RETHINKING CARTOGRAPHY CURRICULUM TO TRAIN THE CONTEMPORARY CARTOGRAPHER

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Abstract
In this paper, I discuss my experience over the past five years restructuring the cartography curriculum at the University of Wisconsin–Madison to account for sweeping shifts in conceptual framings, mapping technologies, and professional expectations. To guide the refresh, I aligned the cartography curriculum to an orthogonal pair of axes: the traditional distinction in cartography between mapmaking and map use, and an emerging distinction between representation and interaction. A single course was designed to cover each of the four pairwise antipodes of the orthogonal axes, with a fifth course positioned at the intersection of these axes to integrate influences and technologies. In the paper, I discuss the pedagogical philosophy guiding the revised curriculum, the organization of design concepts and technical skills taught in each course, and lessons learned from my experience for keeping curriculum malleable as cartography continues to evolve.

Keywords*: cartography education, pedagogy, map design, UI/UX design, web mapping technology*

INTRODUCTION

Ongoing technological innovation has dramatically transformed what cartographers "do" over the past 25, 10, and 5 years [1-3]. Similarly, new insights from theoretical, empirical, and critical scholarship have reshaped the way we understand, study, and teach cartography [4-6]. Arguably, cartography's innate state of flux is what makes our professional both unique and valuable: as we engage in the design process, we are able to tinker, adlib, and adapt across a wide array of techniques in order to find an optimal solution for a specific mapping context [7]. In this way, we must embrace the day-to-day chaos of change on a micro-scale in order to keep nudging cartography forward on a macro-scale [8, 9].

Yet, it is easy for educators to be "swept up" by this whirlwind of change. While the increasing accessibility, flexibility, and interoperability of mapping technologies are generating exciting new opportunities in cartography, they are also expanding exponentially the range of technical competencies educators need to cover in curriculum [10]. Further, few empirically-derived first principles or time-tested best practices exist to inform thoughtful, effective, and ethical application of these emerging technologies during design [11]. For instance, the Geographic Information Science & Technology Body of Knowledge—an authoritative compendium of competencies for geospatial education [12]—was largely drafted before the release of Google Maps and the subsequent proliferation of web map mashups, and thus misses a now thriving area of research and development on interactive, online, and mobile map design. As a result, educators are faced with the challenge of replanning curriculum every semester or the risk of becoming stale. To what degree should we embrace versus overcome such planned obsolescence in cartographic education?

In this paper, I discuss my experience over the past five years to restructure the cartography curriculum at the University of Wisconsin–Madison in order to account for these sweeping shifts in conceptual framings, mapping technologies, and professional expectations. The paper is meant to serve as an anecdotal case study on pedagogy in the context of rapid cartographic change, with reflections on my experience offered to inform, rather than prescribe, curricular redesign given that all campuses and programs have different curricular needs and constraints. The intention of this paper also is to offer broad insights about organizing and executing a comprehensive cartography curriculum, and I provide only brief comments on the development trajectory of individual cartography courses. In the following sections, I discuss the pedagogical philosophy guiding the revised curriculum, the organization of design concepts and technical skills taught in each course, and lessons learned from my experience for keeping curriculum malleable as cartography continues to evolve.

BACKGROUND AND PHILOSOPHY

The cartography curriculum at UW-Madison dates to 1937 and was expanded rapidly after Arthur Robinson joined the UW Geography faculty following the end of World War II [5, 13]. Today, the cartography curriculum sits within a campus-wide array of courses covering geospatial data, GIS, remote sensing, and spatial statistics. Five of these courses are fully or partially dedicated to cartography instruction (Figure 1: yellow). Teaching cartography at UW is both exciting and challenging because the cartography curriculum supports six different degree programs:

1. Undergraduate Major in Geography: Students must select between an intermediate course in cartography or GIS as a breadth requirement;
2. Undergraduate Major in Cartography & GIS: Students must complete one intermediate course in cartography and select two advanced cartography or GIS electives;
3. One-year Post-Baccalaureate GIS Certificate: Students must complete one intermediate course in cartography and select two advanced cartography or GIS electives;
4. Resident Masters in Cartography & GIS: Students must complete one intermediate course in cartography, one graduate seminar in cartography or GIS, and select two advanced cartography or GIS electives;
5. Online Masters in GIS & Web Map Programming: Students must complete two advanced courses in cartography in addition to other required GIS and geocomputation coursework;
6. PhD in Geography: Students must complete two graduate seminars in cartography, GIScience, or geography, and may complete additional coursework in cartography based on the dissertation focus and background deficiencies.

