clunky and I wish it had some features available in ArcGIS (and I know next to nothing about code), it can manage at least 75% of what I need it to do, which is good enough to not spend constant hours in a lab" (Participant 208).

Participants note that the use of free and open source alternatives, particularly QGIS which is free of cost and available on multiple platforms, whereas ArcGIS is only available for Windows, is a more equitable learning experience. This is because students are not disadvantaged according to location. They can work anywhere, because they are not forced to work on a computer at a particular location, e.g. on-campus, due to having access to only a Mac and not a PC. Additionally, free and open source alternatives provide more equitable educational opportunities because complicated (and sometimes expensive) licensing issues do not pose barriers to potential users. Free and open source alternatives such as QGIS are available to anyone at any time.

Although companies like ESRI do attempt to offer free licenses for educational purposes, the equitability of this arrangement ends after the graduation for many users. This is the theme of several participants' comments in the "Needed outside Academia" section of Table 4.3. Participants 200 and 105 note needs after graduation, feelings that they would be "more prepared" (Participant 105) and that their skill would "travel further" (Participant 200) if they knew QGIS. Participants 208, 17, and 103's comments provide more insight into why. According to these participants, ArcGIS is too expensive for "nonprofits" (Participants 17 and 103), "smaller institution(s)" (Participant 103), or any "organizations that need GIS but who can't afford the price or planforms that restrict the use of ArcGIS" (Participant 208). It is not just large companies or government organizations that could benefit from the use of GIS, but in difficult economic times, paying for expensive licenses to use proprietary software such as ArcGIS can be a significant barrier to adoptions. Additionally, because ArcGIS, specifically the desktop application, works only on Windows, an additional barrier to adoption could be switching to Windows operating systems if other operating systems, such as Mac OS X or Linux, are currently in use. For some, it may not be possible to switch, because more operations-critical programs could require an operating system other than Windows.

ESRI's development of ArcGIS is profit-driven, but development of QGIS is user-driven. This ties into the social implications raised by Participants 103, 128, 200, and 208 (see Table 4.3). Participant 103 claims that proprietary software, such as ArcGIS, can contribute to the consolidation of "power and access to knowledge." To counteract this, free and open software can be used by "people and groups who do not have the resource for proprietary software." Complementarily, Participant 128 describes the resulting effect of using free and open source software as "socially leveling," which is likely due to its "transparency." Additionally, cartography and other applications of GIS become more "democratic" as a result of using free and open source software, such as QGIS (Participant 200). Participant 208 explains how this is desirable, noting that "a more democratized and more geographically literate group of people would be better able to make critical decisions if GIS were more widespread, and this is more likely to happen with free and open source software." The ongoing development and adoption of free and open source QGIS is able to address broader concerns relevant to the production of knowledge and the exercise of power.

Because free and open source software contributes to a more equitable learning experience, is needed outside academia, and has important social implications, it is not surprising that several participants felt that QGIS should be included in a well-rounded GIS education. Participants 203 asserted, "Nowadays, many companies/software go open source. I believe, QGIS is an essential software to learn for students." In agreement, Participant 58 stated, "This should be an alternative presented and/or taught in GIS courses." It was suggested by no one that ArcGIS be replaced with QGIS. It is simply imperative that QGIS be given fair treatment within the curriculum, as it is becoming a powerful force for change.

Suggestions for Improvement

At the end of the post-workshop survey, participants were prompted to give suggestions for how the workshop could be improved. Only about a third (79 of 234, 33.76%) of the participants provided feedback, and about half (34 of 79, 43.04%) just said the workshop was "good" or "great" and gave no suggestions. Of those remaining (45 of 79, 56.96%) , 15 wanted the workshop to be shorter, while 5 wanted it to be longer; 3 wanted it harder, and 2 wanted it easier. Of those who wanted the workshop to be longer, one particularly enthusiastic participant wrote, "Would love an in-depth, day long workshop on this! This was fantastic!" (Participant 104). More substantive feedback included suggestions for more interaction (9 participants), and suggestions for particular exercises (2 participants).

Only 3 participants cited technical issues that needed fixing. Participant 50 specifically cited the broken file paths at the beginning of Exercise 3, and it is reasonable to assume that the other two participants were referring to the same technical issue, as they had participated in the first and second workshops. It wasn't until the third or fourth workshop that it was decided to use this glitch as a means to prevent participants from moving to the next exercises too soon. After this decision was made, workshop participants were notified that this glitch was intentionally left unresolved. Participant 207, who participated in the ninth workshop, actually made a note about this in his final comments on the post-workshop survey, stating, "Smooth transition on Exercise 3 where 'I didn't have it auto load the reference files so that I could get everyone's attention etc.'" In reference to this technical glitch, Participant 145 made a very helpful suggestion: "Make a code to unlock each activity when you are finished with the

PowerPoint so people don't/aren't tempted to work ahead." This would have helped as the technical issue could have been resolved, and participants would have been blocked for advancing to any exercise too soon.

One other substantive comment was provided by Participant 51, who suggested, "Maybe a comparison of exercises using both QGIS and a commercial product to gauge preference." This had been considered in the original design of these workshop experiences, but it was dismissed due to the complexity it would have introduced into the workshop design and due to the increase in workshop length that would have been required to cover both QGIS and ArcGIS. It was decided that covering one software would have been beneficial for participants' learning experience, especially considering it was expected that many of the participants could be beginners with no experience with GIS whatsoever. Participant 51 was an experienced GIS user with QGIS and ArcGIS experience, as well as course experience and strong familiarity with color concepts. Such a comparison would have been suitable for such an advanced user, but designing for such users would have additionally diminished sample size. As previously discussed, the workshop design was a combination of many factors, but this possibility is being considered for future research.

Confounding Variable

What these results and this discussion do not indicate is the presence of a potentially confounding variable: whether or not the participant was participating in the workshop for extra credit in a course. Two instructors in UGA's Department of Geography appear to have offered extra credit across a total of three different courses. These included a 1000-level course with 325 registered students, another 1000-level course with 87 registered students, and a 4000/6000-level course with 12 registered students. The workshop facilitator observed that a substantial majority of participants were participating for extra credit in at least one of the 1000-level courses, but it is impossible to say exactly how many participated for extra credit, because this information was not gathered in either the pre- or post-workshop surveys. Unfortunately, including a question regarding participants' motivations for participating in the workshop was not considered until a majority of the workshop data had been gathered.

However, based on the workshop facilitator's observations, many of the participants from the 1000-level courses attending the workshop for extra credit appeared to be freshmen and sophomores without GIS experience or relevant coursework, and based on an examination of these participants' level of color familiarity, they were likely to have little or no familiarity with color concepts as applied to maps (see Table 4.7).

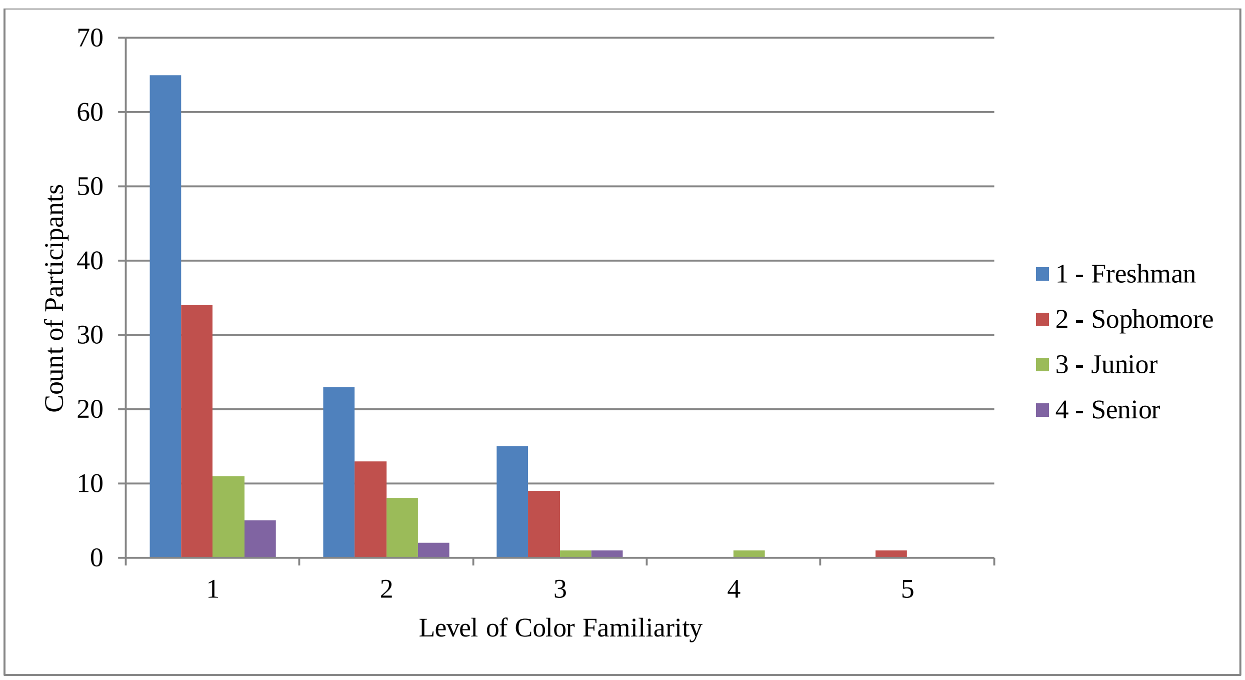

Figure 4.7 Undergraduate participants without GIS experience or relevant coursework.

As shown in Table 4.7, the total number of freshmen and sophomores without GIS experience or coursework and little or no familiarity with concepts of color as applied to maps (Level 1 or 2) totaled 135. Just these participants represent 57.7% of all who participated in the workshop, but again, it is unclear how many, if not all, of these participants were attending the workshop for credit. Similarly, it is unclear how many of the other participants (with higher levels of color familiarity, with GIS experience and relevant coursework, or graduate students) were attending the workshop for extra credit.

The results from the first set of t-tests comparing participants' characteristics and background experience might be explained by the influence of some participants' participation in the workshop for extra credit. Again the four statistically significant variables affecting results were undergraduate vs. graduate, GIS experience, relevant coursework, and color familiarity (1 vs. 2, 3, 4, and 5 combined). The former three indicated that graduate students, participants with GIS experience, participants with relevant coursework answered questions in an opposite manner than those with no familiarity with color concepts; this was likely due to the fact that a strong majority of those with no familiarity with concepts were likely to also be undergraduate students with neither GIS experience nor relevant coursework. Some of the statistically significant differences among these participants' responses may be partially explained by the confounding variable. It is suspected that those attending the workshop for extra credit were less emotionally "invested" in their participation in the workshop and completion of the surveys, especially the post-workshop survey, than those who participated for no other benefit than what they could learn from participating in the workshop.

For example, less emotionally invested participants may have been more likely to provide identical responses to "As a result of this workshop, I better understand [color concept]" and

“Using the QGIS software helped me learn about [color concept],” which should not have had identical responses, since certain concepts were not included in the QGIS exercises. An examination of participants’ responses to these two Likert-scale statements shows that 77 (32.91%) of the participants gave identical responses. Of these, 51 were freshmen and sophomores without GIS experience or coursework and little or no familiarity with concepts of color as applied to maps (Level 1 or 2). These 51 represent 66.23% of those who gave identical responses, 37.78% of all freshmen and sophomores without GIS experience or coursework and little or no familiarity with concepts of color as applied to maps (Level 1 or 2), and 21.79% of all participants.

Again, it is unknown exactly how many of these participants were participating in the workshop for extra credit and may have been less emotionally invested in their participation and completion of the surveys. However, the influence of extra credit is not seen as a serious disadvantage to this study for several reasons. First, a lack of investment in the post-workshop survey did not necessarily indicate a lack of investment in learning and participating in workshop activities. The workshop facilitator was able to observe participants as they listened to the presentations and completed the exercises, and most participants were able to complete the exercises and ask substantive questions that indicated engagement with what they were learning. Second, the overall trend of responses to the post-workshop survey could have been different. The overall trend of responses was very positive, and it could have been different, i.e. more negative. Among participants who were less invested in the experience, these participants could have more frequently provided responses that trended negatively. Among the participants who give all identical responses to the color concept statements, 49 responded “Strongly Agree” to all, and 18 responded “Agree” to all. These same participants could have provided more negative responses about the learning experience, responding to all as “Neutral,” “Disagree,” or even “Strongly Disagree,” but this did not happen. It is still useful to know that the general trend of responses was positive.

Finally, the influence of extra credit was actually an advantage in that it helped to reach an unusual group of students. At the University of Georgia, most GIS courses are offered at a 4000/6000-level, and this typically attracts junior and senior undergraduate students and graduate students. Few freshmen and sophomores have had exposure to GIS, so this was a unique opportunity to assess the readiness of GIS and the readiness of freshmen and sophomores to learn GIS at a lower level. On the basis of the overall positive response to the workshop and the fact that the majority of participants were freshmen and sophomores, it could be argued that GIS can be and needs to be taught to undergraduates sooner than is typically experienced when GIS courses are only predominantly offered at a 4000/6000 level. It may have been the case that GIS was too advanced in its early years (1980s and 1990s, perhaps even the early 2000s) to be offered at a lower level. However, considering the advancements made in the field and the increasing use of GIS among potential employers, especially free and open source software alternatives, it is important that students be exposed to GIS sooner. With earlier exposure, students can balance a more well-rounded GIS education indo their course of study and be more competitive and prepared for the job market or graduate school, as applicable.

Despite the fact that this research design was able to handle the influence of the confounding variable of extra credit, future research designs will consider this influence. This can be easily accomplished simply by including a question that asks participants whether or not they are participating in the experience for extra credit. Additionally, it will be considered whether or not participation for extra credit will even be allowed. Other incentives will be considered that may encourage participation, while at the same time having a less substantial effect on participants' responses.

Conclusions

The purpose of this research study was to investigate how well QGIS can facilitate a substantial learning experience for cartographic color concepts. The major outcomes from this research study include the following:

1. The experience resulted in substantial learning of cartographic color concepts.
2. The use of QGIS was considered beneficial to participants' learning.
3. It is recommended that free and open source alternatives, particularly QGIS, be incorporated into regular GIS curriculum, if not already incorporated, based on the following reasons:
    a. The use of free and open source software can facilitate a more equitable learning experience, as students are not limited by barriers resulting from platform limitations, which result in physical location limitations.
    b. QGIS addresses needs outside of academia. As many choose to use it for financial reasons or platform limitations, graduates need to be familiar with alternatives to proprietary software, such as ArcGIS to be competitive.
    c. There are social implications centered on the consolidation of power and access to knowledge, and the use of free and open source software alternatives encourages the democratization of decision making.
4. These workshops, with predominantly freshman and sophomore participation, show that concepts and software previously reserved for advanced courses can be taught to students in introductory courses.

Additionally, it was observed that participation resulting from extra credit offers introduced a confounding variable, but this was not substantial enough to invalidate the results.

There are multiple directions for future research which could naturally follow and complement this research study, including the following:

- *Research studies that compare/contrast QGIS with ArcGIS.* As indicated by Participant 51, it would be interesting to compare users' experiences doing the same workshop with ArcGIS *and* QGIS, to see which was more intuitive to use and more beneficial to their learning. Past experience with free and open source software may have been too "buggy" for adoption in educational contexts, and it needs to be confirmed (or disproved) that this is no longer the case.
- *Research studies that examine how well QGIS can facilitate substantial learning experiences for concepts other than color.* The conclusions reached in this research study

are based only on participants' learning of color. However, this is a critical issue which was chosen because creating maps (usually with color, nowadays) is a task that almost all, if not all, GIS users must face.

- *Research studies that evaluate substantial learning experiences in contexts other than workshops*. This learning experience was a highly concentrated learning experience, as it was completely self-contained and limited to three hours. Other learning contexts, such as traditional courses, online courses (both long and short), etc. would be useful in evaluating users' experiences using free and open source software.
- *Research studies that include follow-ups with participants to evaluate their long-term learning.* Learning experiences need to be compared and contrasted with one another to see what types of activities, environments, or approaches to teaching and learning result in substantial learning, particularly in terms of students' long term learning. To address this issue, researchers need to follow up with participants at different temporal intervals after learning experiences to see how much knowledge and skill has been retained.
- *Research studies that investigate the need for free and open source software alternatives for GIS.* Educator and students need to know more about when, where, and how free and open source software alternatives for GIS, such as QGIS, are being used and by whom. This will further assistant instructors in designing learning experiences that are relevant to their students.
- *Research studies that investigate the broader social implications of using free and open source software*. Current and potential users of free and open source software need to know how their choices impact production of and access to knowledge, so researchers need to delve deeper into the social implications and how to communicate these with a broad audience.

It will be interesting to observe the long term effects of adopting free and open source software alternatives, especially for GIS applications, and the impact of what is likely to be widespread adoption will have in educational spheres and in broader society.

CHAPTER 5

CONCLUSION

Student-Centered GIScience Education

This dissertation has examined directions that GIScience education may explore to remain relevant and student-centered. In Chapter 2, instructors' and students' first-time experiences with the flipped classroom were examined. This project was considered student-centered because it inverted the typical paradigm of instructor-centered teaching to student-centered learning, a paradigm shift discussed by Barr and Tagg (1995). In these flipped classroom experiences, the individual learning space, what happened outside of class or at home, was where students were to be exposed to new information, and the group learning space, what happened during the scheduled class time, was focused on students understanding and application of the new material. The results showed that a means of aiding students' learning in the flipped classroom would be to emphasize accountability measures to ensure that students complete the pre-class activities in preparation for the in-class activities. Activities that hold students accountable to do the individual learning activities benefit their participation during the scheduled class time and their development of substantial learning. The project also reflected the importance of "instructor 'buy-in'" for the flipped classroom to work. As observed by the researcher, the level of "instructor 'buy-in'" affected the degree to which the class day was "flipped," and as few of the class days included in this study were truly "flipped," the researcher suggests that more attention be given to "instructor 'buy-in'" in future studies.

In Chapter 3, graduate students were interviewed for thoughts and perspectives on their past and desired learning experiences in GIScience courses offered by the Department of Geography at the University of Georgia. This project was considered student-centered, because it focused exclusively on students' opinions and suggestions, specifically those of graduate students, whose voices have largely been ignored. Additionally, not only is the design of the study student-centered, the results arising from graduate students' feedback are also student-centered. Graduate students are concerned with their ability, as well as the ability of others, to obtain the skills they need for finding a job and thriving in a new career after graduation. As graduate students attempt to make themselves competitive in a difficult job market, they reflect upon whether or not their overall educational experience in GIScience at the University of Georgia meets their goals, and they provide constructive feedback in areas that could use addressing, such as offering the programming for GIScience course more frequently and regularly. Last but not least, the implications of this study are focused on student-centered learning. Departments other than geography both at the University of Georgia and other educational institutions are encouraged to listen more to the voices of their students. Graduate students and the pressures they experience, both research and employment pressures, can inform curriculum revision and enhancement in any discipline.

In Chapter 4, workshops were created and used to evaluate how well QGIS, a free and open source software, can facilitate a substantial learning experience for color as applied in cartography and visualization. This project was considered student-centered for several reasons. First, as indicated in the graduate student interviews (Chapter 3), learning how to use free and open source software is an interest for students hoping to acquire a job outside of academia. Individuals with free and open source software experience are desirable to employers who cannot or do not wish to invest money into obtaining expensive proprietary software such as ArcGIS. So this workshop was an opportunity to gain a little more experience with the free and open source software QGIS. Second, also as indicated in the graduate student interviews, learning more about good practices in cartography and geovisualization is desirable for individuals who want to learn how to better communicate geospatial results. The subject of color is important for designing any map and creating all manner of geographic visualizations. Third, a workshop format was chosen so that the learning opportunity was accessible to everyone, not just students in the single cartography course offered recently by the geography department at UGA, which is only available to undergraduate students. This workshop was independent of any course, and both undergraduates and graduate students could participate. Fourth, the overall design of the workshop was designed to be student-centered; the workshops were designed to be suitable for a broad audience, ranging from novice GIS users to advanced "GIS-ers." Finally, results of this research study are also student-centered, making a case that QGIS can facilitate a substantial learning experience, even for freshmen and sophomores. If they have not already done so, geography departments may wish to consider incorporating free and open source software alternatives for GIS, such as QGIS, into their GIScience curriculum to address students' needs outside of academia. This research study achieved its objectives, showing that free and open source software can facilitate a substantial learning experience. The QGIS software very successfully facilitated a substantial learning experience for color as applied in cartography and visualization. However, this and future studies could improve upon this study by incorporating better control for confounding variables, such as the confounding variable of participants' motivations for participating in the workshop, which in this case was for extra credit.

These research studies are all connected by their focus on student-centered learning, but there are a few ways that these projects overlap. First, in both the flipped classroom project and graduate perspectives project, students provided feedback indicating interest in more integrated learning experiences, i.e. experiences that combine lectures and labs. This was achieved in the QGIS workshops project, which was an integrated learning experience; students received new information via short presentations, which were immediately followed by opportunities to apply what they learned via hands-on exercises. Second, the feedback from the graduate perspectives project contributed to the content choices for the QGIS workshops project. In the graduate perspectives project, graduate students indicated interest in both free and open source software, specifically citing QGIS, and in cartography. The workshops utilized QGIS and focused on color for cartographic application. Finally, the primary data collected for all projects was feedback from students: 1) students who participated in the flipped class days, 2) graduate students who participated in the interviews, and 3) students who participated in the QGIS workshops. This prioritization of feedback from students was a substantial link among the three projects and a critical contributor to this dissertation's focus on student-centered learning.

Directions for Future Research

These research projects inspire numerous directions for future research. Other than the directions previously explored in each chapter, other directions for future research include the following:

- *Research studies that examine GIScience courses that fully integrate lecture and lab.* Graduate student interviews revealed a desire among some students for GIScience courses that more fully integrate the currently separate lecture and lab sessions. Research into multiple different programs that offer integrated GIScience courses, specifically examining how the integration works, may offer insights into how to integrate effectively without having to "re-invent the wheel."
- *Research studies that explore how to create learning experiences that bridge human geography, physical geography, and techniques/GIScience.* As noted in multiple

graduate student interviews, graduates students feel as though the primary "branches" of modern geography, human geography, physical geography, and techniques/GIScience, are too isolated from one another, a sentiment expressed by other geographers. Addressing this fracturing of the discipline by exploring ways to re-integrate the discipline in the classroom would contribute to broader unification efforts, for if students are taught geography disparately, they will continue to practice it disparately.

- *Research studies that investigate how to provide GIScience instructors with training to teach GIScience courses most effectively*. Interviews with instructors during the flipped classroom study revealed that instructor participants had little or no 'formal' training in teaching and learning. Research that delves into what training instructors need and how best to deliver this training to instructors, who frequently experience significant time constraints, could be beneficial to instructors as well as students.
- *Research studies that address how to keep online GIScience courses student-centered.* This dissertation research primarily dealt with student-centered learning needs in residential education; but as online education continues to proliferate, more research needs to be done on which learning experiences students find most beneficial and why. Such insight would help keep educational opportunities student-centered, even as they migrate to the virtual realm.

These are but a few of many possible directions for future research in student-centered GIScience education.

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APPENDIX A

FLIPPED CLASSROOM EXPERIENCES: STUDENT SURVEY

1. Describe the activities that took place during class on this day.
2. How similar were the activities on this day to the activities on other days in this course?
    a. Entirely Similar
    b. Somewhat Similar
    c. Somewhat Different
    d. Entirely Different
3. Explain your answer to the previous question. (What made this day similar to or different from other days in this course?)
4. Describe what you learned during class on this day.
5. What part(s) of the class on this day were most beneficial, helping you learn? Please explain.
6. What part(s) of the class on this day were least beneficial, NOT helping you learn? Please explain.
7. The structure of class today facilitated an engaging and valuable learning experience throughout the entire class period.
    a. Strongly Agree
    b. Somewhat Agree
    c. Neutral
    d. Somewhat Disagree
    e. Strongly Disagree
8. Explain your answer to the previous question. (Why do you agree/disagree?)
9. Please provide practical suggestions for how this class day could be improved in future semesters.
10. In the future, would you like to have more class days (in this course and/or other courses) structured like this one?
    a. Yes
    b. Maybe
    c. No

    Please elaborate. (Why or why not?)

