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VISUALIZATION RESEARCH: SCOPING REVIEW ON DATA VISUALIZATION COURSES

Fabio Capra-Ribeiro[a,b]
[a]Louisiana State University, USA
[b]Universidad Internacional de Valencia, Spain

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ABSTRACT

Understanding data visualization as one of the foundational skills of the 21st century, this research aimed to define up-to-date guidelines to effectively teach data visualization courses and–from there–developed the first version of a new data visualization course. To do so, it faced the following questions: What is the current role of data visualization in higher education? What have been the main trends in data visualization courses in higher education? What methodologies have been used to teach data visualization courses? What difficulties have been identified in data visualization courses? What recommendations have been offered by previous professors that have taught this kind of courses? Considering this broad set of questions, the research was developed as a scoping review that served to collect hundreds of publications from where 22 peer-reviewed articles published between 2008 and 2021 were finally selected and analyzed. Among the most important results, the research found that data visualization interest in higher education has been growing exponentially and data visualization courses prioritize practical exercises over theoretical content. Some of the most common recommendations synthetized through the review suggested to select topics that the students should find interesting to promote their engagement. Also, several authors recommended to start the visualization process as soon as possible and spend the least possible time on learning tools. Finally, the results of this review should be useful to support and promote new data visualization courses while they were already used to create the first iteration of a graduate and upper-level undergraduate professional elective course on data visualization under the title *Visualization Research*. The review and assessment of this course will be the next step of this research process.

KEYWORDS

Information representation; graphing; mapping; design studies; higher education.

1. INTRODUCTION

"We live in a data-saturated moment, in which [visualizations] distill complex realities into seemingly palpable truths" (Battista and Conte 2017, 147–48). This information representation process can improve people's lives by making it easier for them to access relevant information. But, unless it is communicated in a clear, engaging, and effective way, is very difficult for the message to reach the recipient. Furthermore, nowadays the amount of data and information grows exponentially, as well as the communication channels, which makes the whole process of representation and understanding more complicated. Even so,

images remain one of the clearest and most powerful means of communication, especially in a globalized world with different languages, disciplines, and perspectives in close contact.

> "Generally, people, even without specific training, can still understand meanings graphs refer to. Considering the speed and efficiency, it is easier for people to memorize graphs than mass textual data. If a graph can exactly express the meaning, less explanation and shorter thinking process will be needed to understand. Compared with regionalism in language and character as well as obscurity in science and interdisciplinary knowledge, graphic symbols containing metaphor content can resolve the foothold of information in the communication of cross-cultural information (Yunqing, Linglin, and Yanzi 2016, 698)."

This almost universal condition is combined with the trust that society usually has on data, often understanding it as an irrevocable truth. The development of technology has made information visualization become involved in "every aspect of our life before we come to realize it" (Yunqing, Linglin, and Yanzi 2016, 696). Thus, there is a constant and growing demand for visualization design that must be addressed in higher education by training professionals with these skills. In this sense, it is important to study, develop and share experiences of visualization courses for "instructors to improve their teaching materials and help students achieve desired learning outcomes" (Lo, Ming, and Qu 2019, 11).
So, understanding data visualization as one of the foundational skills of the 21st century, this research aims to define up-to-date guidelines to effectively teach data visualization courses. Complementary, the research expects to support the creation of the first version of a data visualization elective course to be implemented in the Louisiana State University School of Architecture. As this course will be available to undergraduate and graduate students in the College of Arts & Design, the research focuses on data visualization for design related students. To achieve these objectives, the research seeks to understand what the current role of data visualization is in higher education? More specifically, what have been the main trends in data visualization courses in higher education? What methodologies have been used to teach data visualization courses? What difficulties have been identified in data visualization courses? What recommendations have been offered by previous professors that have taught this kind of courses?

2. METHODOLOGY

To address these questions, the research was based on a literature review focused on peer reviewed results of data visualization courses. Being this a topic-based search with several broad questions that could also include other reviews, it has been defined as a *scoping review*. The search centered on the term *data visualization,* being this a specific term that clearly identifies this area of knowledge. But the term *information representation* was also considered due to the well-known fact that it has been widely used to treat these topics. Thanks to the specificity of these terms, no more keywords were deemed necessary to define the topic. But the search also included the terms *learning* and *teaching* to focus on higher education. These two were favored over others such as *university*, *pedagogy*, and *course*, because they represented a simple solution that included any part of the educational process. It wasn't necessary to include any specific keywords about higher education because data visualization courses have mostly (if not only) been implemented in higher education scenarios. These keywords were organized in the following equation: TI/AB/KEY= ("data visualization" OR "information representation") AND TI/AB/KEY= ("learn*" OR "teach*"), which was adapted and implemented to three available databases: Web of Science, WorldCat, and Google Scholar. Combining the

results, 874 papers were initially collected, but after duplicates were removed, papers were screened by abstract and titles, and full text assessed for eligibility, the research identified only 22 papers that focused on data visualization courses (Table 1). These documents were later analyzed in relation to the proposed research questions.