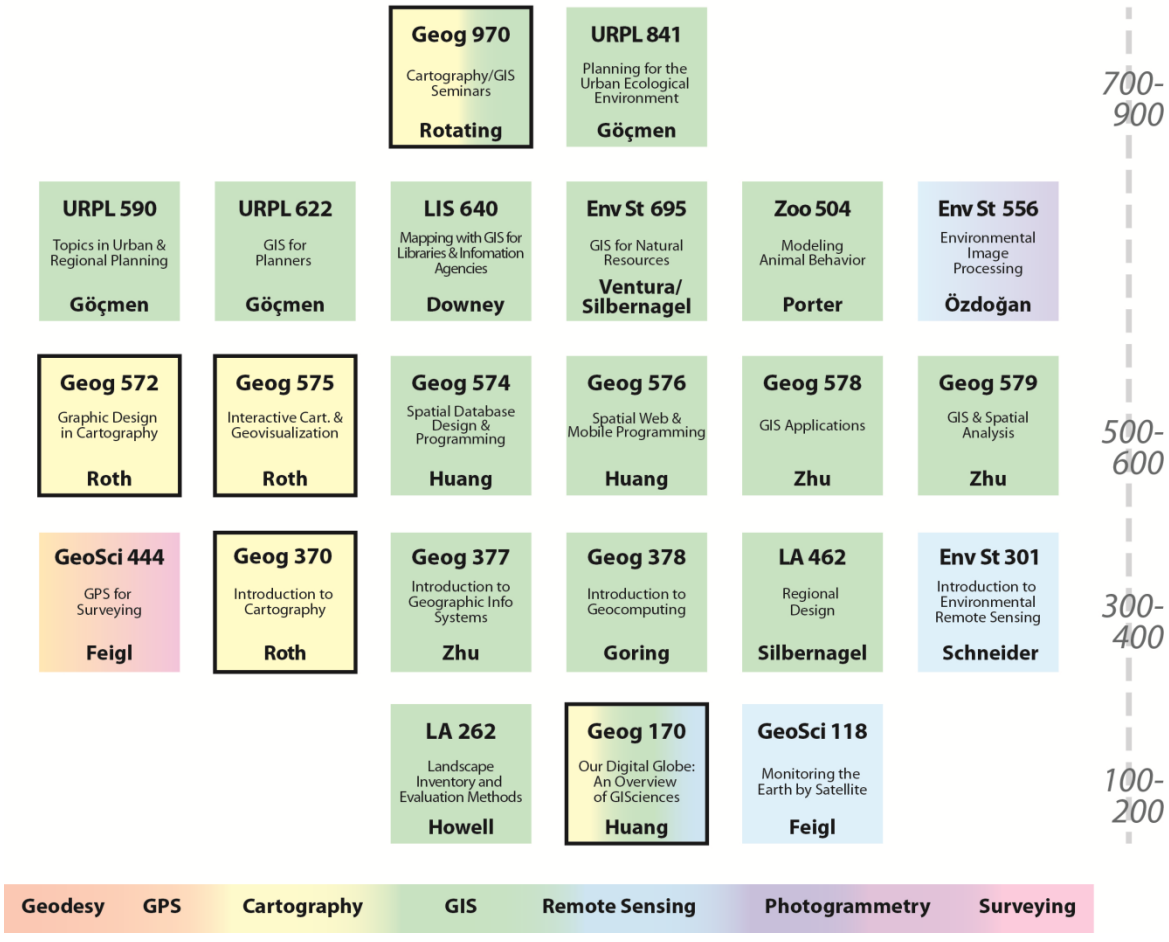

Figure 1. GIScience at UW-Madison, 2015-2016. The cartography curriculum sits within a campus-wide array of courses covering geospatial data, GIS, remote sensing, and spatial statistics. Cartography courses are marked in yellow. Image courtesy of Karen Tuerk.

To support this diverse range of learners, I redesigned the cartography courses to follow the pedagogical philosophy of ***active learning***—or supervised learning by doing [14, 15]—in which students engage in classroom discussions and map design assignments that apply cartographic concepts to timely geographic problems and examples. Given institutional support from the range of aforementioned programs, I was able to design several of the cartography courses as 4-credit offerings split between a lecture and laboratory component (including laboratory student teaching support), with each component receiving two credit hours. Lecture lessons reserve the majority of contact for discussion of professionally-designed map examples, anchoring critique in timely, real-world mapping contexts. Students use social media—with all key terms in lecture notes doubling as hashtags (see #uwcart on Twitter)—to continue discussion asynchronously and to shape the examples that will be discussed in subsequent lecture lessons.

Laboratory lessons provide the necessary ***scaffolding***—or instructor demonstration and intervention, which decreases throughout the course as the "training wheels" are removed [16, 17]—for students to creatively approach a set of 2-5 map design assignments and a culminating final project. All assignments, including the final project, impose a realistic client request as a guiding scenario, with the assignment instructions then emphasizing design thinking and problem-solving workflows rather than prescriptive step-by-step tutorials [18]. Students must find and prepare their own datasets for each assignment, selecting topics that creatively meet the scenario requirements and dovetail with other aspects of their professional development. Thus, both lecture and laboratory lessons empower students at different levels of learning (general undergrads, undergraduate majors, certificate students, graduate students) and different interests (planning, conversation, journalism, critical theory, etc.) to tailor their active learning experience to their unique needs.