APPENDIX B

GRADUATE STUDENT INTERVIEW QUESTIONNAIRE

1. Please give me some information about yourself. (Note: Identifying information will not be shared, but this information may allow some results to be shared in summary form.)
    a. What year of graduate study is this for you?
    b. Are you a Master's or Ph.D. student?
    c. Is your primary focus in techniques, physical, and/or human geography?
2. What are your research interests and goals?
3. Which three techniques or GIS-based classes were most relevant to your research? (If you have taken less than three, just list the one or two that you have taken.)
4. For the *first* course you listed, elaborate on the following:
    a. What do you recall of your expectations for the class before taking it?
    b. What did you end up leaning in that class?
    c. Was there anything that you wish the class had covered, but it did not?
    d. What suggestions might you give for enhancing that class in future semesters?
    e. Do you have comments to make about the way that class was taught?
5. For the *second* course you listed, elaborate on the following:
    (Same as previous.)
6. For the *third* course you listed, elaborate on the following:
    (Same as previous.)
7. What other techniques or GIS-based courses were you able to take, if any?
   What suggestions might you give for enhancing any of those classes in future semesters?
8. Are there any particular topics that you think should be included in the GIScience curriculum here at UGA but are currently not included? Please elaborate.
9. Are there any particular techniques or GIS-based courses that you wanted to take and can't? If so,
    a. What are they, and why can't you take them?
    b. What would you hope to get out of those classes?
    c. How would those classes contribute to the GIScience curriculum here at UGA?
    d. How much interest do you estimate that there may be in those classes, if they were offered?
10. Generally speaking, what suggestions would you give a committee working on enhancing the GIScience curriculum here in UGA's Department of Geography?
11. Do you have any opinions that you'd like to share on the program options (certificate, MS, Ph.D., etc.) offered by UGA's Department of Geography?
12. Do you have anything else that you would like to add?

APPENDIX C

PARTICIPANTS' COMPLETED COURSEWORK

The following two pages contain a table that represents the coursework discussed by participants during the one-on-one interviews. These are coded as follows:

A	relevant, GIScience (top 5)
B	relevant, GIScience
C	relevant, non-GIScience
D	irrelevant, GIScience
E	irrelevant, non-GIScience
O	other

(continues on next page…)

Table C.1 Coursework completed by participants.

Participant	2011	3510	4300/6300	4330/6330	4350/6350	4370/6370	4380/6380	4430/6430	4460/6460	4470/6470	4570/6570	4590/6590	8300	8350	8450	8510	8570	8590	8910	**A**	**B**	**C**	**D**	**E**	**O**	Total
1							**B**			**D**							**A**			1	1	0	1	0	0	3
2						**A**	**D**			**A**							**D**			2	0	0	2	0	0	4
3				**A**	**A**	**A**														3	0	0	0	0	0	3
4	**O**	**B**								**A**		**B**	**E**							1	2	0	0	1	1	5
5					**D**					**A**							**A**			2	0	0	1	0	0	3
6					**A**															1	0	0	0	0	0	1
7				**A**	**A**	**A**			**D**					**D**						3	0	0	2	0	0	5
8			**C**		**D**					**A**		**B**	**C**	**D**	**D**					1	1	2	3	0	0	7
9										**A**										1	0	0	0	0	0	1
10						**D**				**A**							**D**			1	0	0	2	0	0	3
11						**A**														1	0	0	0	0	0	1
12					**A**	**A**				**D**							**A**			3	0	0	1	0	0	4
13				**D**										**B**	**D**	**D**	**D**			0	1	0	4	0	0	5
14		**O**		**D**	**D**		**B**			**D**		**B**		**D**			**A**			1	2	0	4	0	1	8
15						**A**														1	0	0	0	0	0	1
16				**A**					**B**					**B**						1	2	0	0	0	0	3
17					**A**		**B**			**A**										2	1	0	0	0	0	3
18					**A**		**D**			**A**							**A**			3	0	0	1	0	0	4
19	**O**	**B**				**A**		**D**	**D**								**A**			2	1	0	2	0	1	6
20				**A**					**B**											1	1	0	0	0	0	2

Participant	2011	3510	4300/6300	4330/6330	4350/6350	4370/6370	4380/6380	4430/6430	4460/6460	4470/6470	4570/6570	4590/6590	8300	8350	8450	8510	8570	8590	8910	**A**	**B**	**C**	**D**	**E**	**O**	Total
21				**D**		**A**				**A**					**D**		**A**			3	0	0	2	0	0	5
22										**D**							**A**			1	0	0	1	0	0	2
23					**A**	**A**				**A**							**D**			3	0	0	1	0	0	4
24						**A**				**A**	**B**									2	1	0	0	0	0	3
25			**C**																**C**	0	0	2	0	0	0	2
26				**A**								**B**		**B**			**A**			2	2	0	0	0	0	4
27				**D**		**A**								**B**	**D**	**B**	**A**			2	2	0	2	0	0	6
28					**A**					**D**							**D**	**C**		1	0	1	2	0	0	4
29				**A**	**A**	**D**								**B**	**B**		**D**		**E**	2	2	0	2	1	0	7
30						**A**														1	0	0	0	0	0	1
A	0	0	0	6	9	12	0	0	0	11	0	0	0	0	0	0	10	0	0	48						
B	0	2	0	0	0	0	3	0	2	0	1	4	0	5	1	1	0	0	0		19					
C	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1			5				
D	0	0	0	4	3	2	2	1	2	5	0	0	0	3	4	1	6	0	0				33			
E	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1					2		
O	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						3	
Total	2	3	2	10	12	14	5	1	4	16	1	4	2	8	5	2	16	1	2							**110**

APPENDIX D

COURSE NUMBERS, NAMES, AND DESCRIPTIONS[44]

GEOG2011 Introduction to Geographic Information Science

"Introduction to principles and applications of Geographic Information Science (GIS). Examines spatial data retrieval, accuracy, management, visualization, and analysis. Emphasis on interdisciplinary nature of GIS and relevance to society. Involves computer examples and exercises that emphasize real-world problem solving."

GEOG3510 Cartography and Graphics

"Map design techniques including cartographic theory and principles, map interpretation map database preparation, compilation, symbolization, computer mapping, map reproduction techniques, color, and thematic map design."

GEOG4300/6300 Introductory Spatial Analysis

"Descriptive and inferential techniques used in quantitative geographic analysis. Probability distributions, sampling techniques, parametric and nonparametric inference, analysis of variance, spatial autocorrelation measures and regression procedures. Applications of statistical methods to spatial analysis and geographic research design. Exercises develop knowledge of statistical programming with computer software."

GEOG4330/6330 Aerial Photography and Image Interpretation

"Principles and techniques of extracting descriptive and metric information about the environment from aerial photographs acquired in analog and digital forms. Applications emphasize planimetric mapping and interpretation of physical and cultural landscapes. A term project using the techniques is required."

GEOG4350/6350 Remote Sensing of the Environment

"Remote sensing with emphasis on aerospace applications in the natural sciences. Fundamental properties of the electromagnetic spectrum and remote sensing devices such as multispectral cameras, thermal infrared line scanners, and television and radar imaging systems."

GEOG4370/6370 Geographic Information Science

"Principles and applications of geographic information systems (GIS). Examines the nature and accuracy of spatially referenced data, as well as methods of data capture, storage, retrieval, visualization, modeling, and output using one or more GIS software packages"

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[44] All course descriptions are from the UGA Bulletin, which is available at http://bulletin.uga.edu/CoursesHome.aspx?Prefix=geog (accessed June 23, 2016).

GEOG4380/6380 Transportation Modeling and GIS

"Theoretical frameworks for transportation network modeling and transportation planning strategies are explored."

GEOG4430/6430 Advanced Image Analysis and Photogrammetry

"Theories of analytical and digital (soft copy) photogrammetry as applied to topographic mapping. Topics include refinement of photographic measurements, coordinate transformations, stereoscopic parallax, collinearity equations, aerial triangulation, orthophotography, and digital image correlation."

GEOG4460/6460 Field Methods in Remote Sensing

"A field-based remote sensing course that teaches students the theory and practical applications of field spectroscopy or proximal sensing (non-imaging systems). The field exercises will include experiment design and data collection using in situ sensor, model calibration, and validation to quantify environmental biophysical parameters."

GEOG4470/6470 Geospatial Analysis

"Geographic analytical methods and implementation. Theory and concepts of spatial analysis. Description, reduction, and comparison of point, line, area, and volumetric geographic data sets. Implementation and limitation of geographic information systems."

GEOG4570/6570 Advanced Geographic Information Science

"Advanced concepts in the development and implementation of geographic information science (GIS) are presented, including consideration of the underlying structure of GIS models, geodatabase design and geocomputation, GIS applications to locational decision making, network analysis, geographic representation and spatial cognition."

GEOG4590/6590 Programming for Geographic Information Science

"Computer programming skills tailored to the needs of advanced users of geographic information science (GIS) are developed, including customization of GIS applications with academic and commercial programming tools. Topics include GIS user-interface design, advanced functions and tools coding, fundamental spatial data structures and algorithms, and geospatial database management."

GEOG8300 Multivariate Techniques in Geography

"Application of multivariate statistical procedures to research problems in geography, with emphasis on peculiarities of such applications. Spatial autocorrelation, areal aggregation, modifiable areal unit problem, spatial interpolation, and trend surfaces are investigated with statistical and GIS software packages."

GEOG8350 Advanced Remote Sensing and Geospatial Techniques

"Mapping datums, coordinate systems, and accuracy requirements for geographic information systems (GIS). Global position system (GPS), softcopy photogrammetry, and digital image processing techniques for GIS database construction. GIS modeling for environmental studies. Includes the use of various software packages."

GEOG8450 Geospatial Techniques in Landscape Analysis

"Topics on geospatial analysis tools to display, analyze, model and visualize landscape characteristics. Aspects of geographic information systems, remote sensing, spatial analysis, geovisualization, landscape metrics, and landscape ecology will be included."

GEOG8510 Seminar in Cartography and Visualization

"Special problems in the application of cartography. Emphasis on problems involving map design and production, computer graphics, map perception, cartographic visualization, and map animation."

GEOG8570 Seminar in Geographic Information Science

"Problems in geographic information systems, including methods and techniques and the application to specific topical areas."

GEOG8590 Directed Problems in Geographic Techniques

"Topics in mapping sciences, such as cartography, air-photo interpretation, remote sensing, photogrammetry, and geographic information systems."

GEOG8910 Seminar in Geographic Thought and Methods

"Development of geographical philosophy and methods; contemporary methodological concepts and problems. Required for all graduate majors."

APPENDIX E

OTHER TOPICS OR COURSES OF INTEREST

It is worth noting 1) other existing courses of interest, including both courses that participants have taken and recommend and courses that participants are interested in taking; 2) other topics that participants would like to see featured more in existing or new courses; and 3) participants' ideas for other new courses.

First, among existing courses, participants recommend, based on their experience, the following: the "LiDAR course" (Participant 13), a "proposal writing course" (Participant 23), and "plant geography" and "urban landscape" (Participant 28). Other recommended courses likely include those courses most frequently identified as relevant, particularly the Geographic Information Science course, which Participant 30 felt should be a required course for all geography majors. Also among existing courses, participants indicated interest in taking remote sensing courses (Participants 9 and 15), the "Problems in Remote Sensing" course (Participant 16), and a field methods course during the summer (Participant 20).

Second, participants' topic interests include the following: "natural resources" (Participant 5); "raster data," "raster maps," "dasymmetric mapping," and "topographic mapping" (Participant 6); the "qualitative potential" of GIS, particularly "embedding videos or incorporating text driven narratives or sound files… into maps" (Participant 11); "ethics of GIS" (Participant 13); and "web maps" and "data licenses (Participant 26). Regarding data licenses, Participant 26 explained that they are "really important and have never been covered by any of the classes I've taken… That's something that could be taught in every class. It's relevant to everything that people are doing… either consuming data and we're using other people's data, or because we're making presentations or distributing data which we generate later on."

Third, participants ideas for new courses include the following: an "advanced" geospatial analysis course (Participants 17, 21, and 18); public health and medical GIS (Participants 6, 14, and 19); big data GIS (Participant 4 and 9); GIS for meteorology (Participant 4); "spatial database design" (Participant 9); food and agriculture GIS (Participant 12); "online GIS" and "international GIS" (Participant 14); GIS for physical geography (Participant 15); "beer geography" (Participant 21); GIS for climatology and a seminar in transportation GIS (Participant 23); GIS research design (Participant 27); and a hybrid course with the content of the GIS seminar and structure of the geospatial analysis course, because students "learn a lot of the new techniques… but maybe we cannot really understand it [after] just one week and reading by ourselves" (Participant 5).

APPENDIX F

COMPARISON OF TEXTBOOK COLOR CONCEPTS

The color concepts included in the *GIS&T Body of Knowledge*'s color-related learning objectives were compared with color concepts included in the following map design and cartography-related texts:

- *Cartography: Thematic Map Design* (Chapter 14) by Dent et al. (2009)
- *Thematic Cartography and Geovisualization* (Chapter 10) by Slocum et al. (2009)
- *Principles of Map Design* (Chapter 4) by Tyner (2010)
- *Web Cartography: Map Design for Interactive and Mobile Devices* (Chapter 5) by Muehlenhaus (2014)
- *GIS Cartography: A Guide to Effective Map Design* (Chapter 5) by Peterson (2014)
- *Designing Better Maps: A Guide for GIS Users* (Chapters 4 and 5) by Brewer (2005)
- *Making Maps: A Visual Guide to Map Design for GIS* (Chapter 11) by Krygier and Wood (2011)

The results of the comparison are shown in Table F.1. Concepts listed in bold were addressed in the workshop.

(continues on next page…)

Table F.1 Comparison of color concepts between learning objectives and textbooks.

Topic	**New**[45]	**Old**[46]	**D**[47]	**S**	**T**	**M**	**P**	**B**	**K**	**TOTAL**[48,49]
cyan, magenta, yellow, key (CMYK) color model	1	1	1	1	1	1	1	1	1	8
color blindness	1	1	1	1	1	1	1	1	1	8
red, green, blue (RGB) color model	1	1	1	1	1	1	1	1	1	8
additive color theory	1		1	1	1	1	1	1	1	7
black and white, grayscale	1	1	1	1	1	1	1		1	7
color connotations	1	1	1	1	1	1	1		1	7
color interactions	1		1	1	1	1	1	1	1	7
Commission internationale de l'éclairage (CIE) specifications	1	1	1	1	1		1	1		6
diverging color schemes	1	1	1	1	1			1	1	6
color models	1	1	1	1	1	1		1		6
perceptual dimensions of color	1		1	1	1	1		1	1	6
qualitative colors	1	1	1	1	1			1	1	6
sequential color schemes	1	1	1	1	1			1	1	6
subtractive color theory	1		1	1	1		1	1	1	6
hue, saturation, brightness/lightness (HSB/HSL)			1	1	1	1	1			5
hue, saturation, value (HSV)	1		1	1		1	1	1		5
Munsell color model			1	1	1			1	1	5
printers vs. monitors	1	1	1	1		1			1	5
color preferences	1		1	1	1	1				4
color schemes	1	1	1		1			1		4
color theories	1		1	1		1	1			4
gamut	1	1	1	1		1				4
harmony, concordance, balance	1	1	1		1		1			4
complementary colors	1		1			1	1			3
color conventions	1	1	1			1				3
figure-ground relationship	1		1		1		1			3
human eye	1	1	1	1						3
light and color spectrum	1		1	1	1					3

(continues on next page…)

[45] The "New" column indicates which concepts are addressed in the revised learning objectives considered in this study's workshop design.
[46] The "Old" column indicates which concepts are addressed in the original learning objectives found in the *GIS&T Body of Knowledge*.
[47] The individual letters represent the texts being compared; the letter corresponds with the first letter of the first author's name.
[48] The "Total" column represents the total number of times a concept was mentioned in the *GIS&T Body of Knowledge* and the various texts (i.e. a sum of "Old" and "D" through "K").
[49] This table is sorted first by the "Total" column (high to low) and then by "Topic" column (alphabetically).

Topic	New	Old	D	S	T	M	P	B	K	TOTAL
photocopying	1	1	1					1		3
spectral color schemes	1	1	1	1						3
visual variables	1		1	1					1	3
warm/cold colors	1		1			1	1			3
color cubes	1		1					1		2
color contrast	1		1				1			2
fastness and constancy		1	1							2
functions of color	1		1		1					2
hexadecimal colors						1	1			2
label colors	1	1	1							2
Moellering-Kimerling coloring		1		1						2
advancing/retreating colors	1		1							1
base map coloring	1					1				1
color mixing	1							1		1
color proofing for map publication		1								1
color separates		1								1
decisions for workflow		1								1
factors for selecting colors		1								1
graphical excellence									1	1
hardware	1			1						1
hue, value, chroma (HVC)				1						1
inspiration for color	1						1			1
color palettes/ramps	1						1			1
quality and price for color maps		1								1
quality evaluation (color laser prints)		1								1
TOTALS	**40**	**27**	**38**	**28**	**22**	**20**	**20**	**18**	**16**	

These results of this comparison where used to formulate the new learning objectives, based on a balance between which concepts were addressed most frequently in the texts and which concepts were addressed in the original learning objectives.

APPENDIX G

REVISED LIST OF LEARNING OBJECTIVES FOR COLOR

This list includes the revised learning objectives resulting from comparing the color concepts included in the GIS&T Body of Knowledge's learning objectives with color concepts addressed in a variety of map design and cartography-related textbooks. Those listed in bold contain concepts (underlined) that were explicitly addressed in the research workshops.

- List several functions for the visual variable of color, as applied in cartography and geovisualization.
- **Explain the phenomenon of color in the context of the <u>electromagnetic spectrum</u>.**
- **Discuss the <u>anatomy of the eye</u>, and explain how its visual sensor cells affect how one sees color.**
- **Explain and illustrate the differences among the perceptual dimensions of color: <u>hue, saturation, and value</u>.**
- **Compare and contrast various color models, including <u>HSV</u>, <u>RGB</u>, <u>CMYK</u>, CIE Lab, etc., and demonstrate <u>color mixing</u> using these models.**
- Determine the RGB and CMYK primary amounts in a selection of colors.
- **Explain <u>additive and subtractive color theories</u>, illustrating how their respective primary colors combine into secondary colors and others (e.g. using a color cube).**
- Discuss the concepts and usages of complementary colors, analogous colors, etc., using a color wheel as a visual aid.
- **Discuss the role of <u>color preferences and connotations</u>, noting cultural differences in color connotations, as they affect map design and interpretation.**
- **Exemplify a variety of <u>color conventions</u> (e.g. warm vs. cool colors), particularly emphasizing qualitative and quantitative conventions.**
- **Demonstrate proper application of <u>sequential and diverging color schemes</u> for quantitative data.**
- Formulate a position regarding the use of spectral color schemes, engaging with different positions of the ongoing debate surrounding their use.
- **Create one or maps that illustrate how <u>color contrast</u> can be used to establish <u>figure-ground relationship</u> in a map (e.g. using advancing/retreating colors).**
- Exemplify and explain color interactions (e.g. simultaneous contrast, successive contrast, etc.) in maps.
- Choose appropriate color(s) for all type and labeling in a map, troubleshooting any contrast problems resulting from varying background colors (e.g. applying halos).

- **Design or redesign a map with colors appropriate for map readers with the most common form of <u>color blindness</u> (i.e. red-green color blindness).**
- Create a map in grayscale and/or alter a color map so that it is prepared for black-and-white photocopy distribution.
- Prepare a color map for printing, using well-established production and reproduction practices.
- Prepare a color map for distribution electronically, such as either a static map or interactive map to be included on a website.
- Discuss hardware limitations, such as gamut, that may affect color choices when designing a map.
- Compare and contrast the overall color harmony of multiple maps attempting to achieve similar purpose, commenting on specific color choices in component parts.
- Provide a critical evaluation of a map design, specifically noting good/bad color choices and providing specific suggestions for enhancement when/where necessary.
- Identify sources of inspiration for the development of custom color palettes and color ramps.
- Create an original cartographic work with innovative color choices.

APPENDIX H

PRE-WORKSHOP SURVEY

Section 1

Please enter your access code here: ____________________

Section 2

Are you currently a UGA student (undergraduate or graduate)?

- o Yes
- o No

If no, continue to Section 3. If yes, continue to Section 4.

Section 3

You are not eligible to participate in this study, but you are welcome to continue participating in this workshop!

Section 4

What is your gender?

- o Prefer not to answer.
- o Female
- o Male
- o Other: ____________________

Are you an undergraduate or graduate student?

- o undergraduate
- o graduate

If undergraduate, continue to Section 5. If graduate, continue to Section 6.

Section 5

Choose the option that best reflects your current year:

- o Freshman
- o Sophomore
- o Junior
- o Senior
- o Other: ____________________

What is/are your major(s)? ____________________

Continue to Section 7.

Section 6

Are you a Master's or Ph.D. student?

- o Master's
- o Ph.D.

What year of study is this for you? ____________________

What is your field of study (i.e. department)? ____________________

Continue to Section 7.

Section 7

Do you have any experience using QGIS?

- o Yes
- o No

If yes, how much experience do you have using QGIS? ____________________

Which of the cartography or GIS-related courses have you taken, if any? Include courses taken at UGA and elsewhere. Select all that apply.

- □ GEOG3510 Cartography and Graphics (OR equivalent introductory cartography course)
- □ GEOG4370/6370 Geographic Information Science (OR equivalent introductory GIS course)
- □ GEOG4570/6570 Advanced GIS (OR equivalent advanced GIS course)
- □ Other: ____________________

How familiar are you with concepts of color as applied to maps?

Not at all familiar. 1 2 3 4 5 Entirely familiar.

Please elaborate. ____________________

Please enter any further comments that you would like to provide here:

APPENDIX I

WORKSHOP INSTRUCTIONS FOR EXERCISES

The instructions provided to each workshop participant are included on the following pages.

(continues on next page…)

Workshop: Make Maps with Impressive Color using QGIS

Overview

The structure of today's workshop should be pretty straightforward. We're going to have a series of short presentations, and we're going to have practical, hands-on exercises between presentations.

Part 1: What is "GIS"?
Exercise 1: Looking around QGIS

Part 2: How do map designers think about color?
Exercise 2: Mixing Colors in QGIS

Part 3: Which colors do I choose?
Exercise 3: Conventional Colors in QGIS

Part 4: How do I color quantitative data?
Exercise 4: Color Ramps in QGIS

Part 5: Which color tip is most important?

Please feel free to speak up at any point if you have questions about either the presentation material or the exercises. When we're working on the exercises, please feel free to introduce yourself to your neighbor and work together!

Out of respect to your fellow workshop attendees, please refrain from doing activities not related to the workshop during the workshop. Additionally, please silence cell phones and other electronic devices. Thanks!

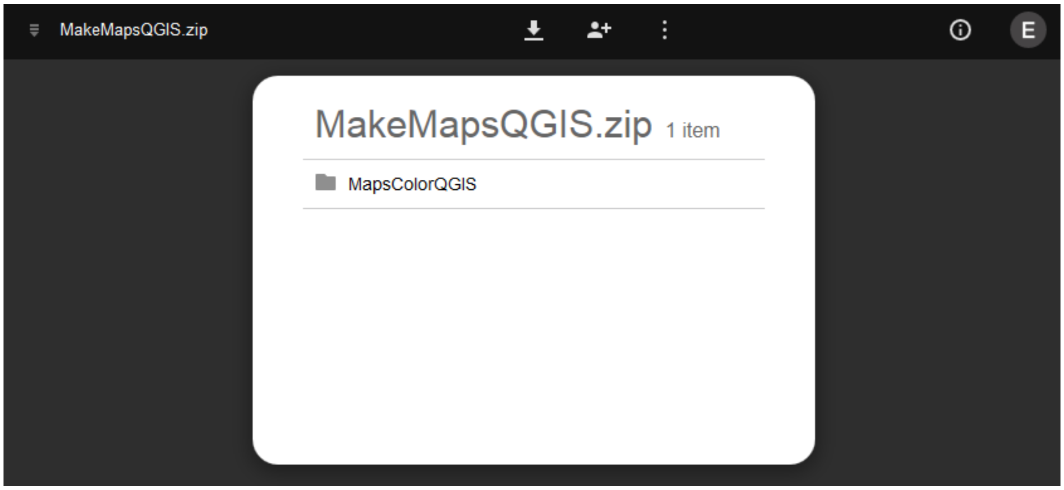
Pre-Workshop Survey

Please complete the Pre-Workshop Survey, which you can access here: http://goo.gl/forms/8RmD49CmPC.