Title	Year	Authors
Innovative Pedagogy for Teaching and Learning Data Visualization	2021	Byrd, Vetria L.
Experience of Teaching Data Visualization using Project-based Learning	2021	Kammer, Dietrich; Stoll, Elena; Urban, Adam
Remote Instruction for Data Visualization Design—A Report from the Trenches	2021	Aerts, Jan; Peeters, Jannes; Bot, Jelmer; Kafetzaki, Danai; Lamqaddam, Houda
What more than a hundred project groups reveal about teaching visualization	2020	Burch, Michael; Melby, Elisabeth
Information Visualization in the Educational Process: Current Trends	2020	Liu, Zhi-Jiang; Levina, Vera; Frolova, Yuliya
Introducing information visualization to design students	2020	Mauri, Michele
Teaching Data Visualization as a Skill	2019	Ryan, Lindy; Silver, Deborah; Laramee, Robert S.; Ebert, David
Learning Vis Tools: Teaching Data Visualization Tutorials	2019	Lo, Leo Yu-Ho; Ming, Yao; Qu, Huamin
Teaching Data Visualization in/nFirst-Year Courses	2019	Clement, Ryan
Teaching News Design and Data Visualization	2019	Britt, Rebecca Katherine
Creative Data Literacy: A Constructionist Approach to Teaching Information Visualization	2018	D'Ignazio, Catherine; Bhargava, Rahul
Teaching with data: Visualization and information as a critical process	2017	Battista, Andrew; Conte, Jill A
Teaching and Learning Data Visualization: Ideas and Assignments	2016	Nolan, Deborah; Perrett, Jamis
Teaching data visualization in evl's cyber-commons classroom	2016	Johnson, Andrew
Tool for teaching visualization techniques: Learning and homework assignments for multivariate data visualization	2016	von Landesberger, Tatiana; Brodkorb, Felix; Schneider, Philipp; Ballweg, Kathrin
Using pedagogic design patterns for teaching and learning information visualization	2016	Craft, Brock; Emerson, R-m; Scott, Taylor Jackson
The Application of Information Visualization Design in Teaching Field	2016	Yunqing, Wan; Linglin, Tu; Yanzi, Liu
Teaching Students to Focus on the Data in Data Visualization	2015	Wolfe, Joanna
Teaching Information Visualization via Creative Design	2014	Spence, Bob
Aligning trends in mainstream media and data visualization with teaching practice	2012	Chong, Alan
Teaching Information Visualization	2008	Kerren, Andreas; Stasko, John T.; Dykes, Jason
What ordinary people need most from information visualization today	2008	Few, Stephen; Edge, Perceptual

Table 1. Documents selected for analysis.

3. RESULTS

The review served to identify several important issues such as the role of data visualization in higher education, teaching methodologies, and specific issues and recommendations. These results are organized below following the same order presented by the research questions.

3.1. The role of data visualization in higher education

The analyzed documents that mentioned the topic agreed that the importance of data visualization has been growing exponentially in all areas. "Data visualization has rapidly become a standard approach to interrogating and understanding the world" (D'Ignazio and Bhargava 2018). Its application has spread in research, business, journalism, etc., which is why "knowing how to collect, find, analyze, and communicate with data is of increasing importance in society" (D'Ignazio and Bhargava 2018). Recent research showed that in the US the demand for this skill grew 1500% in the last decade, from "1888 jobs in 2010 to 30327 jobs in 2018" (Ryan et al. 2019, 97).

Data scientists are increasingly valued in all kinds of industries to analyze exponentially growing information. But this is only part of the process. Today it is possible to observe governments, organizations, communities, that make decisions related to the way in which the information provided is presented. In other words, the good representation of information can increase the influence that it has on the audience (Yunqing, Linglin, and Yanzi 2016, 696), for better or worse.

Graphic representation allows to emphasize "statistical thinking over calculations" which, combined with the creation of beautiful and useful visualizations, "can be very rewarding for students" (Nolan and Perrett 2016, 15). It is important to prioritize teaching the thought process over the use of specific tools because tools and trends change rapidly (Lo, Ming, and Qu 2019, 14). Likewise, data visualization is not a mechanical process in which certain numbers are expressed, it requires analyzing said data and understanding that its processing is not neutral, but rather requires taking decisions about the ideas that will be communicated (Wolfe 2015, 345–47).

Considering its recent expansion, the wide variety of industries and disciplines where it is applied, and its importance in research, data visualization have a great influence in today's world. The appropriate representation of information can solve many of the problems and opportunities that people face today, a representation that in turn becomes the tool to facilitate deeper thinking (Few and Edge 2008).

> "Critically, the technical knowledge of how to work effectively with data is in the hands of a small class of specialists (D'Ignazio and Bhargava 2018)."