CURRICULUM ORGANIZATION

To guide the refresh, I aligned the cartography curriculum to an orthogonal pair of axes capturing the range of competencies defining contemporary cartography (Figure 2). The first axis captures the traditional distinction between mapmaking and map use made popular in cartography by the Robinson era communication model [19-21]. Here, ***mapmaking*** describes the iterative and active design decisions involved in map production while ***map use*** describes the interpretation and application of these map products. As many scholars have noted, this binary increasingly is becoming blurred in positive and negative ways by neocartographic tools [22-25]. The second axis then captures an emerging distinction between representation and interaction increasingly recognized in cartography and the related fields of information visualization and visual analytics [11, 26, 27]. ***Representation*** describes the graphic (or sonic, haptic, etc.) encoding of geographic information that enables the map to "stand for" geographic phenomena [28], while ***interaction*** describes the two-way, digitally-mediated dialogue between the map and its users that enables concomitant changes to the map encoding and the user's understanding of the encoding [29].

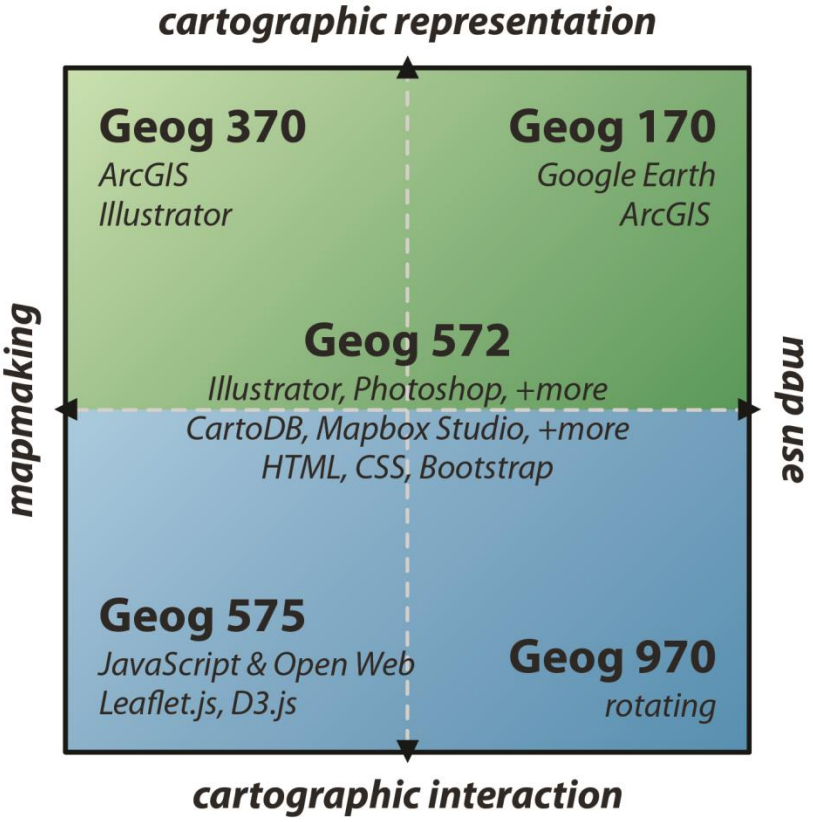

Figure 2. Cartography Curriculum at UW-Madison, 2015-2016. To guide the refresh, I aligned the cartography curriculum to an orthogonal pair of axes capturing the range of conceptual competencies defining contemporary cartography. The UW–Madison cartography courses are positioned within this framework, with the associated technical competencies listed beneath the course for reference. Image modified from [9].

The Figure 2 framework organizes the learning objectives of each of the five UW–Madison cartography courses. Four of the five cartography courses cover the pairwise antipodes of these orthogonal axes (i.e., the corners in Figure 2): Geography 170, a survey course on the uses of geospatial technology in society (map use + representation); Geography 370, an intermediate-level course on the fundamentals of reference and thematic map design (mapmaking + representation); Geography 575, an advanced level course on interaction design for web and mobile mapping (mapmaking + interaction); and Geography 970, an graduate seminar on problems in interactive, online, and mobile mapping (map use + interaction). The fifth course, Geography 572, is positioned at the intersection of these axes to integrate influences and technologies across cartography. In the following, I use the department course numbers to identify each course during discussion and to reinforce the learning levels implemented at UW–Madison (100-200=elementary, 300-400=intermediate, 500-600=advanced, 700-900=graduate-only); specific numbers within levels are not meaningful. All descriptions are specific to the 2015-2016 course offerings.