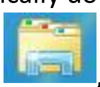
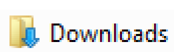
Table of Contents

Tips for Downloading and Unzipping your Data Files (ZIP)

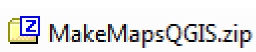
Once you click on the link provided in the Make Maps with Impressive Color using QGIS Google Form (https://drive.google.com/file/d/0B3OkVJavNJRlUDRVWTFSWld5c3c/view?usp=sharing) to access your Data Files (ZIP), you are taken to a Google Drive page with a MapsColorQGIS.zip file.



You may browse the contents of the folder if you wish, but to download the files, you need to click the download button .

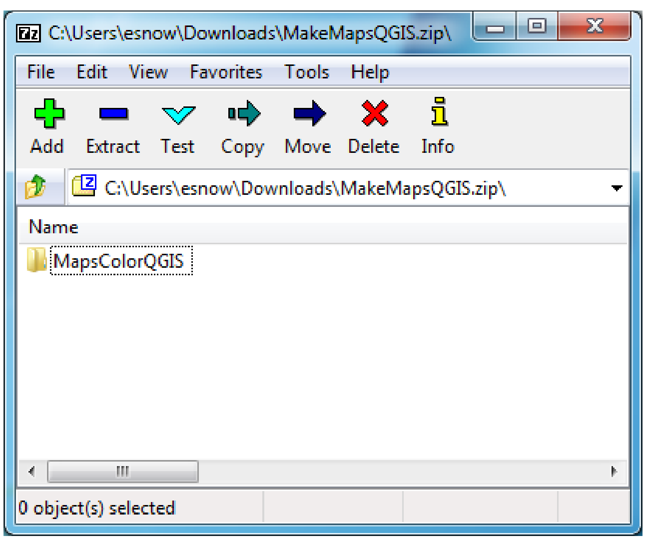
If you are prompted where you wish to save your files, just select the Downloads folder. The files may automatically download to the Downloads folder. Open the Downloads folder by opening Windows Explorer , and clicking Downloads 

.

Double click makeMapsQGIS.zip 

.

This will open the zip folder in 7Zip.



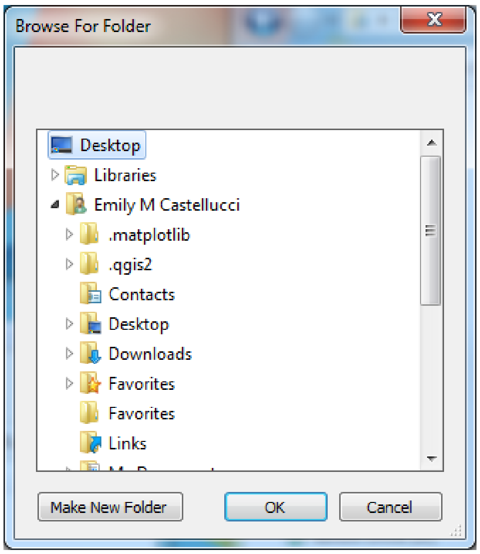
Click Extract to retrieve all the files in the folder 

.

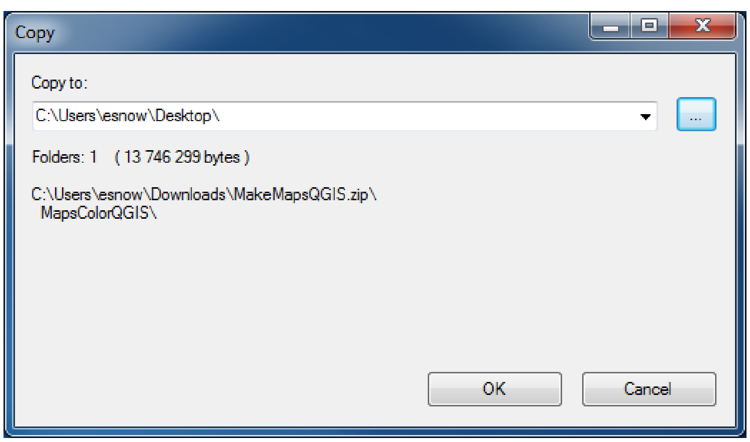
A Copy window will appear, asking you where you want your files copied (saved) to. Click the ellipses button to select where you want to save your data 

.

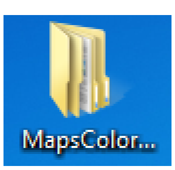
A Browwse For Folder window will appear. Select Desktop and click OK.



The filepath to the Desktop should now appear in the “Copy to:” box of the Copy window.



Click OK, and the files should appear on your Desktop!



You may minimize or close all windows, as you desire.

Exercise 1: Looking around QGIS

If you have not already downloaded your data files, please do so now! (See "Tips for Downloading your Data Files", pp. 2-3, for more information).

From the Desktop, open the folder MapsColorQGIS.

Open Exercise1&2. (We'll be using the same files for Exercise 1 and Exercise 2.)

You should see a QGIS project file entitled Exercise1&2.qgs. It should be easily recognizable with its QGIS icon 

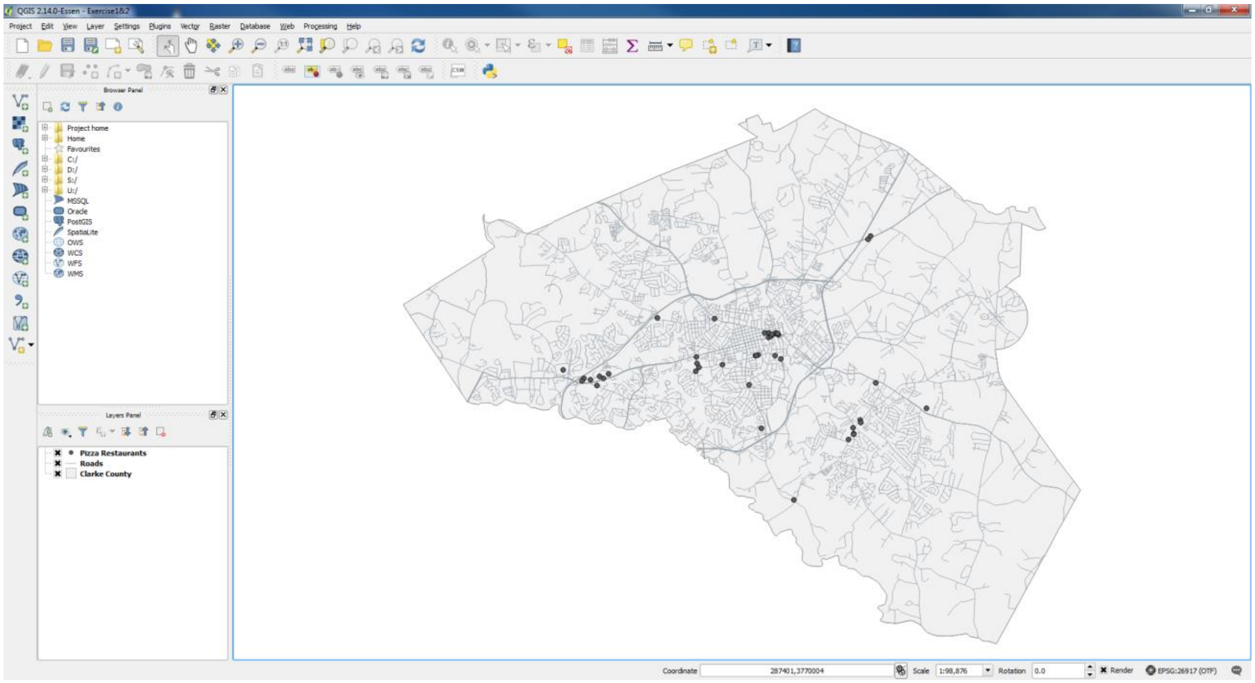
.

*NOTE: Don't see the file extension *.qgs? If you would like to see your file extensions, press Alt on your keyboard when you're in Windows Explorer. Go to Tools → Folder Options…. Under the View tab, deselect (uncheck) "Hide extensions for known file types" and click OK. You should now see all file extensions as you browse your data files in Windows Explorer.*

Double click Exercise1&2.qgs to open it in QGIS. The QGIS 2.14 Essen software, which has already been installed on the computers in this lab, will load.

If after this workshop you would like your own copy of QGIS, just go to QGIS.org and download it for free! QGIS is available for Windows, MacOS X, Linux, and Android.

Then the Exercise1&2.qgs project file will open, showing you a very basic map with a few layers. What you see should look similar to the image below:



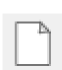
Now, let's take a look around QGIS!

- Beginning at the top, we have a series of horizontal toolbars:
  - Menu Toolbar
  - File Toolbar | Map Navigation Toolbar | Attributes Toolbar | Help Toolbar
  - Digitizing Toolbar | Label Toolbar | Web Toolbar | Plugins Toolbar
- Down the left side we have:
  - Manage Layers Toolbar
  - Browser Panel | Layers Panel
- At the bottom, we have information about scale, coordinates, etc.

If you hover your mouse over each button in these toolbars, you can see what each is called and get a general impression regarding what each button (tool) might do.

These toolbars and panels can be rearranged and customized, and there are other toolbars and panels available for more advanced tasks. (They're just not being shown right now, but if you'd like to see what they are, right click on blank toolbar space, and you can see a complete list.)

Here is a selection of tools that you may find beneficial for getting started with QGIS:

New – This opens a new QGIS project file. (No need to click this one right now, but if you already did, just exit it once it opens and reopen your Exercise1&2.qgs project file from Windows Explorer.)

Open – This opens an already existing QGIS project file. When we you reach Exercise 3 and Exercise 4 later in this workshop, you could choose the QGIS project files for those exercises from here, if you wish.

Save – Just click this save button or press Ctrl+S on your keyboard to save your work. It is recommended that you save your work frequently, as it is not periodically automatically saved.

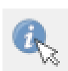
 Pan Map – Select this tool and "grab" your map by clicking and holding. Move the map up, down, left, right, etc. as if you were shifting a piece of paper across a table.

 Zoom In – You may zoom in by clicking on the area of interest, but you may find that clicking and dragging a box around the area of interest will give you more control over the zoom in tool.

 Zoom Full – If you want to zoom out to see all your data at once, this is the tool for you! It's also helpful if you find that your mapped area has gone out of view for unexplainable reasons… (It happens!)

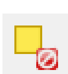
 Zoom Last - If you would like to go back to the zoom scale you were just using, just click this button to return to it. This is very useful if your zooming efforts get a little carried away.

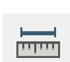
To utilize the tools listed below, you need to select a layer in the layers panel. Try selecting (clicking once) ***Pizza Restaurants*** *in the Layers Panel and explore the following tools:*

 Identify Features – Click on a point feature. You should see an Identify Results window up on the right side of your screen, giving you information about the pizza restaurant located there. (You may need to scroll to the right to see the details.)

 Open Attribute Table – To view the details for all the pizza restaurants, select this button to open the attribute table, which contains all the details about all the pizza restaurants included in this dataset. Browse the attribute table to see which details are available.

 Select Features by Area or Single Click – Click one of the pizza restaurants or click and drag a box around a group of pizza restaurants to select them. They'll be highlighted in the map *and* in the attribute table.

 Deselect Features from All Layers – If you do not want features selected anymore, this will clear all selections from all layers.

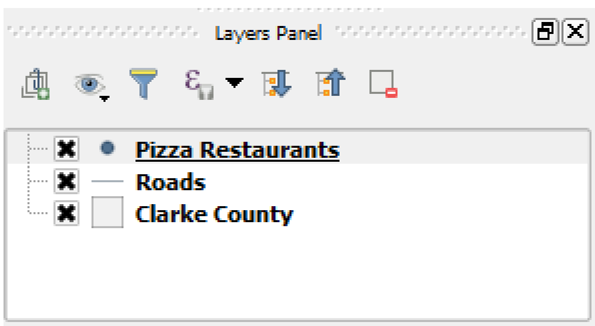
 Measure Line – If you want to measure the distance between two locations, use this tool. Results appear in a Measure window, and you can change the units to whatever is most familiar to you.

 Toggle Editing – Turn this on when you need to make an edit to the data, either to the location/shape of a feature on the map or to the details of the feature in the attribute table.

Layer Labeling Options – Add labels to your map features using this tool. When you click it, a Layer labeling settings will appear. To label Pizza Restaurants by name, change "No labels" to Show labels for this layer. Make sure the "Label with" option says "abc NAME". Click OK.


Add Vector Layer – This is one of the many tools you can use to add data to the project. This one adds vector-based files, such as the shapefiles used to create this map.

Now, let's take a look at the Layers Panel!



We have three layers in our Layer Panel, including Pizza Restaurants (point data), Roads (line data), and Clarke County (area data). You can turn each of these off and on again by deselecting and reselecting the X box next to each layer. Experiment turning each on off and on again.

Important: The order in which these layers appear in the Layers Panel reflects the order in which they are drawn in the mapped area. Right now, pizza points are drawn on top of the road lines, which are both drawn on top of Clarke County. When the layers are not in a logical drawing order in the Layers Panel, they may obscure one another. Experiment with reordering the layers in the Layers Panel to understand the effect of drawing order. Return the order to the way it was when you're finished!

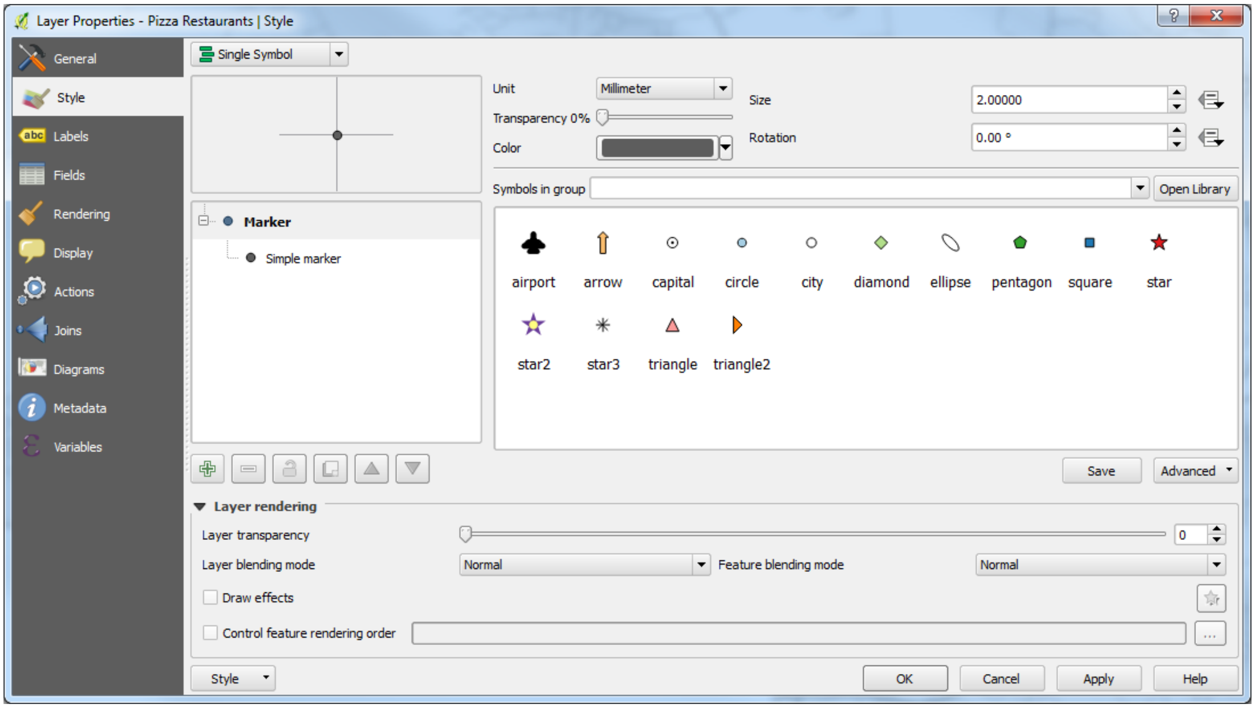
Great job familiarizing yourself with QGIS's user interface and tools! Waiting for everyone to finish?

How about a quick challenge! This workshop is about color, right? Let's change the color of our pizza restaurant points!

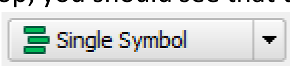
Open the attribute table for Pizza Restaurants. You may have noticed a Health column. This contains the current health scores of the pizza restaurants included in this data set (as of April 3, 2016). These scores were obtained from the Northeast Health District's Restaurant Scores for Clarke County at http://publichealthathens.com/healthscores/Clarke_county_restaurant_scores.html.

We can change the color of our pizza points according to their health scores, so let's give that a try.

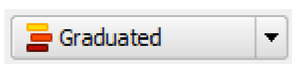
Close the attribute table. Right click on Pizza Restaurants in the Layers Panel, and click Properties. (Alternatively, you can just double click Pizza Restaurants in the Layers Panel.) A Layer Properties window should appear, looking something like this:



If Style is not already selected, select Style.

At the top, you should see that the Pizza Restaurants layer is not being symbolized according to a Single Symbol 

.

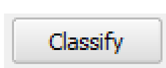
Let's change that to Graduated 

.

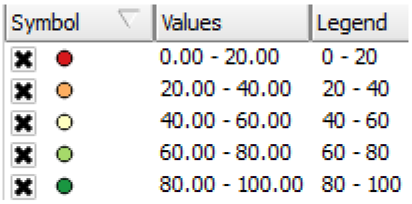
A graduated color scheme means that the colors of the map features change according to their values.

We want our pizza points to change according to Health score, so select the dropdown arrow next to Column and select Health.

Choose a color ramp that you think would well-represent the range of health scores that we have in our data set; the lowest score is 81 and the highest score is 100. We'll talk more about color ramps soon; just use your best judgment for now!

Next, click the Classify button. 

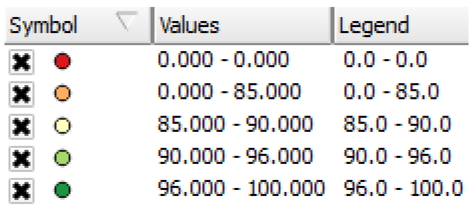
QGIS has divded our range of values in to groups for us, but using the default classificaton mode (Equal Interval), it has created class with a range of 0 to 100.



Symbol	Values	Legend
	0.00 - 20.00	0 - 20
	20.00 - 40.00	20 - 40
	40.00 - 60.00	40 - 60
	60.00 - 80.00	60 - 80
	80.00 - 100.00	80 - 100

Why did it do this? If you check the values in the attribute table, you'll notice that two values are 0. This is because no health score exists for those restaurants yet. To circumvent this problem, choose Natural Breaks (Jenks) as your Mode (of classification), and click the Classify button again.

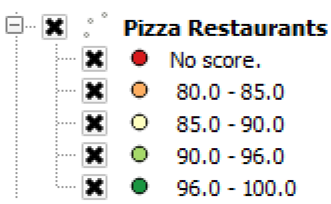
The 0 values are now in their own class, and the rest of the classification is sufficient.



Symbol	Values	Legend
	0.000 - 0.000	0.0 - 0.0
	0.000 - 85.000	0.0 - 85.0
	85.000 - 90.000	85.0 - 90.0
	90.000 - 96.000	90.0 - 96.0
	96.000 - 100.000	96.0 - 100.0

Tip: If you'd like to change the range of the class from 0 - 85 to 80 - 85, just double click the range in the Legend column and type. You can change labels of class ranges this way.

Click Apply to apply the colors to the points on the map. Make changes as you see fit, and when you're satisfied with your result, click OK. Your Layers Panel may have changed to look something like this for the pizza restaurants:



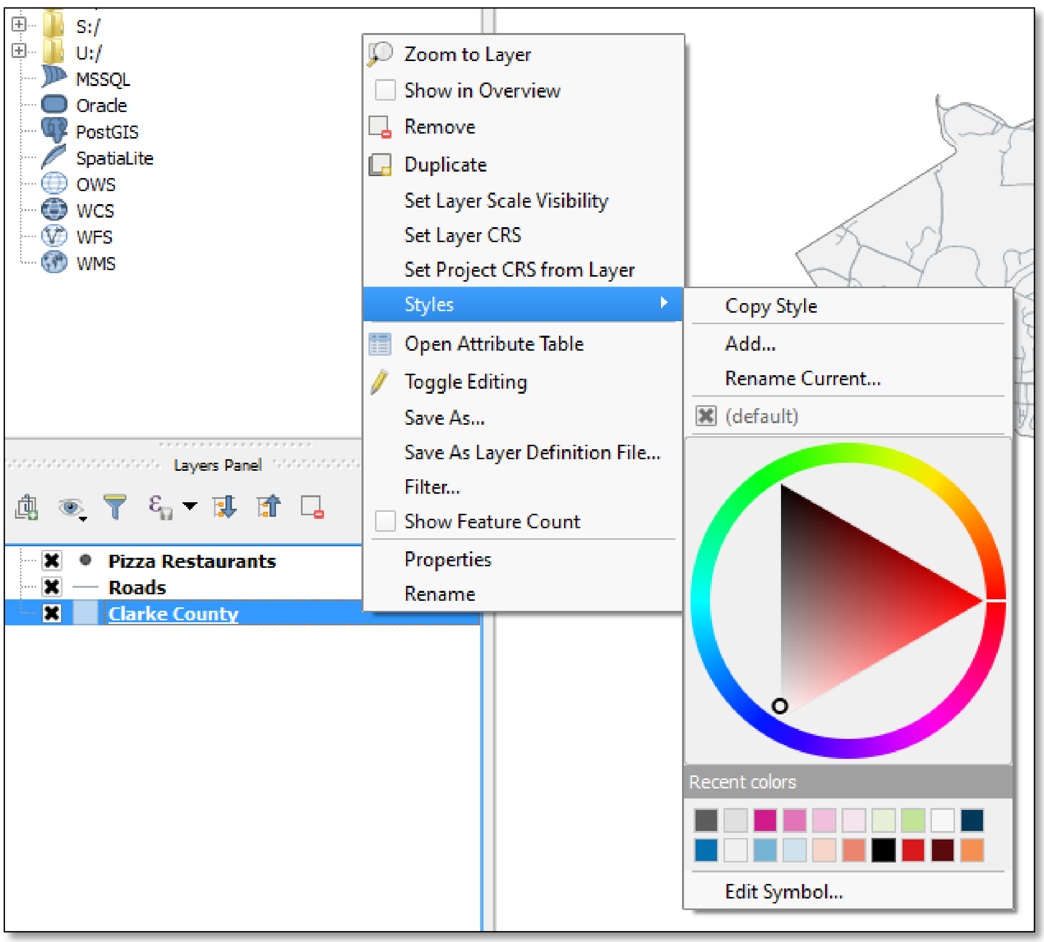
You have changed the colors of your pizza restaurant points according to health scores. Great job!

Exercise 2: Mixing Colors in QGIS

We're going to experiment with color mixing in QGIS using the same files from Exercise1. If you closed your work from Exercise, reopen it (double clock Exercises1&2 in Windows Explorer).

In QGIS, Pizza Restaurants, Roads, and Clarke County were all provided to you in gray tones. Let's spice that up! (If you completed the challenge in Exercise 1, return your Style for Pizza Restaurants to Single Symbol.)

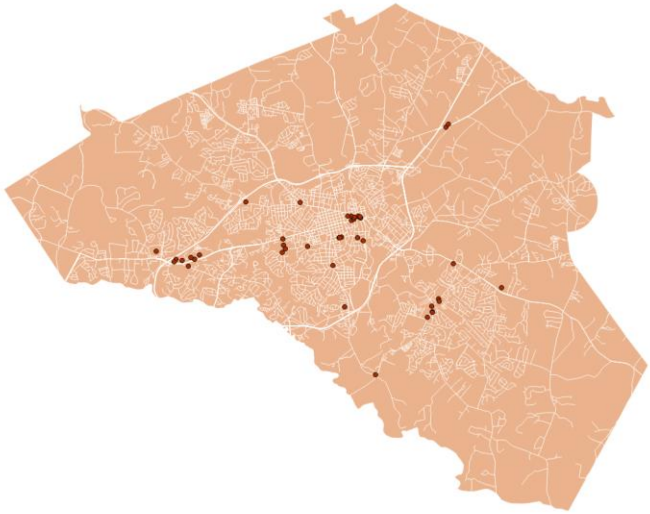
The colors of point, line, and area features can all be changed rather quickly. For starters, right click on Clarke County, and go to Styles. You should see a very colorful wheel-and-triangle color selector available for selecting colors.



There is a small circle that represents the currently chosen color for the layer selected (Clarke County). Click and hold the small circle, and move it around in the triangle. Watch the color of Clarke County change as you move your mouse.

If you do not want the triangle to be focused on the current color, look for the line in the wheel, which should be located at one of the points of the triangle. Click and hold the line, and movie it around the circle. The selected color will change as you move the point of the triangle around the wheel.

Familiarize yourself with this color selector, and use it to change the colors of Clarke County, Roads, and Pizza Restaurants. (Don't worry about picking the "right" colors, just have fun!) For example:

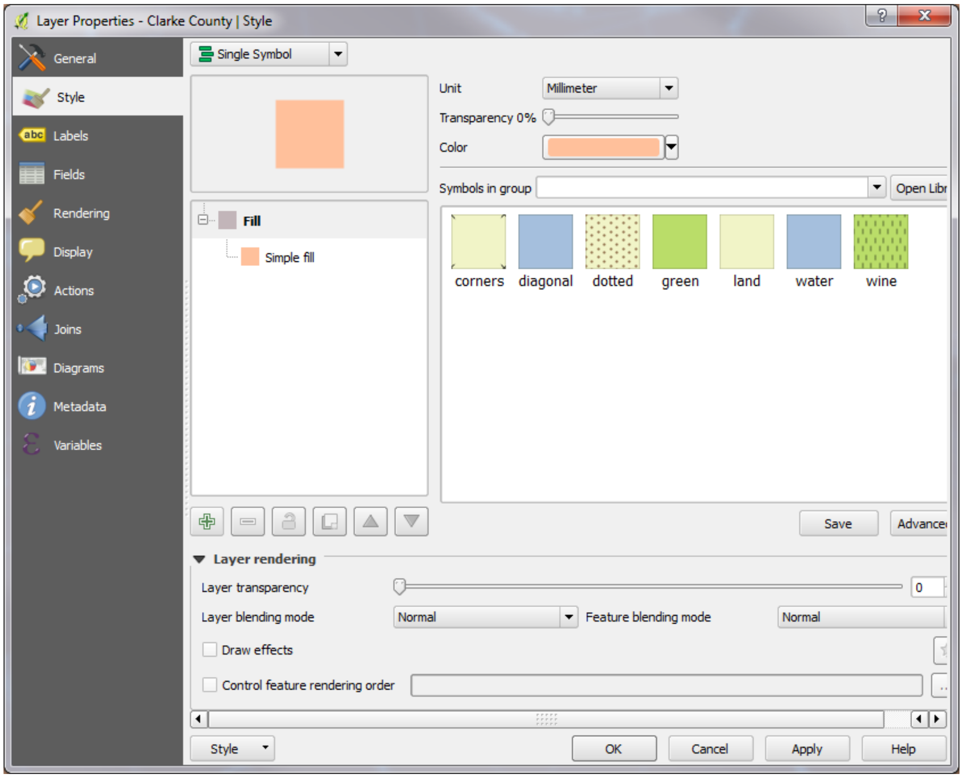


And here's a zoomed in view of the pizza restaurants downtown with road labels in white.

Now, let's take a closer look at our options for doing color mixing.

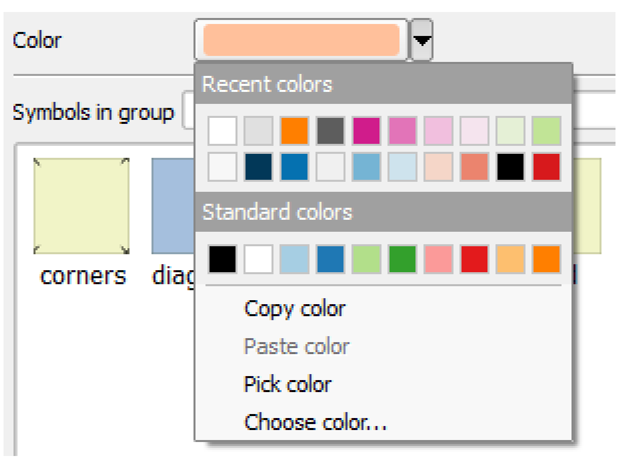
Another way to the colors of any layer is in the Layer Properties window. You can access this by right clicking on a layer in the Layers Panel and selecting Properties, or you can simply double click the layer of interest.

Double click Clarke County in the Layers Panel, and the Layer Properties window for Clarke County should appear. Style is usually selected by default, but if it is not selected, go ahead and select it now. Styles is where you change color(s).



Click the dropdown arrow next to the current color .

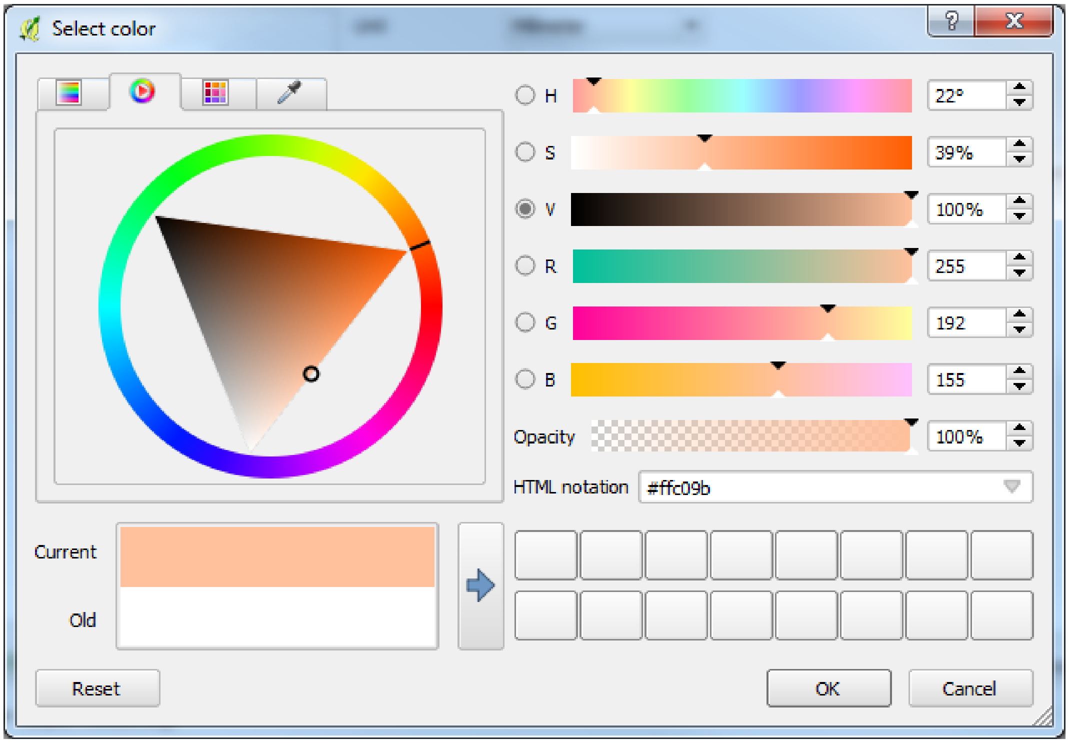
You should see options for Recent colors and Standard colors, but that's not much of a selection.



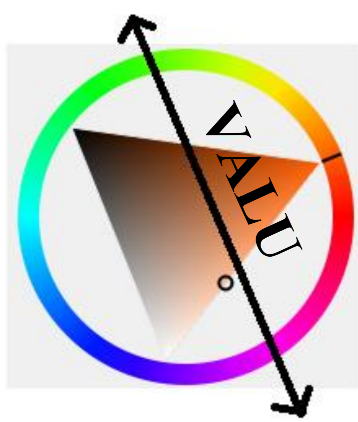
However, a fun tool in this dropdown list is "Pick color". Select it, and you should see a little dropper appear as your mouse. You can use it to pick any existing color in the QGIS window. Give it a try!

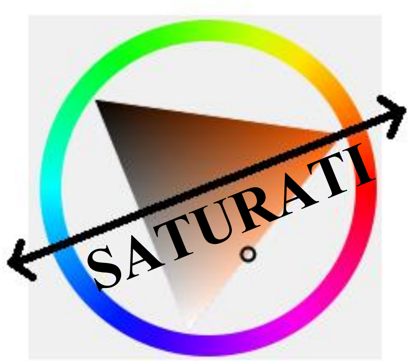
Also in this dropdown list is "Choose color…", which is where you want to go to explore the full range of color options available to you in QGIS. Go ahead and select "Choose color…". This should open the Select color window. (Alternatively, you can just select the block of color to open the Select color window.)

The second tab of the Select color window shows the same wheel-and-triangle color selector that you were just using when you right clicked on each layer and went to Styles.



As you may have already guessed, this wheel-and-triangle color selector is based on the HSV color model. The rainbow circle represents hues, and the value and saturation differences are represented in the triangle as shown below:





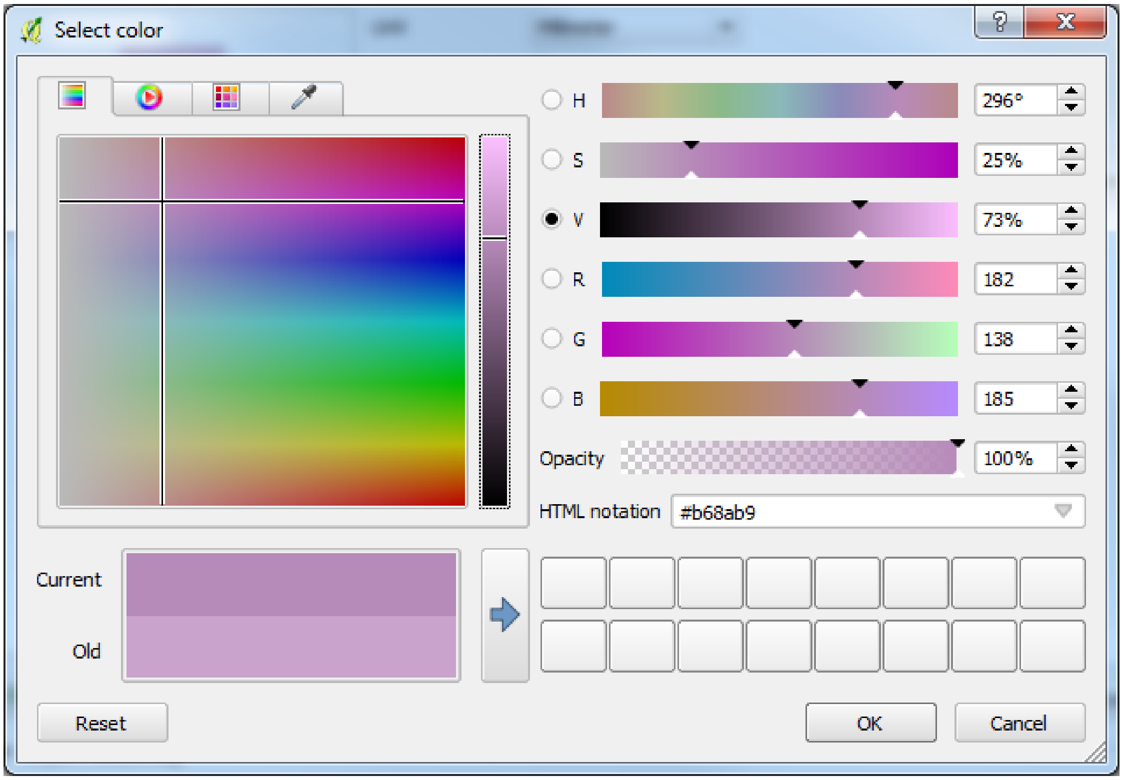
Try moving the circle in the triangle along the direction of value, and you will see the corresponding V numbers change from 0% (completely black) to 100% (completely white).

Try moving the circle in the triangle along the direction of saturation, and you will see the corresponding S numbers change from 0 % (completely desaturated [gray]) to 100% (completely saturated [vivid]).

Experiment with moving the HSV sliders, and changing the HSV numbers. (Note: H numbers range from 0° to 360°, which make sense considering the hues are around a circle.)

- The H slider should make the triangle (and line) move around the circle.
- The S and V slider should make the circle within the triangle move.

QGIS also has another HSV color selector, which you can access by clicking the first tab in the Select color window. It should look something like this:



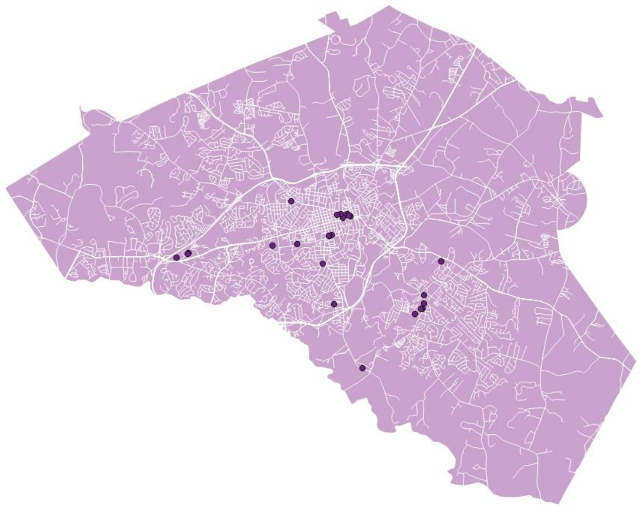
In this HSV color selector, one changes hues by moving the crosshairs up and down. One changes saturation my moving the crosshairs left and right, and one changes value by moving the bar up and own in the area to the right of the hue-saturation area.

Let's pick a good color for Clarke County. Since this is a background layer, you will likely want something that is ***high in value*** (~80%) and ***low in saturation*** (~20%). Choose a color that satisfies these requirements that you think will be suitable as a background color. Once you're satisfied with your selection, click OK. Click OK again to exit the Layer Properties window.

Let's work on picking a good color for Roads now. Open the Layer Properties window for Roads, and enter the Select color window. Roads is also a background layer, since the focus of this map is pizza restaurants, so we need the roads to fade into the background. However, the roads are important for orienting the pizza points in the map space, so the roads do need to contrast well with background. Try a color that is ***even higher in value (~90%)*** and ***even lower in saturation (~10%)*** and contrasts well with your background color. (You could also just try using white.) Once you've chosen a color and are satisfied with your selection, click OK. Clock OK again to exit the Layer Properties window.

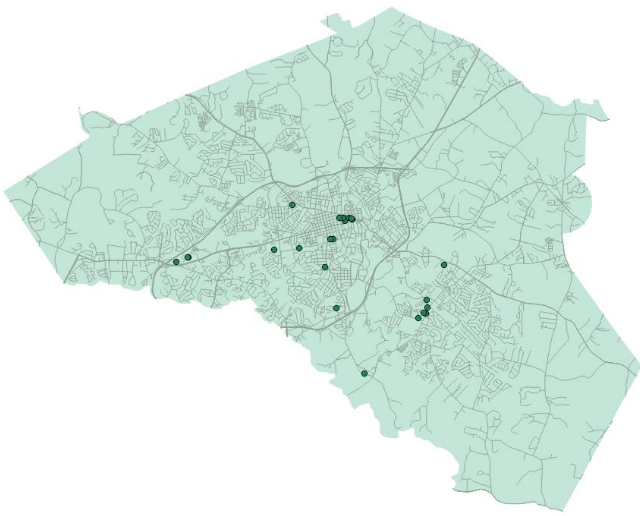
Finally, let's pick a color for our Pizza Restaurants. These are the focus of the map, and as such, they need to pop! Try a color with a moderate value (~50%) and moderately high saturation (~75%). Choose a color that contrasts well against your background layers. Once you're satisfied with your selection, click OK. Click OK again to exit the Layer Properties window.

Here is one of many possible results (with labels off):



The background is a light purple, the roads are white, and the pizza points are a dark purple.

An alternative color scheme could be to make the background even lighter and the roads somewhat darker than the background but still lighter than the pizza points. For example:



The background is a light green, the roads are gray, and the pizza points are a dark green.

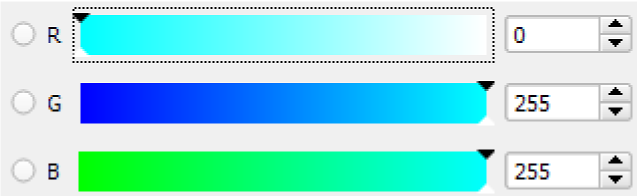
Similar hues were chosen for the background and points in both examples, because it produced a more harmonious result. Differences in saturation and value were used to establish contrast in these maps.

Great job mixing colors! If you're waiting for others to finish, let's take a moment to chat about mixing colors using the RGB approach.

RGB Color Mixing. As you were mixing colors using the HSV sliders, you probably noticed that there were sliders for red (R), green (G), and blue (B). These correspond with additive color theory, which is based on the idea of mixing emitted light.

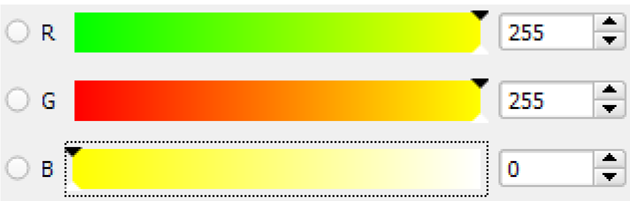
When mixing colors using the RGB model, you select different amounts of the primary colors (red, green, and blue). When you fully mix two primary colors, you achieve one of the secondary colors (cyan, magenta, and yellow). See examples of mixing the primary colors to achieve the secondary colors here:

When mixing blue and green, you get cyan.



When mixing red and blue, you get magenta.

When mixing red and green, you get yellow.

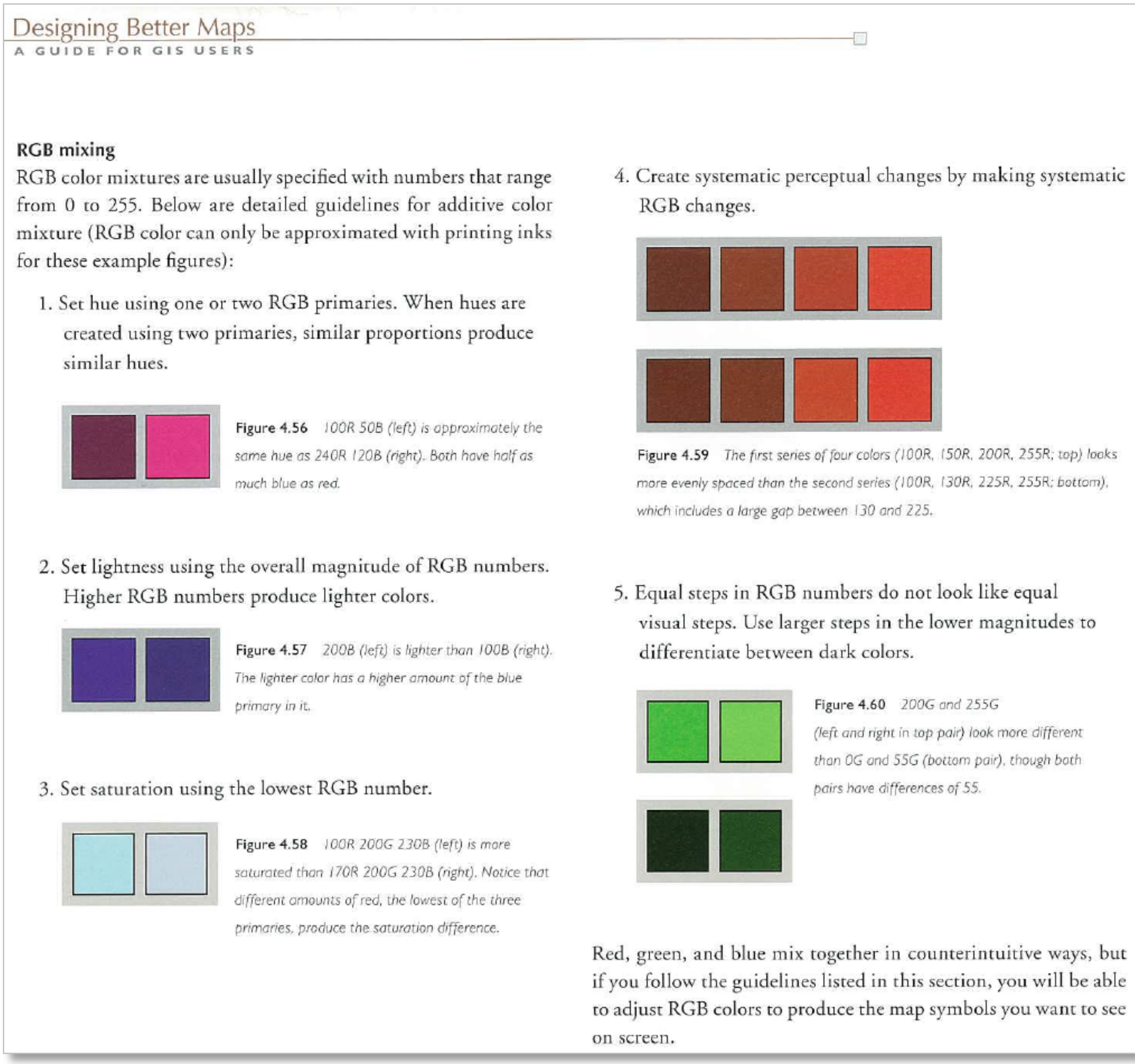


High amounts of red, green, and blue make lighter colors (see left below), and low amounts of red, green, and blue make darker colors (see right below).

In Cynthia Brewer's book *Designing Better Maps* (2005), Brewer discusses RGB color mixing noting that,

"RGB mixtures are usually specified using numbers from 0 to 255 because that range balances detail and efficient computation… Higher amounts of RGB in additive mixture produce lighter colors. In RGB, 255 R is lighter than 50 R, and dark colors are mixed by reducing amounts of the primaries… Big differences in primary amounts produce more saturated colors, while nearly equal amounts of the three primaries produce less saturated colors… A big difference between one primary amount relative to the other two is the key to high saturation. Desaturated colors are produced by mixing similar amounts of RGB."

Here are some more tips from Brewer's book on RGB color mixing.



Designing Better Maps
A GUIDE FOR GIS USERS

RGB mixing

RGB color mixtures are usually specified with numbers that range from 0 to 255. Below are detailed guidelines for additive color mixture (RGB color can only be approximated with printing inks for these example figures):

1. Set hue using one or two RGB primaries. When hues are created using two primaries, similar proportions produce similar hues.