Map Use + Representation: Geography 170

Developed by my colleague Dr. Qunying Huang, Geography 170 is a three-credit survey of geospatial technologies, including a sequence of conceptual modules on geospatial data, GPS, remote sensing, and GIS [30]. The course ends with a three-week module on cartography, primarily focusing on the uses of thematic mapping and quantitative representation to complement the reference mapping topics introduced in other modules. The course uses a number of practical use case examples to demonstrate the utility of geospatial technology across a range of professions and discuss the overall impact of these technologies on society [31, 32]. To complement the survey of map uses, three technology assignments are introduced requiring students to use and interpret Google Earth and ArcGIS Online.

Geography 170 enrolls approximately 200 students per semester and is open to undergraduate students only, primarily targeted towards freshman. Thus, the purpose of the course is to develop an appreciation of maps and mapping technology as new learners arrive on campus, with the goal of converting 10% or more of enrollments to the Cartography & GIS undergraduate major. Geography 170 also is unique in that it is offered solely at a distance, and thus promotes active learning through online multimedia lecture materials (readings and videos), peer-to-peer discussion forums, self-assessment exercises followed by each lecture, and reflection quizzes.

Mapmaking + Representation: Geography 370

Geography 370 is a four-credit intermediate course on cartographic design with lecture and lab components. The lecture lessons cover cartographic theories, best practices, and success stories that are useful for thinking critically about map design and for transitioning design concepts into finished map products [33]. Lecture lessons are organized according to the traditional division between reference mapping and thematic mapping (Table 1), a distinction used in Geography 370 since Robinson taught it. To promote active learning, lectures emphasize discussion of recent examples and typically include one case study on the ethics of map design.

Table 1. Lecture and discussion sequence for Geography 370 (mapmaking + representation).

W#	Topic
1	Course Introduction: Organization & Influences Introduction to Cartography: Mapmaking/Map Use, Rep./Interaction
2	Projections I: Geodesy & the Geographic Coordinate System Projections II: Projection Mechanics & Distortions
3	Generalization I: Map Scale & the Cartographic Problematic Generalization II: Generalization Operators
4	Typography I: Label Appearance Typography II: Label Placement
5	Putting it Together: Visual Hierarchy Putting it Together: Visual Balance & Map Elements
6	Symbolization I: The Visual Variables Symbolization II: Overview of Thematic Map Types
7	Terrain Representation EXAM #1: 75-minute midterm
8	Choropleth Maps I: Normalization Choropleth Maps II: Classification
9	Choropleth Maps III: Color Theory Proportional Symbol Maps
10	Dot & Dot Density Maps Dasymetric Maps
11	Isoline Maps I: Interpolation Isoline Maps II: Design Considerations
12	Cartograms Flow Maps
13	Ethics and Critique in Cartography Professional Cartography Opportunities
14	EXAM #2: 75-minute final (non-cumulative) Final Project Preparation
15	Final Project Presentations Final Project Presentations

Geography 370 lab lessons apply lecture concepts to a set of five map design assignments and a final project. As introduced above, each lab assignment is framed by a client scenario and requires students to acquire their own datasets. As a result, students create very different, personalized deliverables as early as Lab #1. Lab scaffolding introduces the cartographic production workflow using Esri ArcGIS and Adobe Illustrator, with all lab assignments requiring use of both packages in order to develop an understanding of the cartographic design tasks best completed in GIS software versus graphic design software.

Geography 370 is offered in residence only and is a gateway course to the Undergraduate Majors in Cartography & GIS and Geography, the GIS Certificate, and the Resident Masters in Cartography & GIS. Geography 370 also is a service course for other programs outside of Geography and enrolls 80 students per semester. The discussion in the next section regarding instruction across a diverse set of learners draws

from my experience in Geography 370.

Mapmaking + Interaction: Geography 575

Table 2. Lecture and discussion for Geography 575 (mapmaking + interaction).

W#	Topic
1	Course Introduction: Organization & Influences UX *What?* Interaction vs Interface, UI vs UX
2	UX *Why?* Visual Thinking, Exploration, Insight UX *When?/How Much?* Productivity, Flexibility, Constraint
3	UX *Who?* User Ability, Experience, Motivation UX *Where?* Input, Display, Processing, Bandwidth, Mobile
4	UX *How?* Stages of Interaction, Interaction Primitives UX *How?* Goals, Objectives
5	UX *How?* Operators I: Reexpress, Sequence, Overlay, Resymbolize UX *How?* Operators II: Pan, Zoom, Reproject
6	UX *How?* Operators III: Filter, Search, Retrieve UX *How?* Operators IV: Arrange, Calculate, Enabling Operators
7	UX *How?* Operands I: Non-spatial Information Types UX *How?* Operands II: Interacting with Time
8	EXAM #1: 75-minute midterm UI & HCI I: Interface Styles, Direct vs Indirect
9	UI & HCI II: Direct Manipulation in Interactive Maps UI & HCI III: Interface Design Heuristics
10	UI & InfoVis: Information Seeking, Sensemaking UI & InfoVis: Coordinated Visualization, Highlighting
11	UI & Usability Engineering I: Usability vs Utility UI & Usability Engineering II: User-Centered Design
12	UI & Usability Engineering III: Interface Evaluation I UI & Usability Engineering IV: Interface Evaluation II
13	UI & Visual Analytics I: Big Data Analytics UI & Visual Analytics II: Analytical Reasoning
14	UI & Visual Analytics III: GeoCollaboration EXAM #2: 75-minute final (non-cumulative)
15	Final Project Presentations Final Project Presentations

Geography 575 is a four-credit advanced course on user interface (UI) and user experience (UX) design as applied for mapmaking, topics typically treated under the headings of geographic visualization [34] or web mapping [2]. Lecture lessons are organized around map-specific considerations for the broader UX design [following 11] versus software engineering influences on UI design and implementation [35-39] (Table 2). Because principles of cartographic interaction design remain in their infancy, the active learning discussion addresses where interactive mapping is headed as much as where it currently stands today.

Geography 575 lab lessons introduce the technical competencies needed to design and develop interactive maps on the web and for mobile devices. The Geography 575 lab lessons are a primary place in curriculum where we have been challenged over the past five years to respond to broader shifts in mapping technology and professional practice. My colleagues and I conducted a three-stage research study to determine how best to transition our lab curriculum away from reliance on proprietary plugins (i.e., Adobe Flash and ActionScript) and towards integration with the Open Web Platform (e.g., HTML, CSS, and JavaScript) [9]. The study identified Leaflet.js and D3.js as the open libraries best supporting our pedagogical and technical learning objectives regarding interaction design. We currently assign two labs that cover Leaflet and D3 separately—explicitly forcing students to actively consider their functional differences and unique relationships to other Open Web resources—and have a 10-week linear sequence of modularized technical lessons designed to provide the necessary scaffolding for additional competencies needed to develop on the Open Web Platform (the DOM, AJAX, jQuery, the GeoJSON/TopoJSON formats, browser development tools, Github, etc.) [17]. Geography 575 also includes a six-week, intensive group final project. Despite the substantial technological changes since 2011, my recent experience teaching Geography 575 suggests that open web mapping technology currently is in a period of relative stability.

Geography 575 alternates semesters in resident and online format, doubling the instructional attention and resources available to maintain the complex, layered course. As a 500-level course, Geography 575 is available to senior undergraduate majors and is an elective for the GIS Certificate and both Masters programs, regularly enrolling 30-40 students per semester.

Map Use + Interaction: Geography 970

Geography 970 is a three-credit graduate seminar that rotates between topics in cartography and GIS depending on the instructor. For cartography offerings (available every 2-3 years), I customize the course to address a specific, emerging mapping problem and map use context. For instance, the 2014 seminar approached emerging conceptual and technical problems in mobile mapping through a case study on globalization. We worked with faculty in the UW–Madison International Studies Department to design and develop a ***situated learning*** tool—taking the classroom into the streets through mobile maps [40, 41]—that first uses a location-based service to guide students to historic landmarks within the city and then uses the mobile platform to deliver narration, maps, and images contextualizing these places in the globalized world. International studies students collect a visual essay while completing the guided tour and create their own tour in a final paper description of an additional global commodity chain intertwined with Madison.

The weekly seminar meetings were divided into two 75-minute sections. In the first half of seminar, we discussed a set of papers mutually agreed upon by the class that speak to an influence on the case study; for mobile mapping, this included location-based services, responsive web design, and volunteered geographic information, among others. Students were asked to prepare a reflection essay on each influence before class to promote active learning. In the second half of class, students provided a case study project update from the perspective of three teams: visual storytelling (responsible for content and representation design), UI/UX design (responsible for interaction design), and

evaluation (responsible for assessing the design for the use case). Students self-assigned into these teams and were tasked with exploring, presenting, and justifying the techniques and technologies used in the case study project.

Geography 970 is designed for graduate students only, and is taken by students in our resident Masters and PhD programs. The combination of in-depth reading and technical review in the 2014 offering balanced the professional and scholarly demands of these programs (most MS students receive a terminal degree). Further, the team-driven organization of the case study promoted collaborative learning under realistic time and resource constraints. Finally, selection of a map use context focused on situated learning involved graduate students in curriculum design, improving the learning experience of other students on campus. The 2014 seminar included 11 graduate students.