Figure 4.56 *100R 50B (left) is approximately the same hue as 240R 120B (right). Both have half as much blue as red.*

2. Set lightness using the overall magnitude of RGB numbers. Higher RGB numbers produce lighter colors.

Figure 4.57 *200B (left) is lighter than 100B (right). The lighter color has a higher amount of the blue primary in it.*

3. Set saturation using the lowest RGB number.

Figure 4.58 *100R 200G 230B (left) is more saturated than 170R 200G 230B (right). Notice that different amounts of red, the lowest of the three primaries, produce the saturation difference.*

4. Create systematic perceptual changes by making systematic RGB changes.

Figure 4.59 *The first series of four colors (100R, 150R, 200R, 255R; top) looks more evenly spaced than the second series (100R, 130R, 225R, 255R; bottom), which includes a large gap between 130 and 225.*

5. Equal steps in RGB numbers do not look like equal visual steps. Use larger steps in the lower magnitudes to differentiate between dark colors.

Figure 4.60 *200G and 255G (left and right in top pair) look more different than 0G and 55G (bottom pair), though both pairs have differences of 55.*

Red, green, and blue mix together in counterintuitive ways, but if you follow the guidelines listed in this section, you will be able to adjust RGB colors to produce the map symbols you want to see on screen.

Feel free to experiment with mixing colors using the RGB model!

Still waiting for others to finish?

Take the [Ishihara 38 Plates CVD Test] for color blindness to see if you are red-green colorblind!

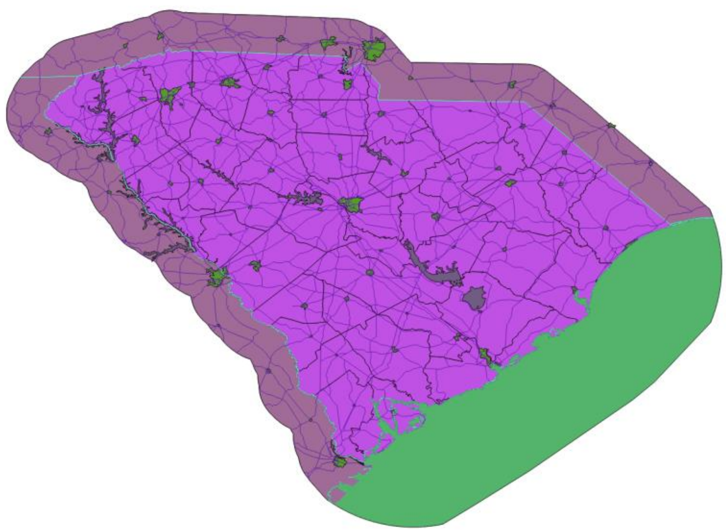
Exercise 3: Conventional Colors in QGIS

For this exercise, you're going to practice applying conventional colors to map layers in QGIS.

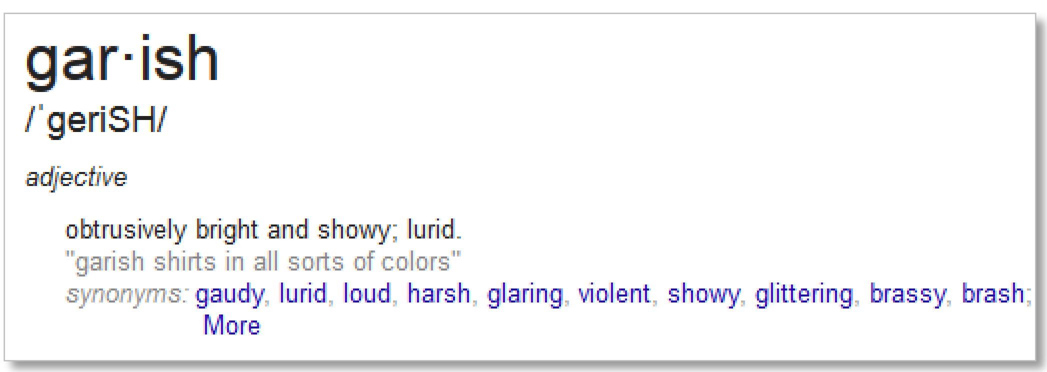
If you have work open in QGIS from Exercises 1 and 2, save your work and close QGIS.

Go to your MapsColorQGIS folder, open the Exercise3 folder. You should see an Exercise3.qgs file. Double click it to open it in QGIS.

What you see should look something like this:



How garish! Do these color choices respect convention in *any* way? Not particularly, no.



Let's change the colors of each map layer to more conventional color choices for the geographic features being represented.

For more advanced GIS users, use the color selecting and color mixing skills you've learned to see if you can do it yourself. For more inexperienced GIS users, follow along and we'll do this together!

Let's first take a look at the data that has been made available to you. It is recommended that you turn off all layers, then turn each on again and off again, one at a time, to be sure that you understand what each layer contains.

- **Roads** – This contains the major interstates, US highways, and SC highways of South Carolina.
- **State Lines** – These are the state lines delineating South Carolina from North Carolina and Georgia.
- **Cities** – These are city areas, which is somewhat unusual to see, because most of the time cities tend to be represented as points, but all cities have a geographic extent as shown here.
- **Lakes** – This contains the major water features of South Carolina, particularly lakes and the Savannah River, which separates Georgia from South Carolina.
- **Counties** – These layer represents the 46 counties of South Carolina.
- **South Carolina** – This is the geographic extent of South Carolina, nothing more and nothing less.
- **Other States** – This contains South Carolina and a little bit of its neighboring states, Georgia and North Carolina.
- **Atlantic Ocean** – This is actually a 20 mile buffer around South Carolina, but it would make a good ocean layer if symbolized blue and drawn in the back.

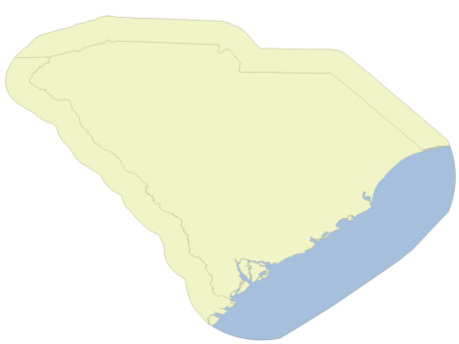
Now, let's symbolize each of these layers, one at a time, working our way from the bottom to the top of the Layers Panel.

Make sure that the Atlantic Ocean layer is showing, and open its Layer Properties window. QGIS has a water symbol, so let's just select that, click OK, and continue to the next layer.

(If we're not satisfied with it later, in conjunction with our other color choices, we can always change it.)

Now turn on the Other States layer. Open its Layer Properties window, and select the water symbol. Click Ok.

Here's what we have now:

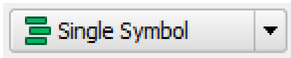


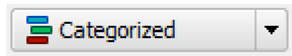
We have established very clear land-water contrast. Great!

(This is already an improvement over the original map, isn't it?)

Turn on the South Carolina layer, and open its Layer Properties window. Select the land symbol, but then change the color of the symbol to white.

Turn on the Counties layer, and open its Layer Properties window. Select the land symbol as before. However, now we're going to do something very different for this layer. We're going to color the counties with differently colored fills, not associated with any underlying data. Such fills simply make it easier to distinguish one county from another.

Change Single Symbol to 

to 

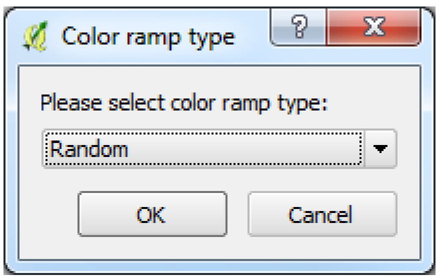
.

Change the column to NAME 

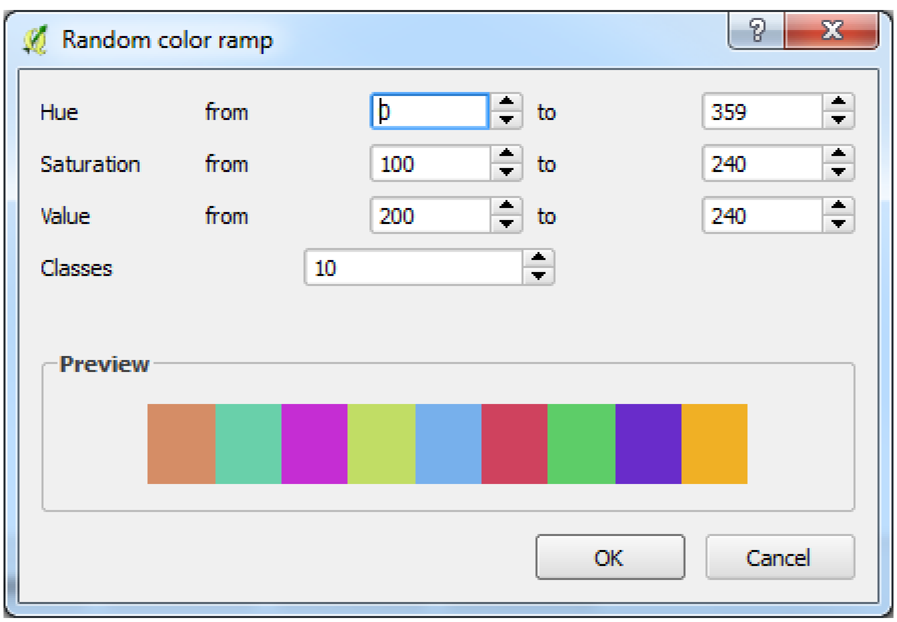
.

Currently Color ramp is set to Random Colors. We want random colors, but we want to have a little control over them. So click the dropdown arrow next to Random colors, scroll to the bottom of the list, and select New Color Ramp…

In the Color ramp type window, select Random.



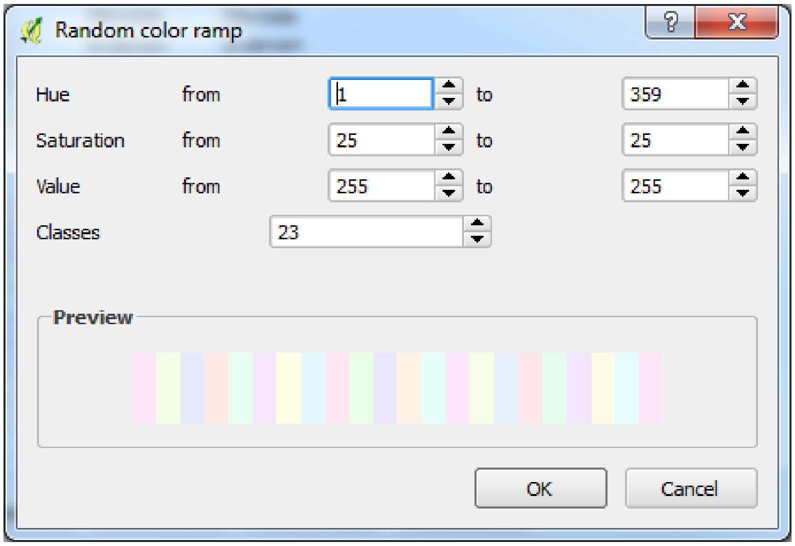
Click OK. A Random color ramp window appears with settings that we can change according to our needs.



Currently the shows a wide variety of hues that are highly saturated. Thankfully we can change this.

Let's try the following settings:

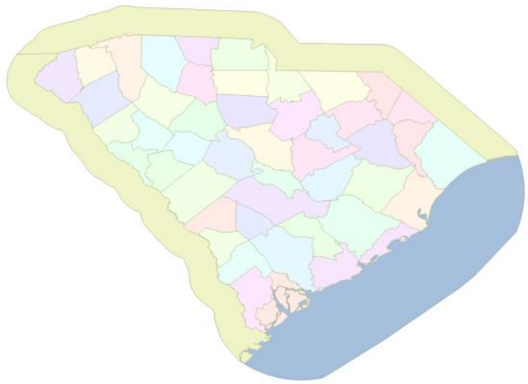
- Hue from 1 to 359. This will draw from all possible hues.
- Saturation from 25 to 25. This will force colors to be more subdued, helping them fade into the background.
- Value from 255 to 255. This will force colors to be much lighter, also helping them fade into the background.
- Classes 23. This means that no more than 2 counties will be colored the same.



Click OK, and a Color Ramp Name window will appear. Call it whatever you like. Click OK.

Click the Classify button. You should see a list of all the counties of South Carolina and the colors they're to be assigned with the color scheme is applied to the map. Click Apply. If you wish to make further changes to the color ramp you've created, you can do so by selecting the Edit button next to the Color ramp dropdown list. Once you're satisfied, click OK to exit the Layer Properties window.

Here is what we have so far:



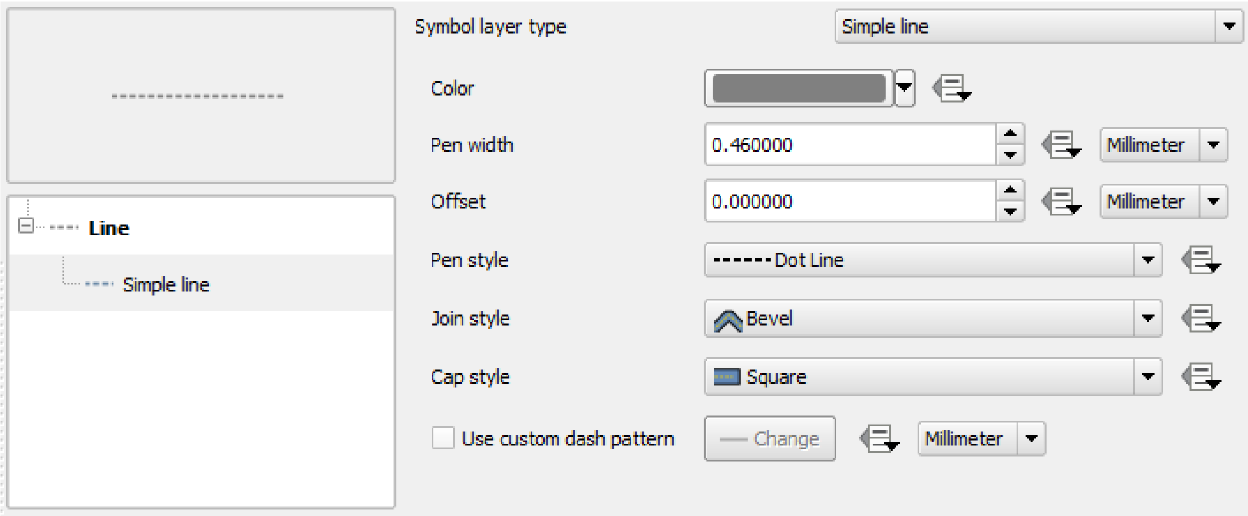
Next, symbolize Lakes in the same way that you symbolized the Atlantic Ocean layer.

Now, let's do cities. Open the layer properties window. Select the land symbol. Then change the color to the following: hue 28°, saturation 37%, and value 96%. You should end up with a muted orange.

To symbolize the state lines, turn on the State Lines layer and open the Layer Properties window. The options are different for line features than they are for area features. We could choose one of the present symbols, but none of the one currently available to us particularly suit state borders. So let's create our own line symbol for the state lines.

Click Simple Line. This open several options for us. Let's try these settings:

- Change the color to 50% gray.
- Increase the pen width to 0.460000.
- Change the pen style to Dot Line.



Click Apply. Make changes as desired. Click OK.

Finally, we're on the last layer: Roads. Turn on the Roads layers.

Roads are usually best symbolized in a hierarchical fashion. Let's see if there is a column that we can use in the attribute table. Open the attribute table and look for a column that differentiates between interstates, highways, etc.

It appears the Type column differentiates between Interstates (Int), US Highways (US), and State Highways (State). Let's use this column to color our Roads. Close the attribute table.

Open the Layer Properties window for Roads. Change Single Symbol to Categorized. Change Column to Type. Click the Classify button. Select and delete the blank class that appears. Reorder the three remaining road symbol to Int (top), US, and State (bottom).

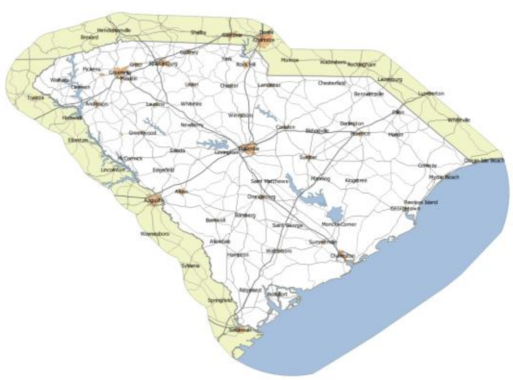
Change the color of these three road symbols by double clicking on each, one at a time, and changing the settings as follows:

- Int – Select Simple Line. Change Color to HSV (0,0,40). Change pen width to 0.46.
- US – Select Simple Line. Change Color to HSV (0,0,40).
- State – Select Simple Line. Change Color to HSV (0,0,60).

As a final touch, select Cities and label the cities by name. (Try enlarging labels slight to 9pts.)

Your final map should look something like the following:

You may prefer the result with the counties turned off, as it reduces “color clutter”.



Beautiful! You’ve done an excellent job addressing the poor color choices of the original map!

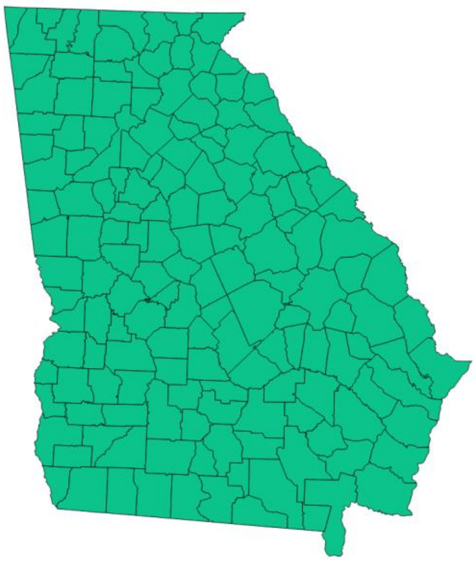
Exercise 4: Color Ramps in QGIS

For this exercise, you're going to practice applying sequential and diverging color schemes to quantitative data.

If you have work open in QGIS from Exercises 1, 2, or 3, save your work and close QGIS.

Go to your MapsColorQGIS folder, open the Exercise4 folder. You should see an Exercise4.gqs file. Double click it to open it in QGIS.

What you should see is a single layer of Georgia's counties.



Open the attribute table to familiarize yourself with the data available to you.

This data was downloaded from the US Census Bureau (census.gov), and it actually contains a lot more data than is being shown here. Many of the columns are simply hidden.

The columns that are of importance are as follows:

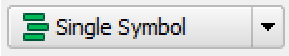
- **DP0010001** – This column contains the total population of each county.
- **SQMI** – This column contains the area of each county in square miles.
- **PopDens** – This column contains the population density of each county.
    - Population Density is calculated by dividing total population by area.
    - The unit for this field is people per square mile.
- **Diverging** – This column contains the percentage greater than or less than the average population density by county.

First, you are going to apply a *sequential* color scheme to Georgia counties according to population density (PopDens).

Second, you are going to apply a *diverging* color scheme to Georgia counties according to the percentage greater than or less than average population density (Diverging).

Let's get started!

Open the Layer Properties window for Counties.

Change Single Symbol 

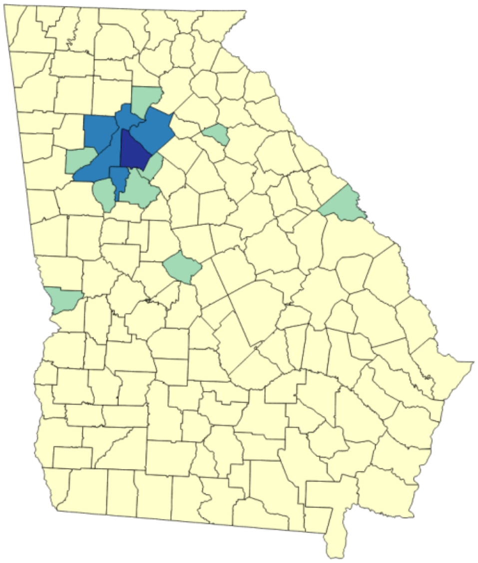
to Graduated 

.

Click the dropdown list next to Column, scroll to the bottom of the list, and select Pop Dens (population density).

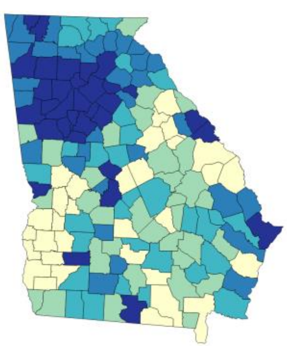
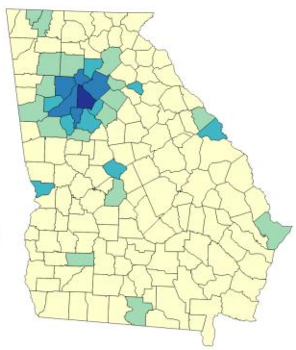
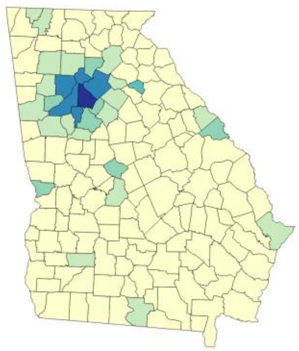
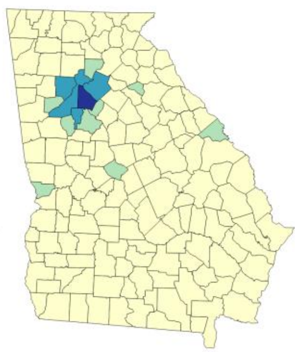
Select a sequential color ramp. Click Classify. Click Apply.

If you used the default classification Mode and default number of classes (5), your result should look something like the following:



Feel free to experiment with the different classification modes and different numbers of classes, as they change the appearance of the map. For example:

Quantile (Equal Count) *Natural Breaks (Jenks)* *Standard Deviation* *Pretty Breaks*

Of these results, Quantile (Equal Count) is the least appropriate for this data as it does not consider the distribution of the data. Natural Breaks (Jenks), which probably best considers the distribution of the data, is likely the best choice of classification made for Georgia population density by county. Natural Breaks (Jenks) is a popular choice among map designers because of how well it considers the distribution of the data, but “Pretty Breaks” is also popular because the class breaks are so intuitive.

Now, let's change the color scheme to a diverging one.

First and foremost, one must remember to change the Column setting to data that is appropriate for a diverging color scheme, i.e. data that diverges from a significant or critical central value.

Select the column that contains population density percentage greater than or less than the average population density, which is the column called "Diverging" in this case.

Choose a diverging color ramp.

The percentages in the Diverging column range from 4.39% to 1358.29%, and the significant central value is 100%.

- Percentages that are close to 100% represent counties whose population density is very close to the average population density of all counties.
- Counties with values between 0% and 100% have population densities below the average population density of all counties.
- Counties greater than 100% have population densities above the average population density of all counties.

Because of the limited range of below average values and the limitless range of above average values, it would be best if we created our own class breaks. Consider the following class breaks:

- 3.125% - 6.25%
- 6.25% - 12.5%
- 12.5% - 25%
- 25% - 50%
- 50 - 100%
- 100% - 200%
- 200% - 400%
- 400% - 800%
- 800% - 1600%

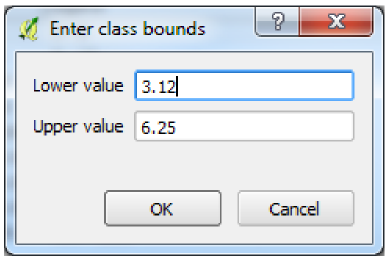
Let's create classes with these breaks.

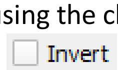
First, return your classification mode to the default Equal Interval.

Second, select 9 for your number of classes.

Third, click the Classify button. We're now going to edit the break values.

- Double click on the first row.
- An Enter class bound window appears.
- Enter 3.125 as the Lower value.
- Enter 6.25 as the Upper value.
- Click Ok.
- Repeat for each row, using the class breaks listed above.