Integration: Geography 572

Geography 572 is a four-credit advanced course designed to integrate conceptual and technical competencies across the full spectrum of contemporary cartography. Lecture lessons are broadly framed by visual storytelling, with each lecture prepared as a three-act narrative introducing the origins, evolution, and designs insights of a single theoretical framework used in cartography. Lessons progress to develop a critical understanding of "how maps work" [28] from the perspectives of visual perception (i.e., how maps are seen), visual cognition (i.e., how maps are understood), and visual culture (i.e., how maps are imbued with meaning) (Table 3). Discussion of visual perception and cognition draws on historical breakthroughs in psychology and cognitive science [e.g., 42, 43-45], while discussion of visual culture draws on an eclectic set of sources on art, design, ethics, and critical theory [e.g., 5, 46, 47-57]. Throughout, students uses these theoretical framings to critique map examples, tracing the etiology of the mapmaking and map use canon in cartography and considering how these principles require rethinking for both representation and interaction as maps and mapping technology evolve.

Table 3. Lecture and discussion sequence for Geography 572 (integration).

W#	Topic
1	Course Introduction: Organization & Influences Visual Storytelling I: The Story of Cartography
2	Visual Storytelling II: Storytelling Genres Visual Storytelling III: Storytelling Tropes
3	Visual Form I: The Eye-Brain System Visual Form II: Contrast, Grouping, & Figure-Ground
4	Visual Attention I: Visual Variable Selectivity & Conjunctions Visual Attention II: Bivariate & Multivariate Mapping
5	Visual Complexity I: Factors of Complexity, Density, & Overload Visual Complexity II: Complexity & Realism
6	Visual Complexity III: Complexity & Spatiotemporal Representation Visual Complexity IV: Complexity & Animation
7	Visual Cognition I: Knowledge Schema Visual Cognition II: Representing Uncertainty
8	EXAM #1: 75-minute midterm Visual Aesthetics I: Art, Emotion, & Design
9	Visual Aesthetics II: Aesthetics, Style, & Taste Visual Aesthetics III: Pastiche Aesthetic Styles
10	Visual Semiotics I: Referent-as-Mediator & Congruency Visual Semiotics II: Interpretant-as-Mediator & Iconicity
11	Visual Semiotics III: Sign-Vehicle-as-Mediator & Levels of Meaning Visual Ethics I: A Code of Ethics from Science
12	Visual Ethics II: A Code of Ethics from Art Visual Critique I: The Story of (Critical) Cartography
13	Visual Critique II: Critical & Radical Cartography Visual Critique III: Persuasion & Propaganda
14	Visual Critique IV: Participatory Mapping & VGI EXAM #2: 75-minute final (non-cumulative)
15	Final Project Presentations Final Project Presentations

Geography 572 lab lessons integrate technical competencies through four lab assignments and a final project. Also framed by a client scenario, lab assignments emphasize workflow and require students to design across 3-4 different technologies. Geography 572 does not introduce JavaScript programming—focusing instead on GUI-based tools—but does provide greater depth on HTML and CSS by way of introducing responsive web design frameworks. Accordingly, the Geography 572 scaffolding is designed to be "flat" or non-linear (unlike the sequential lessons promoting computational thinking in Geography 575), with students integrating lessons on technology as needed for their design solution. Further, many technical lessons are redundantly available in multiple technologies, enabling students to explore the relative advantages and disadvantages of tools for a specific design task. Technical lesson topics include: Adobe Illustrator, Adobe Photoshop, ArcGIS, ArcGIS Online, Blender, Bootstrap, CartoDB, Github Pages, Indiemapper, Mapbox Studio, MapShaper, Terrain Sculptor, and TileMill; again, each lesson emphasizes workflow (i.e., when to use the tool during design). Unlike the relative stability in Geography 575, my recent experience teaching Geography 572 suggests that the number and functional scope of GUI-based cartographic design tools is expanding rapidly, particularly neocartographic tools supporting creation of interactive web maps. As a result, many Geography 572 students write short technical lessons on new technology as part of their final project, summarizing insights from their exploration to share with future students.

As with Geography 575, Geography 572 alternates semesters in resident and online format. Geography 572 is available to senior undergraduate majors and is an elective for the GIS Certificate and both Masters programs. Given the broader theoretical framing—particularly in aesthetics and critique—Geography 572 also is growing in popularity among students in the Masters in Geography program and regularly enrolls 30-40 students per semester.

DISCUSSION: LESSONS LEARNED

In the following, I offer several of the major lessons learned while redeveloping the UW–Madison curriculum. While I offer these lessons as imperatives, the possible solutions for meeting these recommendations are diverse. My discussion focuses on those solutions that I have found to work anecdotally in my courses at UW-Madison, and the following is by

no means a comprehensive summary of cartographic pedagogy. Instead, I offer these recommendations as my initial impressions of potentially viable strategies to adapt curriculum in the context of continual cartographic change.