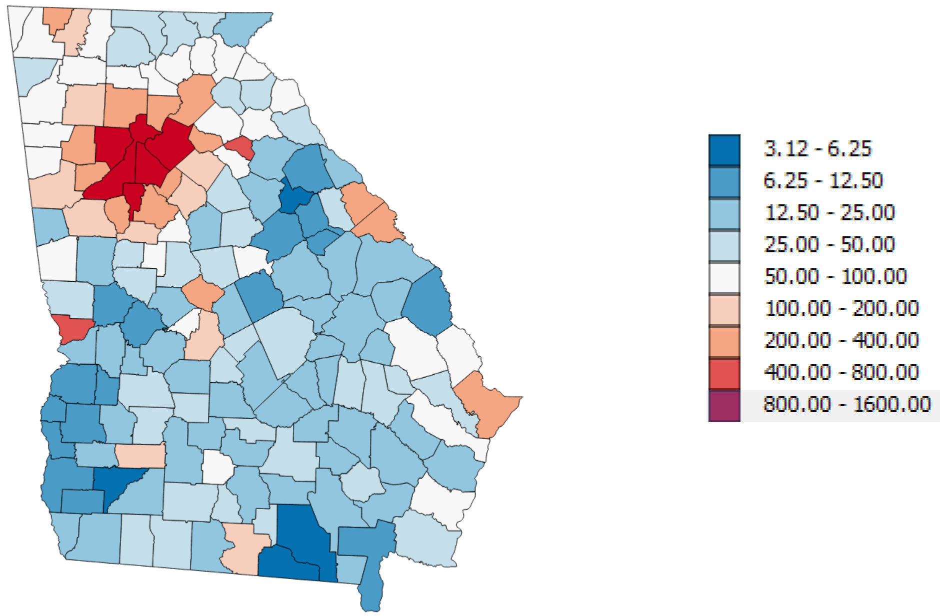


Tip: Consider the Invert option 

if the colors in your color ramp need to be ordered in reverse.

When you're finished, click Apply.

Look at the changes in your map, which should look something like the following:



This map shows percentage greater than and less than the average population density. Areas in the deepest red have a population density that is 800%-1600% the average population density of Georgia counties. Areas in the deepest blue have a population density that is 3.12%-6.25% the average population density of Georgia counties.

In summary, this map shows population density differences in comparison to the average population density. Unlike the sequential map, which only effectively shows areas with greatest population density, this diverging map successfully draws attention to both the most densely populated areas *and* the least densely populated areas. Pretty cool!

Post-Workshop Survey

Please complete the Post-Workshop Survey, which you can access here: http://goo.gl/forms/szWLzhoK0k.

Thank you so much for participating in this workshop!!!

APPENDIX J

WORKSHOP DATA FOR EXERCISES

The following is a list of the names of folders and files that were shared with each workshop participant.[50]

- [Folder] MapsColorQGIS
  - [Folder] Exercise1&2
    - Exercise1&2.qgs
    - [Folder] ACCdata
      - ACC_boundary.dbf
      - ACC_boundary.prj
      - ACC_boundary.shp
      - ACC_boundary.shx
      - ACC_pizza.dbf
      - ACC_pizza.prj
      - ACC_pizza.shp
      - ACC_pizza.shx
      - ACC_roads.dbf
      - ACC_roads.prj
      - ACC_roads.shp
      - ACC_roads.shx
  - [Folder] Exercise3
    - Exercise3.qgs
    - [Folder] SCdata
      - SC_1_Roads.dbf
      - SC_1_Roads.prj
      - SC_1_Roads.sbn
      - SC_1_Roads.shp
      - SC_1_Roads.shx
      - SC_2_StateLines.dbf
      - SC_2_StateLines.prj
      - SC_2_StateLines.sbn
      - SC_2_StateLines.shp
      - SC_2_StateLines.shx
      - SC_3_Cities.dbf

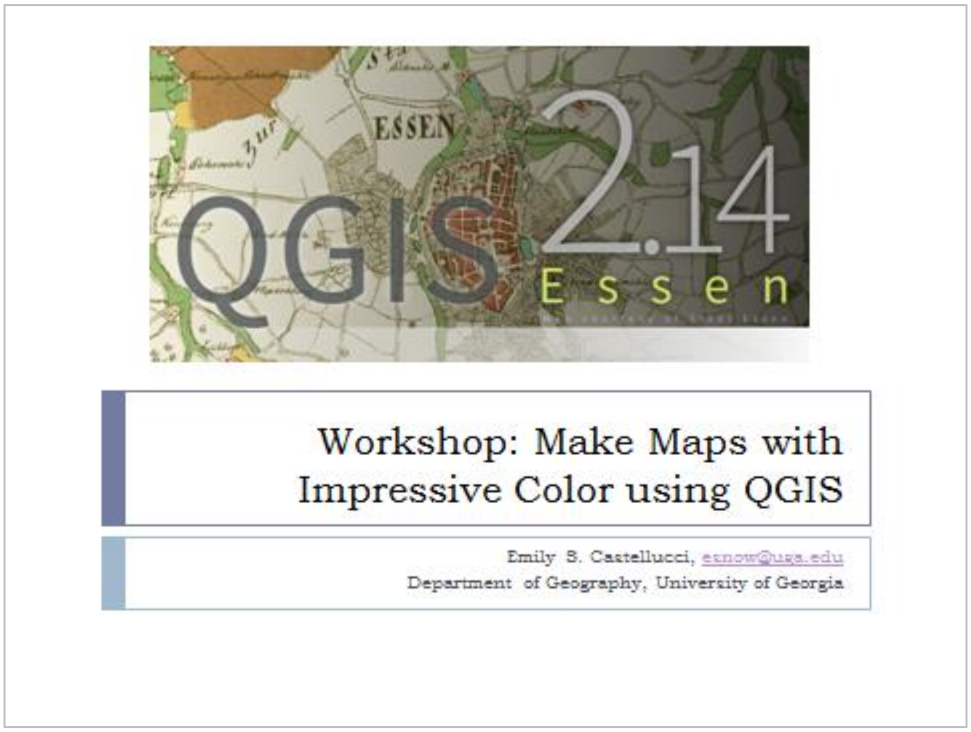
[50] Actual data files may be obtained from the author by emailing ESCastellucci@gmail.com.

        - SC_3_Cities.prj
        - SC_3_Cities.sbn
        - SC_3_Cities.shp
        - SC_3_Cities.shx
        - SC_4_Lakes.dbf
        - SC_4_Lakes.prj
        - SC_4_Lakes.sbn
        - SC_4_Lakes.shp
        - SC_4_Lakes.shx
        - SC_5_Counties.dbf
        - SC_5_Counties.prj
        - SC_5_Counties.sbn
        - SC_5_Counties.shp
        - SC_5_Counties.shx
        - SC_6_StateofSC.dbf
        - SC_6_StateofSC.prj
        - SC_6_StateofSC.sbn
        - SC_6_StateofSC.shp
        - SC_6_StateofSC.shx
        - SC_7_NCandGA.dbf
        - SC_7_NCandGA.prj
        - SC_7_NCandGA.sbn
        - SC_7_NCandGA.shp
        - SC_7_NCandGA.shx
        - SC_8_AtlanticOcean.dbf
        - SC_8_AtlanticOcean.prj
        - SC_8_AtlanticOcean.sbn
        - SC_8_AtlanticOcean.shp
        - SC_8_AtlanticOcean.shx
- [Folder] Exercise4
    - Exercise4.qgs
    - [Folder] GAdata
        - DP_TableDescriptions.xls
        - GA_Counties_UTMZone17N.dbf
        - GA_Counties_UTMZone17N.prj
        - GA_Counties_UTMZone17N.sbn
        - GA_Counties_UTMZone17N.shp
        - GA_Counties_UTMZone17N.shx

APPENDIX K

WORKSHOP PRESENTATION SLIDES

The presentation slides used by the workshop facilitator are included on this and the following pages.



(continues on next page…)

Let's get started!

- **Complete the Pre-Workshop Survey!**

- **Download:**
  - Your Instructions Packet (PDF)
  - Your Data Files (ZIP)

Note: Tips for downloading and unzipping your data files are in the instructions packet!

Part 1
What is "GIS"?

What is geographic information?

"Almost everything that happens, happens ***somewhere***."

"Knowing ***where*** something happens can be critically important."

- Geographic information is…
  - the "where" of everything.
  - the measures of "where" versus "where".
  - recordable in many forms.

Even Waldo is *somewhere*!

What is "GIS"?

"Geographic information systems (GIS) are a special class of information systems" that keep track of **where** "events, activities, and things happen or exist."

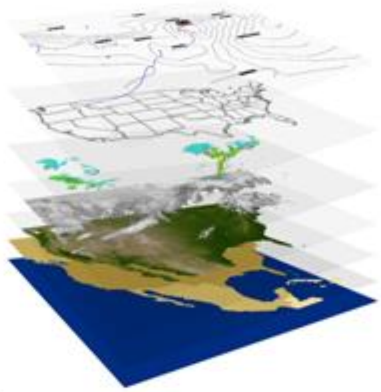
"A geographic information system (GIS) lets us **visualize**, question, analyze, and interpret data to understand relationships, patterns, and trends."

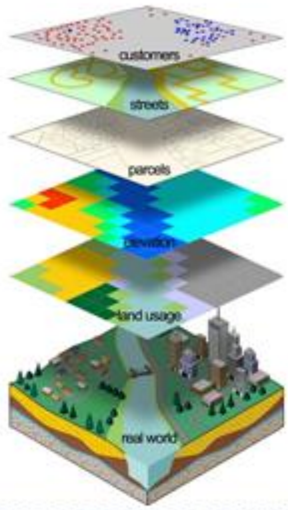
You can use a GIS to visualize your geographic data and make a map!

Sources: *Geographic Information Systems & Science*, 3rd edition by Longley, et al. (2011) and http://www.esri.com/what-is-gis

Making a Map using a GIS

- Important Concept: **Layers**





Making a Map using a GIS (continued)

- Important Concept: **Features**
  - Location
  - Shape
    - Point
    - Line
    - Area
  - Details
- Example

Source: http://www.crimemapping.com/

GIS Software Options

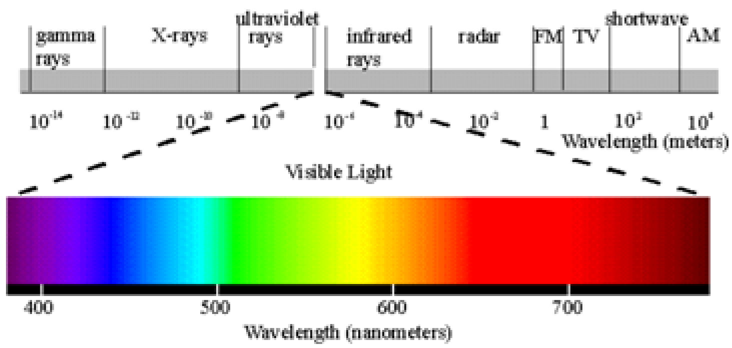
- Wikipedia's List of GIS Software
- Popular Options for Desktop GIS
  - ArcGIS by ESRI (proprietary)
    - http://www.esri.com/software/arcgis/arcgis-for-desktop
  - QGIS (open source)
    - http://qgis.org/en/site/
    - Available on Windows, MacOS X, Linux, & Android.
- What is the difference between **proprietary** and **open source**?
- Why are we using QGIS?

Exercise 1
Looking around QGIS

Part 2
How do map designers think about color?

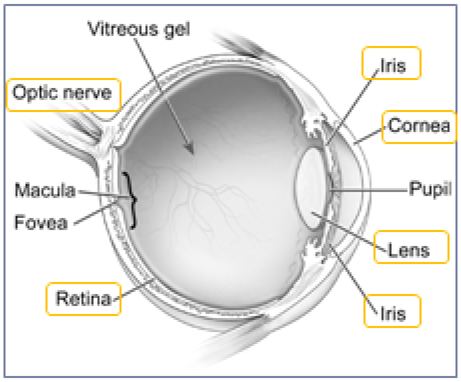
What is color?

- Different wavelengths of visible white light, which is
  - a form of electromagnetic radiation, and
  - a small portion of the electromagnetic spectrum.

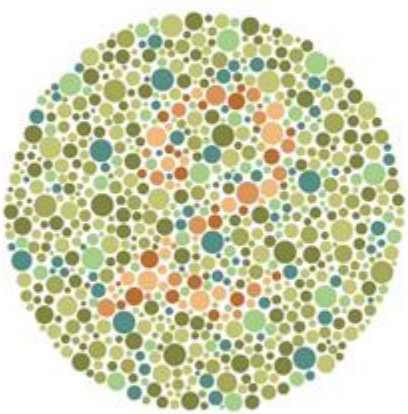


How do our eyes perceive color?

- **Cornea** – transparent outer protective layer; lets in the light
- **Iris** – diaphragm-like muscle that alters the size of the pupil; controls the amount of light
- **Lens** – focuses the light
- **Retina** – thin tissue composed of rod cells and cone cells
  - **Rod cells** – achromatic sensations, no color discrimination
  - **Cone cells** – three types with different wavelength sensitivities (blue, red, green)
- **Optic nerve** – a bundle of nerve cells that transmit the electrical impulses to the brain



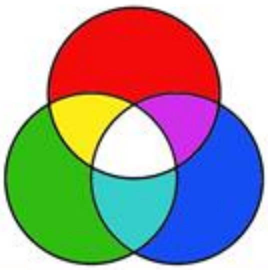
Color Blindness



- Most Common:
  - Perceives blues and yellows
  - Cannot distinguish reds and greens
- Who is affected?
  - 8% of males, <1% of females
  - Usually hereditary, but not always.
- Impacts color choices when designing maps!
  - Do you *really* need that red-green color scheme?
  - Can you choose a different scheme and still communicate your point effectively?

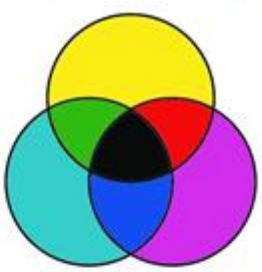
Color Theories & Models

- **Additive**
  - Primary Colors: Red, Green, Blue
  - Secondary Colors: Cyan, Magenta, Yellow
  - Color Model: RGB
  - Example: On-Screen Maps



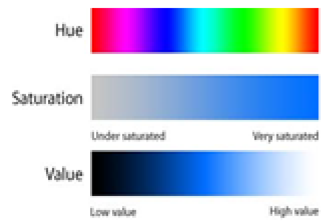
Color Theories & Models (continued)

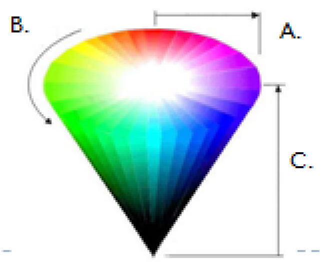
- **Subtractive**
  - Primary Colors: Cyan, Magenta, and Yellow
  - Secondary Colors: Red, Green, Blue
  - Color Model: CMYK
  - Example: Printed Maps



Perceptual Dimensions: HSV

- Three perceptual dimensions:
  - **Hue** (a.k.a. variations in wavelength, e.g. red, orange, yellow, etc.)
  - **Saturation** (a.k.a. chroma, intensity, purity)
  - **Value** (a.k.a. brightness, lightness, darkness)
- Label the following diagram:

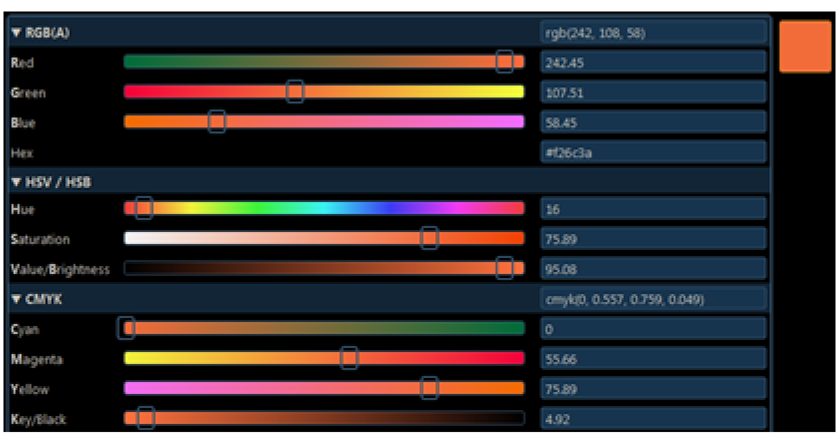


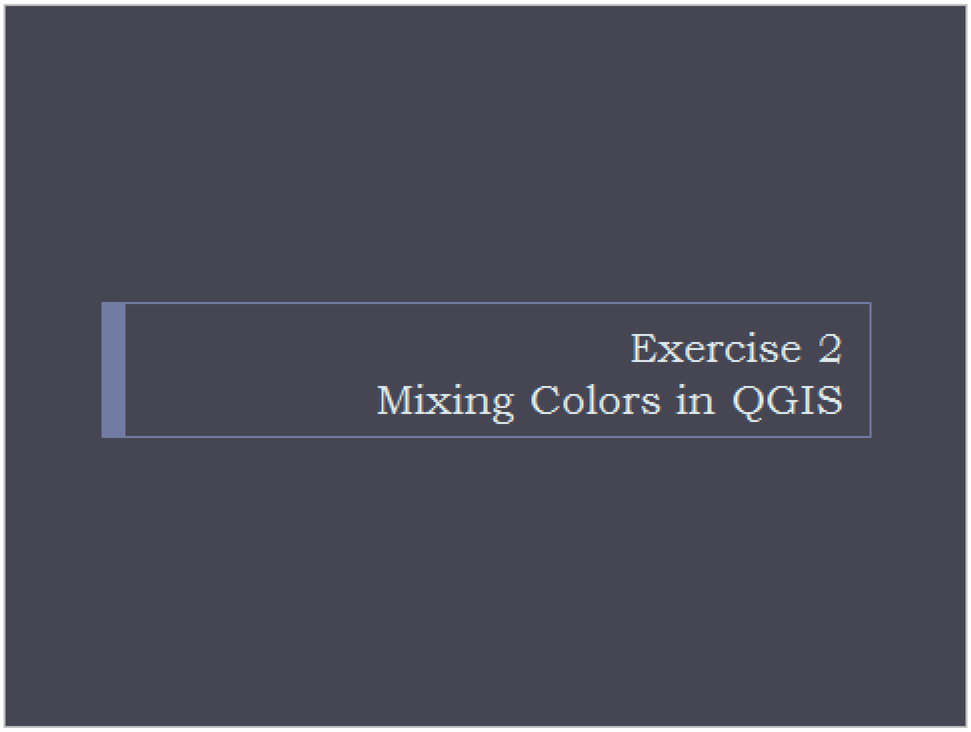


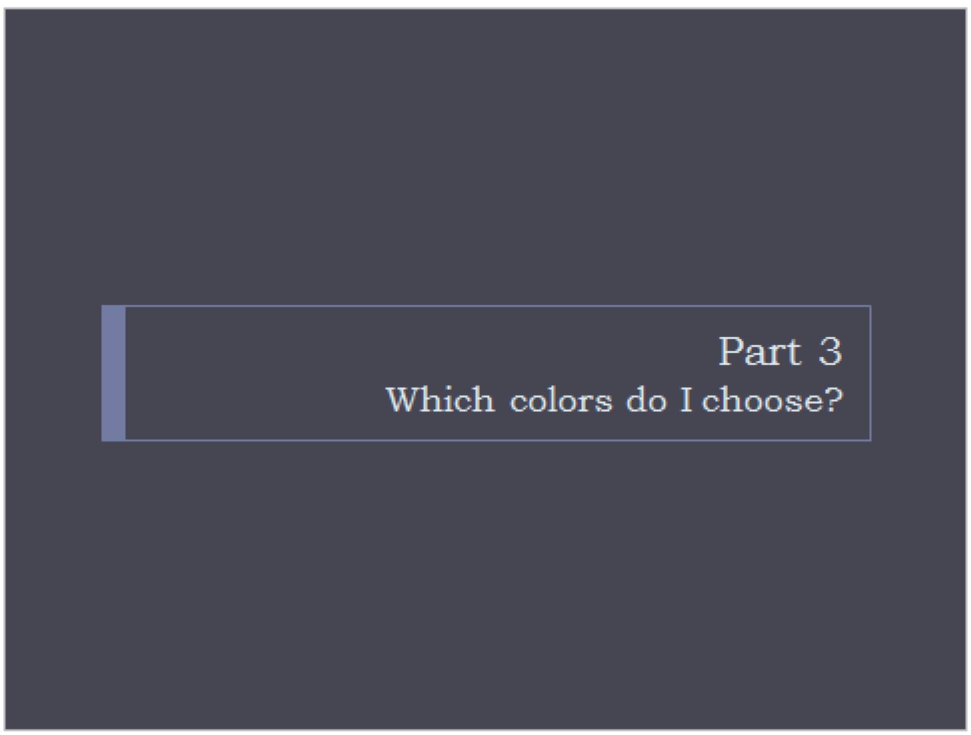
Answers:
A. Saturation
B: Hue
C:Value

Color Mixing

- http://colorizer.org/




Exercise 2
Mixing Colors in QGIS


Part 3
Which colors do I choose?

Thoughts on Color Preferences

"There seem to prevail among otherwise logical thinkers the curious notions that
a) what the individual himself likes another will also, and
b) if someone likes a technique it is therefore good.
If ever means and ends were confused it is in these reactions to color use...
Except within the broadest limits personal preferences should play a small role in the choice of colors."

-*Arthur Robinson, 1985,* The Look of Maps

"If all you had to do was choose pretty colors,
the task would be fairly straightforward;
but I fear too many maps would end up blue,
the most common favorite color."

- *Cynthia Brewer, 2005,* Designing Better Maps

Differing Color Connotations

Generic (Western)

- Green: youth, spring, nature, peace
- Red: warm, important, action, anger, danger, power, warning
- Orange: attention, action, warning
- Brown: earthy, dirty, warm
- Purple: dignity, royalty, sorrow, despair
- White: clean, life, clarity, light
- **Black**: strength, heaviness, death

Cultural

- Green: sacred for Muslims, mourning and unhappiness in Asia
- Red: communists, politically left organizations, purity in India
- Orange: Protestants in Ireland, sacred Hindu color
- Brown: mourning in India, Nazis in West
- Purple: mysticism, prostitution in the Middle East
- White: unhappiness in India, mourning in China
- **Black**: fascists, anarchists, death, mourning in the West

Source: *Making Maps: A Visual Guide to Map Design for GIS* by Krygier & Wood (2011)

Traditional Color Conventions

- Blue for water.
- Red with warm and blue with cool temperature.
- Yellow and tans for dry and little vegetation.
- Brown for land surfaces.
- Green for lush and thick vegetation.

Recent Trends

"Today we are starting to see a general universalization of certain reference map color schemes. This is mostly due to the fact that the largest mapping services in the world, owned by some of the world's largest tech companies, have standardized their own maps and have settled on similar color palettes. Although each service differs slightly in its color choices, a consensus has emerged."

Source: *Web Cartography: Map Design for Interactive and Mobile Devices* by Muehlenhaus (2013)

- Examples?

Google Maps: South Carolina

Bing Maps: South Carolina

Map Quest: South Carolina

Exercise 3
Conventional Colors in QGIS

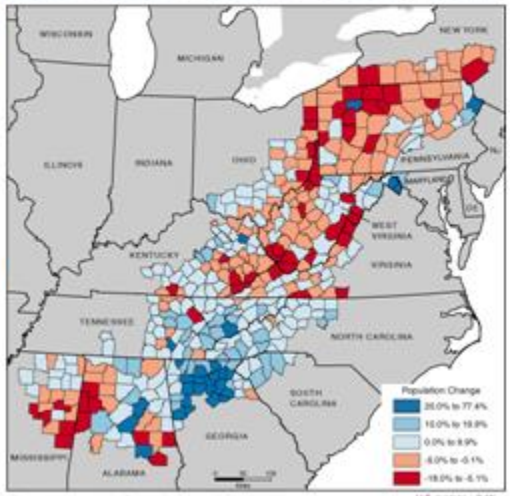
Part 4
How do I color quantitative data?

Sequential Example

The darker the red, the greater the rate of unemployment.

Diverging Example

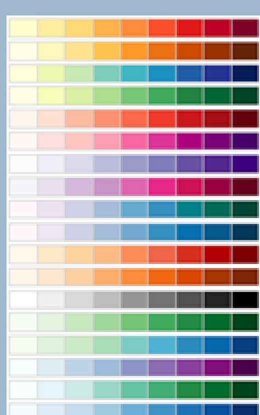
- Appalachia Population Change, 2000-2009
  - Blues indicate increased population.
  - Reds indicate decreased population.
- Values diverge around central value of 0, which indicates no change.



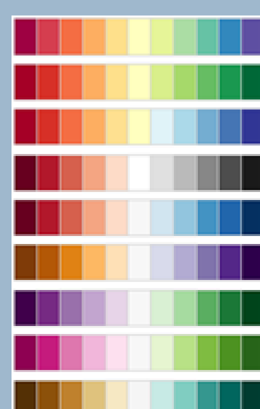
Created by the Appalachian Regional Commission, March 2011
Data Source: U.S. Census Bureau, 2009 Population Estimates

Quantitative Conventions

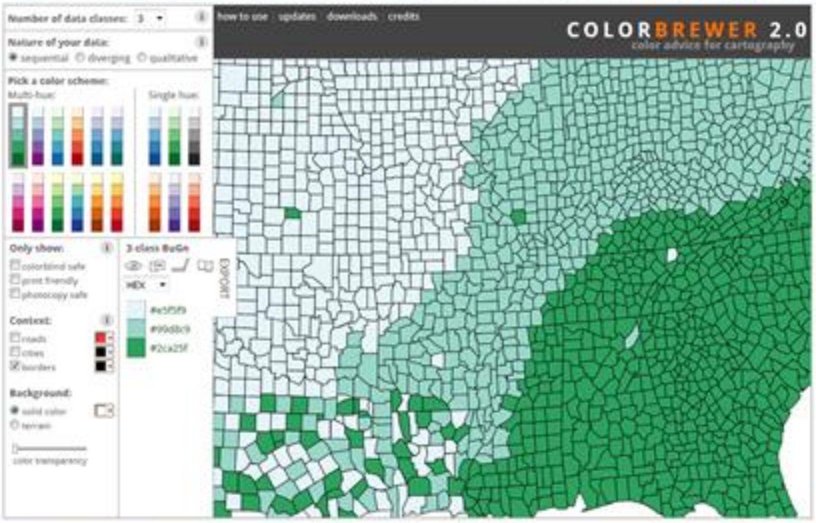
Sequential



Diverging

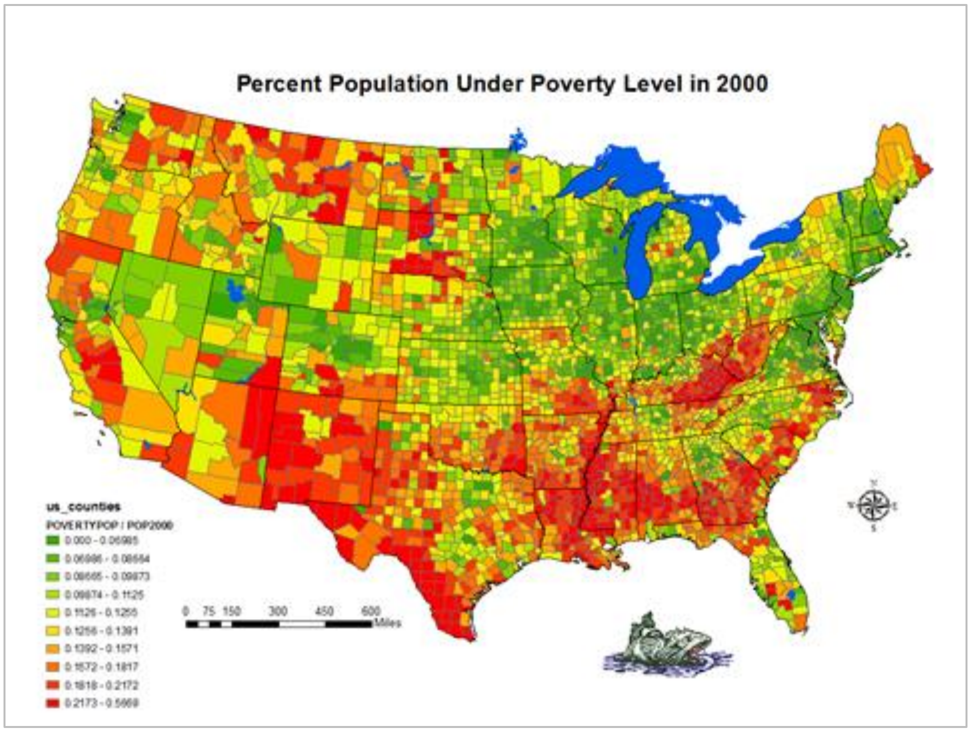


ColorBrewer, http://colorbrewer2.org/



Choosing a Color Ramp

- Color Brewer ramps already imported into QGIS.
- However, most GIS, if not all, do not know whether you need a diverging or sequential color scheme.
- It is up to YOU to make appropriate decision!
- An inappropriate color choice can be misleading.
  - Example…



Exercise 4
Color Ramps in QGIS

Part 5
Which color tip is most important?

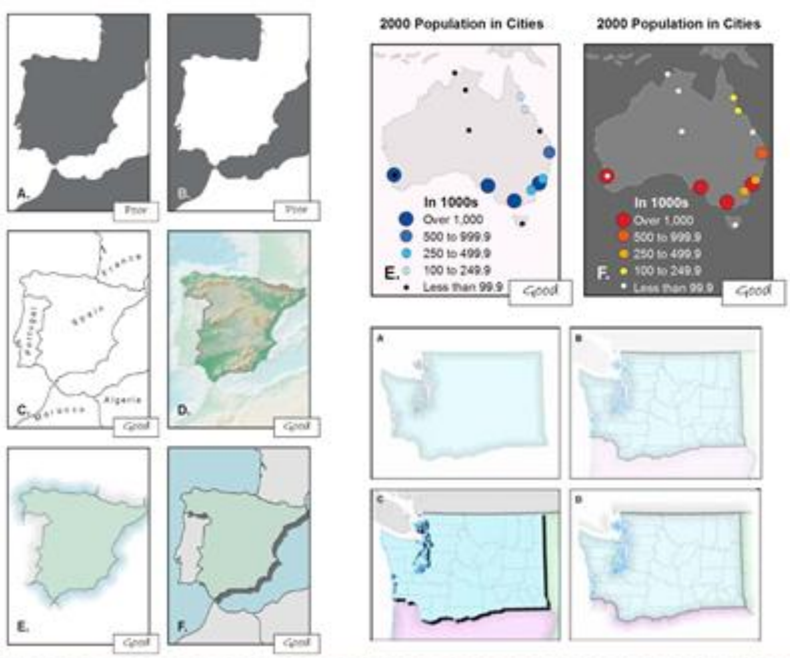
Tips for Combining Colors

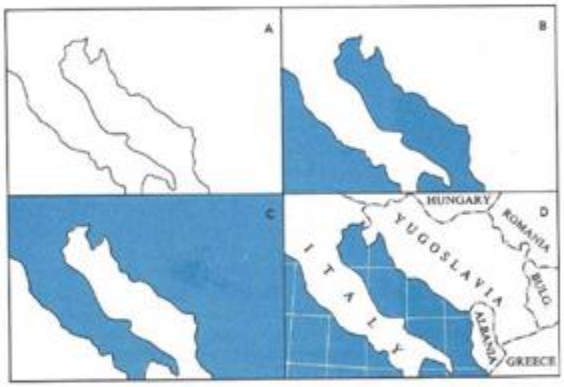
1. The most pleasant combinations result from large differences in **value**. **Value contrast** is necessary in pleasant **object-background** combinations.
2. A good **background color** must be either **light** or **dark**; being intermediate in lightness makes it poor.
3. Consistently **pleasant** object colors are hues in the green to blue range, or other hues containing little gray.
4. Consistently **unpleasant** object colors are in the yellow to yellowish-green range, or other hues containing considerable gray.
5. To be pleasant, an **object** color must stand out from its **background** color by being definitely **lighter** or **darker**.
6. **Vivid colors** combined with **grayish colors** tend to be judged as pleasant (i.e. **saturation** contrast).
7. Good and poor combinations are found for all sizes of **hue** differences (that is, distances apart on the color wheel).

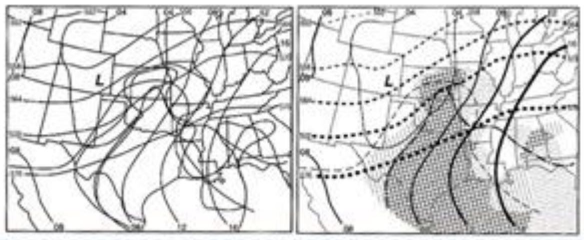
- Source: *Cartography: Thematic Map Design*, 6th edition by Dent, et al. (2009)

Trend: "Figure-Ground Relationship"

- Sometimes termed "object" and "background".
- Not everything is equally important *visually*.
- Figure out what is important to emphasize!
  - Make the important things STAND OUT.
  - Make the less important things fade into the background…
- Figure-ground relationship is established with good CONTRAST.
- Examples…

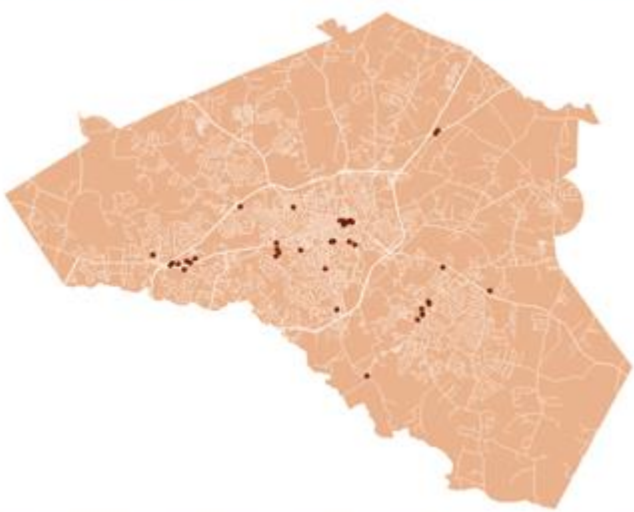






Review: Exercises 1 & 2

Pizza Restaurants in Athens, GA

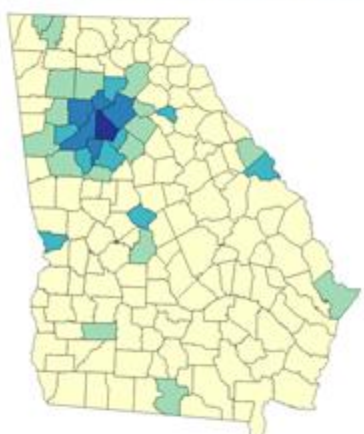


Review: Exercise 3

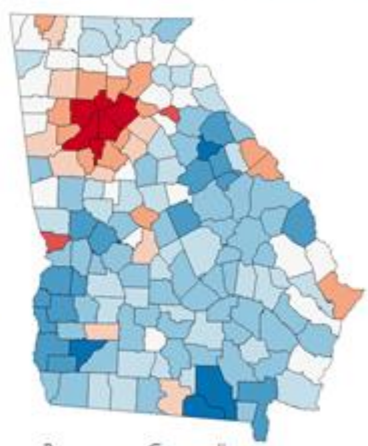
South Carolina (a reference map)

Review: Exercise 4

Population Density in Georgia



Population Density (sequential color scheme)



Percentage Greater/Less than Average Population Density (diverging color scheme)


Post-Workshop Survey
Complete the Post-Workshop Survey before you leave!
Thank you so much for attending this workshop!
Seriously, THANK YOU!!!

APPENDIX L

POST-WORKSHOP SURVEY

Section 1

Please enter your access code here: ____________________

Section 2

Please indicate your level of agreement with the following statements:

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
This workshop was focused on participants' learning.	○	○	○	○	○
This workshop stimulated my critical thinking.	○	○	○	○	○
This workshop has changed the way I think about map color.	○	○	○	○	○
QGIS was an appropriate software choice for this workshop.	○	○	○	○	○

Please elaborate upon your answers here:

____

____

____

Would you be able to apply what you have learned in this workshop, if you needed to make a map in the future?

- Yes
- No

If yes, how do you imagine you would use what you have learned?

____

____

____

If no, why not?

____

____

____

Section 3

As a result of this workshop, I better understand the following concepts related to color:

Please indicate your level of agreement.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Color in the Electromagnetic Spectrum	○	○	○	○	○
Perceiving Color with the Human Eye	○	○	○	○	○
Color Blindness	○	○	○	○	○
Additive Color Theory and the RGB Color Model	○	○	○	○	○
Subtractive Color Theory and the CMYK Color Model	○	○	○	○	○
Perceptual Dimensions: Hue, Saturation, and Value	○	○	○	○	○
Color Mixing	○	○	○	○	○
Color Preferences and Connotations	○	○	○	○	○
Color Conventions	○	○	○	○	○
Sequential vs. Diverging Color Schemes	○	○	○	○	○
Color Contrast	○	○	○	○	○
Figure-Ground Relationship	○	○	○	○	○

Please elaborate upon your answers here:

____

____

____

Section 4

Using the QGIS software was beneficial for helping me learn about the following concepts related to color:

Please indicate your level of agreement.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Color in the Electromagnetic Spectrum	○	○	○	○	○
Perceiving Color with the Human Eye	○	○	○	○	○
Color Blindness	○	○	○	○	○
Additive Color Theory and the RGB Color Model	○	○	○	○	○
Subtractive Color Theory and the CMYK Color Model	○	○	○	○	○
Perceptual Dimensions: Hue, Saturation, and Value	○	○	○	○	○
Color Mixing	○	○	○	○	○
Color Preferences and Connotations	○	○	○	○	○
Color Conventions	○	○	○	○	○
Sequential vs. Diverging Color Schemes	○	○	○	○	○
Color Contrast	○	○	○	○	○
Figure-Ground Relationship	○	○	○	○	○

Please elaborate upon your answers here:

____

____

____

Section 5

Overall, did the use of QGIS benefit or inhibit your learning of the content covered in this workshop?

- benefit
- inhibit

Please elaborate.

____

____

____

Would you be interested in taking a class that utilized QGIS as its primary software of choice?

- Yes
- Maybe
- No

Why?

____

____

____

Do you have any general opinions on the use of free and open source software for GIS?

- Yes
- No

If yes, please elaborate.

____

____

____

Please provide suggestions for how this workshop could be improved.

If you have any additional comments, please provide them here.

APPENDIX M

CODING PARTICIPANTS' CHARACTERISTICS AND EXPERIENCE

Each workshop participant filled out a pre-workshop survey that asked for seven categories of information about the participant and their background experience relevant to the workshop content. These categories were coded as follows:

1. Female (F), Male (M), and Other (O)
2. Undergraduate Student (U) or Graduate Student (G)
3. Freshman (1), Sophomore (2), Junior (3), Senior (4), Other (O), Master's (M), Ph.D. (P)
4. QGIS Experience: No (X) or Yes (Q)
5. ArcGIS Experience: No (X) or Yes (A)
6. Relevant Coursework: No (N) or Yes (Y)
7. Color Familiarity: (1), (2), (3), (4), or (5)

Using this, a seven-character alphanumeric code was generated for each participant. For example, a participant code MGPXAY4 would indicate a participant that is male, a graduate student, specifically a Ph.D. student, without QGIS experience, with ArcGIS experience, who has taken at least one course, and considers his familiarity with color concepts a 4 (on a scale of 1 to 5).

With this in mind, counts of each unique participant code were generated to gain a sense of the similarities among participants' characteristics and levels of experience. Figure M.1 illustrates the results graphically:

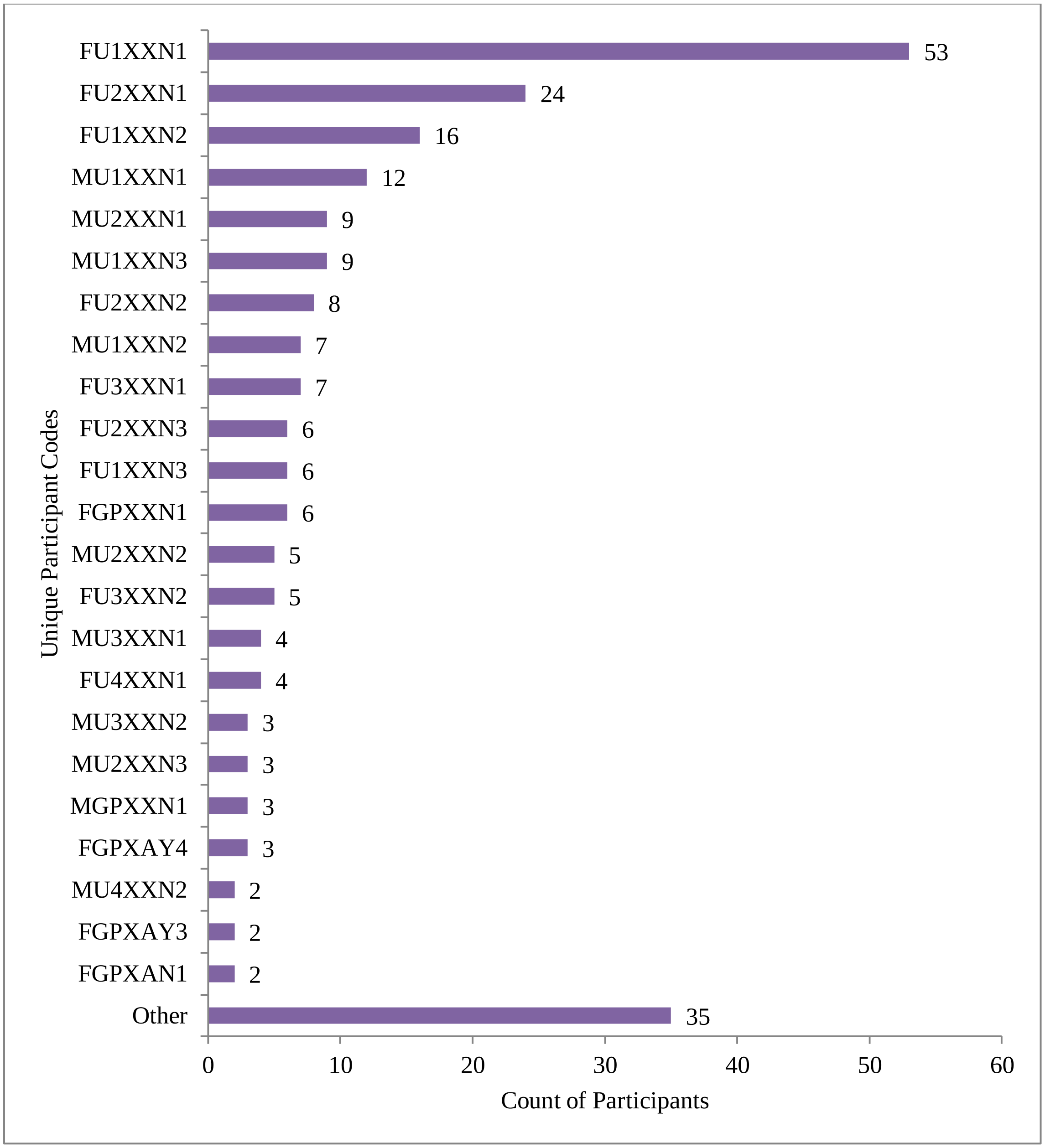


Figure M.1 Count of alphanumeric participant codes generated from participant characteristics and background experience relevant to the workshop.[51]

[51] Other encompasses FGMQAY1, FGMQAY4, FGMXAY4, FGMXXN2, FGMXXN3, FGPQAY1, FGPQAY2, FGPXAY1, FGPXAY2, FGPXXN2, FU2QAN4, FU2XXY1, FU3XXN4, FU4QAY3, FU4QAY4, FU4XAY3, FU4XXN3, FUOXAY4, MGMQAY4, MGMQAY5, MGMXAY2, MGMXAY4, MGMXXN1, MGPQAY4, MGPQAY5, MGPXAY5, MGPXXN2, MGPXXN3, MU2XXN5, MU3XAY4, MU3XXN3, MU4QAN5, MU4XAY4, MU4XXN1, OU2XXN1, which each had a count of 1.

As indicated in Figure M.1, female freshmen with no GIS experience, relevant coursework, or familiarity with color were a substantial portion of the workshop participants totaling 53 (22.64%) of the 234 total participants, but they did not constitute a majority.

APPENDIX N

MEANS OF POST-WORKSHOP SURVEY RESPONSES

This appendix contains the means of all participants' responses to the post-workshop survey's closed-ended questions. Table N.1 contains an explanation of the column headers used in Tables N.2-N.4. Tables N.2-N.4 are colored as follows: Likert-scale questions' means are blue as shown here:

<4
4 to 4.5
>4.5

Yes/Maybe/No questions' means are orange as shown here:

<-0.5
-0.5 to -0.01
0 to 0.5
> 0.5

(continues on next page…)

Table N.1 Explanation of table column headers, including original question or concept, question type, and question category from the post-workshop survey.

Abbreviation	Original Question or Concept	Type	Category
plearning	This workshop was focused on participants' learning.	Likert scale	Substantial Learning
cthinking	This workshop stimulated my critical thinking.	Likert scale	Substantial Learning
changethink	This workshop has changed the way I think about map color.	Likert scale	Substantial Learning
QGISchoice	QGIS was an appropriate software choice for this workshop.	Likert scale	QGIS
apply	Would you be able to apply what you have learned in this workshop, if you needed to make a map in the future?	Yes/No	Substantial Learning
BorI	Overall, did the use of QGIS benefit or inhibit your learning of the content covered in this workshop?	Yes/No	QGIS
CourseInt	Would you be interested in taking a class that utilized QGIS as its primary software of choice?	Yes/Maybe/No	QGIS
Opinions	Do you have any general opinions on the use of free and open source software for GIS?	Yes/No	QGIS
EMS	Color in the Electromagnetic Spectrum	Likert	Concept
eye	Perceiving Color with the Human Eye	Likert	Concept
cblind	Color Blindness	Likert	Concept
RGB	Additive Color Theory and the RGB Color Model	Likert	Concept
CMYK	Subtractive Color Theory and the CMYK Color Model	Likert	Concept
HSV	Perceptual Dimensions: Hue, Saturation, and Value	Likert	Concept
cmixing	Color Mixing	Likert	Concept
prefconn	Color Preferences and Connotations	Likert	Concept
cnvntns	Color Conventions	Likert	Concept
quant	Sequential vs. Diverging Color Schemes	Likert	Concept
contrast	Color Contrast	Likert	Concept
FGrelat	Figure-Ground Relationship	Likert	Concept

Table N.2 Mean responses for substantial learning and QGIS questions.