Anchor Active Learning in Real-World Problems and Examples

Active learning promotes a deeper engagement with course material by requiring students to translate concepts and techniques to real-world problems and examples. In my experience, discussing timely, professionally-designed map examples rather than canned textbook illustrations promotes deeper engagement with the conceptual material. I also find that using real-world examples helps students hone their eye for design: while I may introduce an example to discuss the rationality behind a single map design decision, the collective student engagement with polished designs throughout the course facilitates global understanding of the range of decisions that the cartographer made—and the alternatives therein—which can be applied in their own design. In this way, I only use examples of good design in my teaching, rather than straw man examples of bad design. Further, I find examples that confront important, and perhaps controversial, problems facing society on a global scale to solicit the greatest engagement, and also offer an opportunity to discuss mapping ethics in a context where right and wrong are inherently unclear. Maintaining an up-to-date queue of discussion examples does require extra preparation for the instructor, but social media and collaborative learning activities offset this burden by crowdsourcing examples from the class.

In lab assignments, I find that imposing client scenarios increases exploration of design and technology alternatives, and ultimately promotes the creative thinking necessary for successful, innovative cartographic design. Using a client scenario combats the expectation of a step-by-step walkthrough of a single technology, which is passive, does not build transferable skills, and overall stifles creativity. Further, use of client scenarios allows the curriculum to adapt to a diverse range of student interests and needs, enabling students to "put themselves" in the assignment and take ownership over the learning outcome (the map design) in a manner that does not reflect simple grade-seeking. Finally, using client scenarios better reflects cartography as a profession, helping students transition to the workforce more efficiently given existing experience with the messiness of cultivating a design from conceptualization to delivery.

Support Degree Flexibility through Bracketing and Redundant Lessons

Edification and expansion of cartography curriculum requires careful consideration of many types of learners and institutional programs. Using client scenarios in lab assignments holds the aforementioned advantages regarding active learning and creativity, and also allows cartography curriculum to support multiple degrees and initiatives. Each course in the UW–Madison cartography curriculum is ***bracketed*** to constrain learning objectives to those that can be achieved within the scope and sequence of the course [10]: Geography 170 and 370 assume no existing knowledge in cartography and can be taken as a standalone general elective, and Geography 572, 575, 970 can be taken flexibly in any order (Figure 3). Such bracketing improves student flexibility in putting together degree plans, and ultimately results in cartography reaching more students on campus and online. Bracketing does not necessarily mean removing lessons from the course, but often does mean redundantly assigning the same lessons in multiple courses to support different learning objectives. Redundant lessons serve as an early "refresher", acting as the glue between courses, and promote active learning, as students see the same concepts and technologies applied for different cartographic problems.

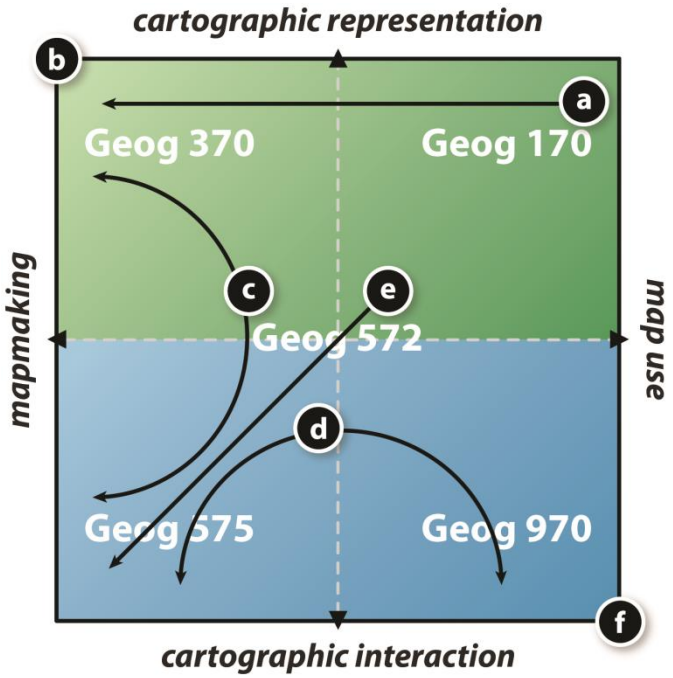

Figure 3. Flexible Sequencing through the UW–Madison Cartography Curriculum. (a) General Undergraduates; (b) Geography Majors; (c) Cartography & GIS Majors and GIS Certificate Students; (d) Resident MS Students; (e) Online MS Graduates; (f) PhD Students. Image modified from [9].

Avoid Technological Path Dependencies by Teaching Concepts First

I have designed the UW-Madison cartography curriculum to expose students to a wide range of mapping technology, perhaps at the expense of gaining great depth in any specific technology. I selected this curricular strategy to avoid ***path dependency***, or the use of a tool beyond its functional life due to overreliance on it and expertise with it [10]. Avoiding path dependency means teaching concepts first and technology second. Centering a course on a single technology (e.g., an ArcGIS Online class, a CartoDB class, a Mapbox Studio class) runs the risk of needing comprehensive revisions—or even closing the course—with a new software iteration or larger shift in the technological landscape. Organizing curriculum by concept (e.g., mapmaking, map use, representation, interaction) maintains consistency across offerings, avoids path dependencies, and promotes active design thinking. To this end, the use of client requests in lab assignments has yet another practical advantage of retaining consistency from year to year, as the conceptual design objectives remain the same while the underlying technology stack evolves.