Category	Count	plearning	cthinking	changethink	QGISchoice	apply	…	BorI	CourseInt	Opinions
Gender - Female	160	4.63	4.31	4.44	4.78	0.98	…	0.98	-0.03	-0.46
Gender - Male	73	4.64	4.21	4.34	4.73	0.92	…	1.00	0.18	-0.23
Freshman	103	4.74	4.41	4.46	4.78	0.94	…	0.98	-0.15	-0.61
Sophomore	59	4.51	4.22	4.46	4.71	0.97	…	0.97	-0.07	-0.56
Junior	22	4.68	4.23	4.36	4.77	0.91	…	1.00	-0.05	-0.55
Senior	13	4.77	4.23	4.46	4.77	1.00	…	1.00	0.23	-0.38
Undergraduates (all)	198	4.67	4.32	4.44	4.76	0.95	…	0.98	-0.08	-0.57
Master’s	10	4.60	4.10	4.30	5.00	1.00	…	1.00	0.90	0.80
Ph.D.	26	4.42	4.04	4.23	4.69	1.00	…	1.00	0.62	0.46
Graduate Students (all)	36	4.47	4.06	4.25	4.78	1.00	…	1.00	0.69	0.56
GIS experience - No	205	4.65	4.29	4.43	4.76	0.95	…	0.98	-0.05	-0.55
GIS experience - Yes	29	4.52	4.17	4.28	4.76	1.00	…	1.00	0.69	0.72
Relevant Course - No	208	4.65	4.30	4.45	4.76	0.95	…	0.98	-0.04	-0.52
Relevant Course - Yes	26	4.50	4.08	4.15	4.73	1.00	…	1.00	0.65	0.62
Color Familiarity - 1	131	4.72	4.41	4.47	4.77	0.94	…	0.97	-0.01	-0.56
Color Familiarity - 2	52	4.54	4.08	4.48	4.79	0.96	…	1.00	-0.04	-0.46
Color Familiarity - 3	32	4.44	4.06	4.25	4.63	1.00	…	1.00	-0.03	-0.19
Color Familiarity - 4	14	4.71	4.36	4.21	4.86	1.00	…	1.00	0.71	0.43
Color Familiarity - 5	5	4.60	4.00	4.00	4.80	1.00	…	1.00	0.60	1.00
ALL PARTICIPANTS	234	4.64	4.28	4.41	4.76	0.96	…	0.98	0.04	-0.39

Table N.3 Mean responses for "As a result of this workshop, I better understand the following concepts of color."

Category	Count	EMS	eye	cblind	RGB	CMYK	HSV	cmixing	prefconn	cnvntns	quant	contrast	FGrelat
Gender - Female	160	4.31	4.41	4.36	4.33	4.28	4.58	4.52	4.59	4.47	4.61	4.54	4.36
Gender - Male	73	4.26	4.25	4.37	4.45	4.42	4.52	4.42	4.42	4.40	4.58	4.48	4.36
Freshman	103	4.45	4.50	4.43	4.36	4.30	4.55	4.59	4.58	4.52	4.60	4.59	4.30
Sophomore	59	4.36	4.36	4.41	4.34	4.27	4.59	4.44	4.46	4.34	4.59	4.51	4.42
Junior	22	4.14	4.27	4.18	4.23	4.27	4.45	4.55	4.59	4.50	4.64	4.50	4.59
Senior	13	4.08	4.08	4.15	4.31	4.31	4.38	4.23	4.38	4.15	4.31	4.46	4.15
Undergraduates (all)	198	4.36	4.40	4.37	4.34	4.29	4.55	4.52	4.54	4.44	4.59	4.55	4.36
Master's	10	4.20	4.20	4.50	4.50	4.60	4.80	4.40	4.60	4.40	4.60	4.50	4.50
Ph.D.	26	3.85	4.12	4.27	4.50	4.42	4.58	4.27	4.50	4.46	4.69	4.35	4.31
Graduate Students (all)	36	3.94	4.14	4.33	4.50	4.47	4.64	4.31	4.53	4.44	4.67	4.39	4.36
GIS experience - No	205	4.34	4.39	4.37	4.33	4.29	4.55	4.50	4.54	4.45	4.60	4.54	4.38
GIS experience - Yes	29	3.97	4.17	4.34	4.59	4.55	4.62	4.41	4.48	4.38	4.59	4.41	4.24
Relevant Course - No	208	4.36	4.39	4.38	4.35	4.30	4.56	4.50	4.55	4.47	4.61	4.55	4.39
Relevant Course - Yes	26	3.81	4.08	4.23	4.50	4.46	4.54	4.35	4.38	4.27	4.50	4.35	4.12
Color Familiarity - 1	131	4.39	4.44	4.42	4.33	4.27	4.55	4.52	4.62	4.54	4.60	4.59	4.44
Color Familiarity - 2	52	4.21	4.35	4.25	4.33	4.29	4.63	4.50	4.48	4.37	4.62	4.46	4.29
Color Familiarity - 3	32	4.16	4.16	4.34	4.34	4.31	4.41	4.34	4.34	4.22	4.56	4.44	4.22
Color Familiarity - 4	14	3.93	4.14	4.29	4.71	4.71	4.64	4.43	4.43	4.29	4.57	4.43	4.29
Color Familiarity - 5	5	4.60	4.40	4.60	4.80	4.80	4.80	4.60	4.40	4.60	4.60	4.40	4.40
ALL PARTICIPANTS	234	4.29	4.36	4.37	4.36	4.32	4.56	4.49	4.53	4.44	4.60	4.53	4.36

Table N.4 Mean responses for "Using the QGIS software was beneficial for helping me learn about the following concepts related to color."

Category	Count	EMS	eye	cblind	RGB	CMYK	HSV	cmixing	prefconn	cnvntns	quant	contrast	FGrelat
Gender - Female	160	4.27	4.23	4.11	4.39	4.34	4.53	4.53	4.43	4.41	4.59	4.57	4.41
Gender - Male	73	4.15	4.18	4.16	4.30	4.30	4.52	4.45	4.38	4.36	4.59	4.42	4.41
Freshman	103	4.40	4.35	4.29	4.46	4.40	4.55	4.59	4.53	4.45	4.62	4.56	4.43
Sophomore	59	4.31	4.27	4.17	4.34	4.34	4.54	4.47	4.32	4.32	4.56	4.47	4.49
Junior	22	4.32	4.32	4.18	4.32	4.36	4.55	4.55	4.45	4.55	4.68	4.59	4.36
Senior	13	4.08	3.85	3.62	4.23	4.38	4.54	4.54	4.54	4.46	4.38	4.54	3.92
Undergraduates (all)	198	4.33	4.29	4.20	4.39	4.37	4.55	4.55	4.46	4.42	4.60	4.54	4.41
Master's	10	3.70	3.70	3.50	4.40	4.10	4.80	4.60	4.30	4.60	4.60	4.20	4.50
Ph.D.	26	3.69	3.85	3.88	4.19	4.12	4.27	4.12	4.08	4.08	4.54	4.54	4.38
Graduate Students (all)	36	3.69	3.81	3.78	4.25	4.11	4.42	4.25	4.14	4.22	4.56	4.44	4.42
GIS experience - No	205	4.32	4.27	4.18	4.37	4.34	4.53	4.51	4.43	4.40	4.60	4.54	4.43
GIS experience - Yes	29	3.66	3.79	3.79	4.34	4.28	4.55	4.45	4.28	4.38	4.48	4.41	4.28
Relevant Course - No	208	4.32	4.28	4.19	4.38	4.36	4.54	4.52	4.45	4.41	4.62	4.55	4.44
Relevant Course - Yes	26	3.54	3.65	3.65	4.23	4.15	4.46	4.35	4.15	4.27	4.38	4.35	4.15
Color Familiarity - 1	131	4.35	4.28	4.18	4.37	4.34	4.59	4.60	4.49	4.44	4.63	4.60	4.49
Color Familiarity - 2	52	4.17	4.19	4.15	4.42	4.37	4.52	4.37	4.35	4.38	4.67	4.58	4.37
Color Familiarity - 3	32	4.09	4.03	4.06	4.16	4.16	4.19	4.22	4.25	4.19	4.41	4.25	4.13
Color Familiarity - 4	14	3.79	4.00	3.86	4.43	4.43	4.71	4.79	4.50	4.50	4.50	4.50	4.50
Color Familiarity - 5	5	4.00	4.40	4.00	4.80	4.80	4.80	4.60	4.00	4.20	4.20	4.00	4.40
ALL PARTICIPANTS	234	4.24	4.21	4.13	4.37	4.33	4.53	4.50	4.41	4.39	4.59	4.53	4.41

APPENDIX O

COMPARING PARTICIPANTS' CHARACTERISTICS AND EXPERIENCE

The tables on the following pages show the results of performing t-tests and chi-squared tests to compare results based on participants' characteristics and background experience.

Important to note:

- The significance threshold for these tests is $p \leq 0.05$. Results that are statistically significant according to this threshold are shaded.
- Blanks indicate no data in one of the categories to be compared.
- NA indicates tests that failed due to "essentially constant data."
- A p-value of 0 does not represent true 0; it represents a small value unable to be represented by four decimal places.
- For the color familiarity variable, 1 is compared against 2, 3, 4, and 5 combined.
- For an explanation of the column headers, see Table N.1 of Appendix N.

(continues on next page…)

Table O.1 Results of t-tests for substantial learning and QGIS questions. Statistically significant values ($p \leq 0.05$) are shaded.

Category	**plearning**	**cthinking**	**changethink**	**QGISchoice**	**apply**	**…**	**BorI**	**CourseInt**	**Opinions**
Male vs. Female	0.8956	0.3480	0.3770	0.5717	0.2556	…	0.1579	0.0360	0.0901
Undergrad vs. Grad	0.1049	0.0845	0.1739	0.8050	0.0250	…	0.1578	0.0000	0.0000
Freshman vs. Sophomore	0.0576	0.1928	0.9927	0.5716	0.6091	..	0.7117	0.4954	0.6971
Freshman vs. Junior	0.6700	0.2811	0.6571	0.9740	0.7385	…	0.3197	0.5196	0.7417
Freshman vs. Senior	0.8133	0.3461	0.9793	0.9546	0.0833	…	0.3197	0.0512	0.4272
Sophomore vs. Junior	0.2921	0.9710	0.6819	0.6948	0.5617	…	0.3215	0.8946	0.9484
Sophomore vs. Senior	0.1197	0.9599	0.9860	0.7239	0.3215	…	0.3215	0.1325	0.5523
Junior vs. Senior	0.6142	0.9875	0.7149	0.9833	0.3287	…		0.2134	0.6234
Master's vs. Ph.D.	0.4165	0.8104	0.7979	0.0027		…		0.0680	0.2179
GIS experience Y/N	0.2845	0.4341	0.3250	0.9793		…	0.1578	0.0000	0.0000
Relevant Course Y/N	0.2180	0.1583	0.0830	0.7310		…	0.1578	0.0000	0.0000
Color Familiarity	0.0280	0.0046	0.2831	0.7520	0.2471	…	0.1581	0.2672	0.0025

Table O.2 Results of chi-squared tests for substantial learning and QGIS questions. Statistically significant values ($p \leq 0.05$) are shaded.

Category	**plearning**	**cthinking**	**changethink**	**QGISchoice**	**apply**	**…**	**BorI**	**CourseInt**	**Opinions**
Male vs. Female	0.0705	0.4065	0.3196	0.3584	0.3669	…	0.8432	0.0514	0.0918
Undergrad vs. Grad	0.1029	0.1244	0.0791	0.5121	0.7305	…	1.0000	0.0000	0.0000
Undergrad Year	0.6013	0.3753	0.9150	0.5122	0.8240	…	0.8854	0.5538	0.8069
Master's vs. Ph.D.	0.5323	0.3250	0.8798	NA	NA	…	NA	0.3268	0.5180
GIS Experience Y/N	0.3044	0.5089	0.4139	0.4465	0.8858	…	1.0000	0.0000	0.0000
Relevant Course Y/N	0.1288	0.1641	0.0575	0.3119	0.9549	…	1.0000	0.0000	0.0000
Color Familiarity	0.0190	0.0014	0.3904	0.9535	0.4408	…	0.4532	0.2238	0.0002

Table O.3 Results of t-tests for "As a result of this workshop, I better understand the following concepts of color." Statistically significant values ($p \leq 0.05$) are shaded.

Category	**EMS**	**eye**	**cblind**	**RGB**	**CMYK**	**HSV**	**cmixing**	**prefconn**	**cnvntns**	**quant**	**contrast**	**FGrelat**
Male vs. Female	0.6219	0.1236	0.9419	0.2004	0.1434	0.4691	0.2815	0.0707	0.4221	0.7148	0.4631	0.9485
Undergrad vs. Grad	0.0069	0.0615	0.7594	0.2109	0.1852	0.3113	0.0782	0.9453	1.0000	0.4176	0.2143	0.9840
Freshman vs. Sophomore	0.4505	0.2280	0.8629	0.8672	0.8040	0.6593	0.1155	0.2132	0.0794	0.9277	0.3987	0.3072
Freshman vs. Junior	0.0474	0.1445	0.3072	0.4310	0.8764	0.5608	0.7385	0.9521	0.8642	0.8055	0.5126	0.0363
Freshman vs. Senior	0.0684	0.0422	0.1992	0.7910	0.9723	0.3876	0.1054	0.2105	0.0056	0.1334	0.4099	0.4884
Sophomore vs. Junior	0.2036	0.6172	0.3629	0.5220	0.9935	0.4262	0.4856	0.3792	0.3007	0.7659	0.9556	0.2336
Sophomore vs. Senior	0.1877	0.1825	0.2500	0.8759	0.8557	0.2964	0.3447	0.6574	0.1801	0.1508	0.7794	0.2161
Junior vs. Senior	0.7928	0.3880	0.9250	0.7269	0.8849	0.7724	0.1997	0.2832	0.0432	0.1383	0.8428	0.0601
Master's vs. Ph.D.	0.2516	0.7444	0.3171	1.0000	0.4441	0.1943	0.5516	0.6340	0.7690	0.6429	0.5721	0.3921
GIS experience Y/N	0.0319	0.1382	0.8582	0.0706	0.0789	0.4934	0.4666	0.6114	0.5143	0.9118	0.3102	0.3744
Relevant Course Y/N	0.0023	0.0340	0.3092	0.3058	0.3219	0.8247	0.1882	0.1682	0.0905	0.4139	0.1312	0.0882
Color Familiarity	0.0263	0.0599	0.2248	0.4089	0.2815	0.7589	0.3668	0.0149	0.0061	0.8893	0.0817	0.0931

Table O.4 Results of chi-squared tests for "As a result of this workshop, I better understand the following concepts of color." Statistically significant values ($p \leq 0.05$) are shaded.

Category	**EMS**	**eye**	**cblind**	**RGB**	**CMYK**	**HSV**	**cmixing**	**prefconn**	**cnvntns**	**quant**	**contrast**	**FGrelat**
Male vs. Female	0.8758	0.3073	0.1657	0.5535	0.2102	0.7564	0.5071	0.1897	0.4888	0.9070	0.6741	0.4937
Undergrad vs. Grad	0.0007	0.0154	0.8755	0.3453	0.2851	0.3805	0.1190	0.9161	0.9980	0.7375	0.4700	0.9629
Undergrad Year	0.1919	0.2362	0.4528	0.7163	0.8897	0.4305	0.3582	0.4324	0.0324	0.5244	0.7180	0.2309
Master's vs. Ph.D.	0.5329	0.3344	0.3034	0.4331	0.5104	NA	0.6627	0.6591	0.4066	0.5202	0.6786	0.4082
GIS Experience Y/N	0.0023	0.2017	0.9277	0.1750	0.1289	0.4693	0.3220	0.5815	0.3204	0.8062	0.4276	0.1874
Relevant Course Y/N	0.0002	0.0564	0.5036	0.4179	0.5474	0.2465	0.1092	0.1251	0.0368	0.5437	0.1614	0.0523
Color Familiarity	0.1781	0.0428	0.2179	0.6096	0.4428	0.6598	0.2425	0.0524	0.0116	0.7792	0.4332	0.3675

Table O.5 Results of t-tests for "Using the QGIS software was beneficial for helping me learn about the following concepts related to color." Statistically significant values ($p \leq 0.05$) are shaded.

Category	EMS	eye	cblind	RGB	CMYK	HSV	cmixing	prefconn	cnvntns	quant	contrast	FGrelat
Male vs. Female	0.3365	0.6988	0.6793	0.3596	0.6891	0.9002	0.4229	0.6909	0.6395	0.9848	0.0978	0.9612
Undergrad vs. Grad	0.0010	0.0021	0.0128	0.2939	0.0890	0.3039	0.0538	0.0514	0.2206	0.7117	0.4113	0.9472
Freshman vs. Sophomore	0.4727	0.5276	0.3829	0.2680	0.6100	0.9078	0.2118	0.0717	0.3036	0.5161	0.3486	0.5686
Freshman vs. Junior	0.6123	0.8734	0.6513	0.4464	0.8292	0.9590	0.7397	0.6431	0.5348	0.6048	0.8400	0.7472
Freshman vs. Senior	0.1138	0.0987	0.0094	0.2251	0.9458	0.9239	0.7332	0.9776	0.9259	0.1364	0.8744	0.0879
Sophomore vs. Junior	0.9403	0.8184	0.9611	0.9114	0.8829	0.9850	0.6326	0.4793	0.2088	0.3428	0.4366	0.5267
Sophomore vs. Senior	0.2823	0.1635	0.0325	0.5667	0.8231	0.9812	0.6974	0.2256	0.4348	0.2890	0.7003	0.0593
Junior vs. Senior	0.2933	0.1629	0.0767	0.7126	0.9276	0.9727	0.9712	0.6967	0.6821	0.0993	0.7858	0.1825
Master's vs. Ph.D.	0.9846	0.6713	0.2490	0.3679	0.9658	0.0137	0.1025	0.5346	0.0511	0.7690	0.2392	0.6517
GIS experience Y/N	0.0004	0.0130	0.0508	0.8640	0.7151	0.8427	0.6587	0.3184	0.9135	0.3312	0.3422	0.3559
Relevant Course Y/N	0.0001	0.0017	0.0090	0.3346	0.2915	0.5685	0.2524	0.0797	0.3626	0.0877	0.1615	0.1018
Color Familiarity	0.0186	0.1542	0.4079	0.8678	0.9532	0.1040	0.0164	0.0923	0.2506	0.2721	0.0367	0.0658

Table O.6 Results of chi-squared tests for "Using the QGIS software was beneficial for helping me learn about the following concepts related to color." Statistically significant values ($p \leq 0.05$) are shaded.

Category	EMS	eye	cblind	RGB	CMYK	HSV	cmixing	prefconn	cnvntns	quant	contrast	FGrelat
Male vs. Female	0.6350	0.9905	0.8863	0.4616	0.8690	0.9858	0.5724	0.9236	0.5764	0.7546	0.0566	0.6146
Undergrad vs. Grad	0.0002	0.0013	0.0036	0.5381	0.1353	0.0594	0.0000	0.0950	0.5323	0.6229	0.3206	0.3875
Undergrad Year	0.5136	0.0530	0.0705	0.6699	0.9303	0.7446	0.7486	0.3261	0.5950	0.3343	0.8154	0.1834
Master's vs. Ph.D.	0.8168	0.8438	0.4357	0.4026	0.9410	0.1411	0.3104	0.5534	0.2610	0.6198	0.2600	0.3984
GIS Experience Y/N	0.0004	0.0069	0.0409	0.6754	0.1918	0.8544	0.1216	0.2102	0.7134	0.3102	0.1322	0.2690
Relevant Course Y/N	0.0000	0.0007	0.0074	0.6380	0.2803	0.7471	0.0817	0.0178	0.2050	0.0760	0.0610	0.0818
Color Familiarity	0.0226	0.3194	0.5377	0.7767	0.7514	0.1237	0.1411	0.1170	0.5050	0.0956	0.0198	0.1149

APPENDIX P

COMPARING PARTICIPANTS' LEARNING OF COLOR CONCEPTS

The tables on the following pages show the results of performing t-tests to compare participants' responses to the color concept questions, "As a result of this workshop, I better understand the following concepts of color," and "Using the QGIS software was beneficial for helping me learn about the following concepts related to color." Each table is ordered from highest mean response and lowest mean response, both from top to bottom and from left to right. The tables are colored according to three different significance thresholds as shown here:

$p \leq 0.05$
$p \leq 0.01$
$p \leq 0.001$

For an explanation of the column headers, see Table N.1 of Appendix N.

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Table P.1 Results of t-tests comparing color concepts from "As a result of this workshop, I better understand the following concepts of color." Statistically significant values are shaded lightly ($p \leq 0.05$), moderately ($p \leq 0.01$), and darkly ($p \leq 0.001$).

Concept	Mean	quant	HSV	prefconn	contrast	cmixing	cnvntns	cblind	RGB	FGrelat	eye	CMYK	EMS
quant	4.60	-	0.4779	0.2438	0.1920	0.0464	0.0061	0.0003	0.0002	0.0002	0.0001	0.0000	0.0000
HSV	4.56	0.4779	-	0.6361	0.5334	0.1861	0.0367	0.0021	0.0014	0.0014	0.0007	0.0001	0.0000
prefconn	4.53	0.2438	0.6361	-	0.8779	0.3985	0.1087	0.0082	0.0059	0.0059	0.0035	0.0006	0.0001
contrast	4.53	0.1920	0.5334	0.8779	-	0.4948	0.1514	0.0129	0.0096	0.0096	0.0059	0.0011	0.0002
cmixing	4.49	0.0464	0.1861	0.3985	0.4948	-	0.4501	0.0596	0.0478	0.0478	0.0341	0.0080	0.0020
cnvntns	4.44	0.0061	0.0367	0.1087	0.1514	0.4501	-	0.2267	0.1955	0.1955	0.1585	0.0489	0.0165
cblind	4.37	0.0003	0.0021	0.0082	0.0129	0.0596	0.2267	-	0.9505	0.9505	0.8984	0.4958	0.2887
RGB	4.36	0.0002	0.0014	0.0059	0.0096	0.0478	0.1955	0.9505	-	1.0000	0.9485	0.5308	0.3119
FGrelat	4.36	0.0002	0.0014	0.0059	0.0096	0.0478	0.1955	0.9505	1.0000	-	0.9485	0.5308	0.3119
eye	4.36	0.0001	0.0007	0.0035	0.0059	0.0341	0.1585	0.8984	0.9485	0.9485	-	0.5614	0.3289
CMYK	4.32	0.0000	0.0001	0.0006	0.0011	0.0080	0.0489	0.4958	0.5308	0.5308	0.5614	-	0.7049
EMS	4.29	0.0000	0.0000	0.0001	0.0002	0.0020	0.0165	0.2887	0.3119	0.3119	0.3289	0.7049	-

Table P.2 Results of t-tests comparing color concepts from "Using the QGIS software was beneficial for helping me learn about the following concepts related to color." Statistically significant values are shaded lightly ($p \leq 0.05$), moderately ($p \leq 0.01$), and darkly ($p \leq 0.001$).

Concept	Mean	quant	HSV	contrast	cmixing	prefconn	FGrelat	cnvntns	RGB	CMYK	EMS	eye	cblind
quant	4.59	-	0.2683	0.2238	0.1256	0.0040	0.0031	0.0013	0.0001	0.0000	0.0000	0.0000	0.0000
HSV	4.53	0.2683	-	0.9373	0.6545	0.0631	0.0539	0.0281	0.0063	0.0017	0.0000	0.0000	0.0000
contrast	4.53	0.2238	0.9373	-	0.7028	0.0680	0.0580	0.0301	0.0066	0.0017	0.0000	0.0000	0.0000
cmixing	4.50	0.1256	0.6545	0.7028	-	0.1577	0.1387	0.0812	0.0247	0.0075	0.0001	0.0000	0.0000
prefconn	4.41	0.0040	0.0631	0.0680	0.1577	-	0.9496	0.7528	0.4707	0.2318	0.0137	0.0053	0.0002
FGrelat	4.41	0.0031	0.0539	0.0580	0.1387	0.9496	-	0.8010	0.5118	0.2571	0.0161	0.0063	0.0003
cnvntns	4.39	0.0013	0.0281	0.0301	0.0812	0.7528	0.8010	-	0.6946	0.3791	0.0301	0.0128	0.0006
RGB	4.37	0.0001	0.0063	0.0066	0.0247	0.4707	0.5118	0.6946	-	0.6008	0.0597	0.0269	0.0014
CMYK	4.33	0.0000	0.0017	0.0017	0.0075	0.2318	0.2571	0.3791	0.6008	-	0.1770	0.0964	0.0081
EMS	4.24	0.0000	0.0000	0.0000	0.0001	0.0137	0.0161	0.0301	0.0597	0.1770	-	0.7796	0.1992
eye	4.21	0.0000	0.0000	0.0000	0.0000	0.0053	0.0063	0.0128	0.0269	0.0964	0.7796	-	0.3045
cblind	4.13	0.0000	0.0000	0.0000	0.0000	0.0002	0.0003	0.0006	0.0014	0.0081	0.1992	0.3045	-