Promote Collaborative Learning and Collaborative Curriculum Design

The UW-Madison cartography curriculum relies heavily on ***collaborative learning***—requiring students to participate in group and team activities to engage more fully with course material [58]—and ***collaborative curriculum design***—encouraging students to assist with the maintenance and expansion of conceptual and technical lessons [9]. First, I use collaborative learning activities in several points of the curriculum to promote active learning: lecture discussion across curriculum facilitated by social media, peer-to-peer discussion boards for online curricula, group final projects in Geography 575, and team assignments in Geography 970. Collaborative learning activities promote active learning and reduce instructor intervention on common missteps. Collaborative learning activities also expand peer-to-peer instruction and evaluation—or beginners teaching beginners, a mantra made popular by MapTime—making feedback more immediate (given the broadened help resources) and potentially more relatable (given gaps in knowledge between expert instructors and beginning learners) [59]. Collaborative projects also allow a team of students to collectively do more with a single assignment—particularly for interactive and mobile maps requiring substantial development time—letting students explore a wider range of technologies and build their professional portfolios.

To complement collaborative learning, I also encourage collaborative curriculum design. Involving students in curriculum design either formally (through teaching assistant positions) or informally (through independent studies or course final projects) has the practical advantage of offloading the burden of maintenance from the instructor. However, I only advise collaborative curriculum design when the lesson revision holds educational value for the participating student. Teaching is the best way to learn, and reversing the roles of student and instructor can lead to deeper engagement with the material and generate new ideas for improving curriculum. Further, self-directed life-long learning is the reality of the professional cartographer, and collaborative curriculum design affords early practice at independent learning within the lower-stakes university setting. While collaborative learning and collaborative curriculum design require substantial and sometimes prohibitive amounts of instructor supervision, Github and other collaborative versioning software have greatly simplified the process of integrating additions and revisions into curriculum. Finally, I

have found that collaborative learning and collaborative instructional design are keys to developing an alumni network, important both for placing students in the profession and for calibrating curriculum to professional practice.

Use and Contribute to Open Educational Resources

The pace of change in cartography leads to my final, overarching recommendation to use and contribute to educational resources in the public commons. ***Open education resources*** make lessons, assignments, tutorials, and other educational materials available for reuse and extension on other campuses [60]. There are far too many conceptual and technical competencies in cartography for any single curriculum to maintain. Using and contributing to open educational resources allows us to share the load collectively. Open educational resources also build community around cartography as a profession, and enable professionals to maintain their skillsets as technology evolves. To-date, we have shared our Geography 575 lab material as open educational resources [61, 62], and we plan on releasing additional resources through the UW Cartography Lab blog in the future.

CONCLUSION AND OUTLOOK

In this paper, I summarize my experience over the past five years refreshing the UW–Madison cartography curriculum. Following tenets of active learning, the lecture and lab lessons provide scaffolding across the conceptual and technical competencies defining contemporary cartography, ranging from mapmaking to map use and cartographic representation to cartographic interaction. We offer five cartography courses at UW–Madison to cover these competencies, with these courses supporting six degree programs in the Geography Department. Because of the institutional support from these programs, the course volume and resources for cartography at UW–Madison may be greater than other universities.

Yet, many of the lessons learned during redevelopment still may apply in different curricular contexts. If only a single course on mapmaking is offered on your campus, consider moving past the traditional reference versus thematic mapping distinction and instead reorganize your material to capture the emerging distinction between representation versus interaction (i.e., modularize the entire Figure 2 framework for a single course). If t single cartography course is currently specific to map use, consider adding a lab dimension to address a subset of technical competencies supporting mapmaking. If you only offer courses on GIS, consider moving to a "full stack" approach that integrates aspects of representation and interaction design as the final presentation of GIS analyses. The recommendations to promote active learning, collaborative learning, and collaborative instructional design are applicable to most curricular contexts, as are the cautions to properly bracket the lesson sequence to improve degree flexibility and to put concepts first to avoid technological path dependency. Finally, we all can and should participate in the open educational resources movement to make sure that we are moving forward as a cartography community with each individual lesson we prepare.

Cartography is and always will be changing, and I argue that such change is good for cartography and cartographers. We have the opportunity to continually renew ourselves and our skillsets as novel problems appear, rather than stagnate into obsolescence. Instead of pushing against this change, cartographic education needs to harness and channel it. Accordingly, educators need to start thinking like development teams to maintain base curriculum and to avoid path dependency. We also must teach students how to navigate the stream of cartographic change once leaving campus. Here, I offer my initial reflections on how to rethink cartography curriculum to train the contemporary cartographer, and I look forward to absorbing similar insights from others as we collectively train the next generation of cartographers.

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BIOGRAPHY

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