This is one of the reasons why it is necessary to train more people capable of appropriately representing information that can help others achieve their goals or understand concepts or ideas that could change their lives, or everyone's lives.

3.2. Two main trends in visualizations

Although some authors understand visualization as a "subfield of computer science" (Ryan et al. 2019, 95), it has been accelerating and diversifying thanks to multidisciplinary and technology. But many efforts around data visualization are still related with coding and using specific software to generate a spectrum of charts. This approach is leaving aside many other possibilities of analysis and representation. In this context, design–understood as the "the way in which something is planned and made" (Cambridge University Press n.d.)–has to play an important role.

> "However, teaching data literacy to computer scientists and statisticians is a different proposition than teaching data literacy to non-technical, adult newcomers such as humanities scholars, journalists, educators, artists and non-profit staff (D'Ignazio and Bhargava 2018)."

The reviewed documents clearly identified these two general trends. Data visualization understood as a big data programming exercise, and data visualization as a manual process where the author and his interpretation take on greater importance. The first option usually has a more standardized range of solutions, where the representation is chosen from a catalog of possibilities, while the second option usually generates specific solutions or at least specific variants from existing solutions.
usually generates specific solutions or at least specific variants from existing solutions.
Although both approaches are complementary, they are sometimes understood as opposed solutions. For example, design students sometimes "tend to see data as something far from their practice and related to other fields" (Mauri 2020, 4442), while students in statistics and data science often have trouble embarking on the creative process of developing appropriate designs (Aerts et al. 2021, 15).

> "Data visualizations can consist of generic plots such as scatterplots and barcharts, but more novel visual designs might be necessary to allow reasoning on complex data (Aerts et al. 2021, 15)."

Therefore, it is necessary to establish symbiotic relationships between these two trends. But this interaction should try to simplify the processes and results to made them useful to the public that need them. Many of the problems that the potential target audience is currently facing "can be handled by a broad range of people using fairly simple visualization techniques" (Few and Edge 2008). It is important to oppose the unnecessary sophistication that focuses on a specialized audience, to be extended to people who need help to understand the world around them (Few and Edge 2008). Connecting with the previous point, the training of new professionals with knowledge in data visualization requires a combined effort from different disciplines, not exclusively from programming or data science.

3.3. Data visualization pedagogy

The studied documents demonstrated different ways of teaching data visualization. A 2008 survey of 19 data visualization courses in Europe and the US found that 72% of the courses used textbooks, 68% assigned required reading articles, but 95% included practical exercises (Kerren, Stasko, and Dykes 2008, 67–72). Following the position taken by more recent paper, the latter seems to also be the most important trend nowadays.
Several of the consulted cases included lectures added to a combination of short exercises and a final exercise. For example, Britt (2019, 2) divides her course into three parts "data visualization, photo visualization, and an integrated final project," but each class has lectures and discussions before moving on to a lab space where they practice the topics they have learned. Craft, Emerson, and Scott (2016) also have lectures and reading-supported group discussion sessions, but have an important web-based visualization exercise. Lo, Ming, and Qu (2019, 11) follow a similar pattern, guided lectures and tutorials that are complemented by hands-on exercises and a group project. Mauri (2020, 4443) is another example where theoretical lessons, group sessions for creation and peer-review, and tutorials are organized. In many cases, whether in the lectures or in the tutorials, an important time dedicated to teaching software tools of a different nature is usually included. In this sense, several cases were observed, such

as that of Kerren, Stasko, and Dykes (2008, 74), where the practical exercises are associated with a particular software.

Although supported by theoric content, the courses tend to have a big practical component. This can be observed through approaches such as learning by doing. This is clearly seen through remarks such as Spencer's (2014, 3) "the best way to become educated in Information Visualization […] is to do it" or Jason Dykes (Craft, Emerson, and Scott 2016, 83–84) when he talks about "emphasis on 'learning through doing' as opposed to a transmissive approach to learning". Likewise, several courses fundamentally use the project-based learning (PBL) approach. For example, Kammer, Stoll, and Urban (2021) state that PBL helps deal with how overwhelmed students often feel when faced with course content. The system itself serves to engage students with all stages of the process, rather than embarking on isolated exercises.

> "Finally, a project-based learning approach to information visualization scaffolds learners through the whole data analysis and visualization pipeline rather than using different datasets and subjects at each stage. In this way, the process becomes iterative, rather than idealized and procedural, and the learners may return to prior stages as they encounter hurdles or identify better questions to ask (D'Ignazio and Bhargava 2018)."

In addition, Spence (2014, 3) proposes the use of a workshop format that allows breaking the traditional teaching format and strengthening relationships between students.

Regarding the organization of the weeks in which the course takes place, the reviewed cases allowed us to identify two main trends. The most common considers that the beginning of the course is mainly characterized by lectures and tutorials and then they move on to the practical part. In the other, shorter cycles are built in which lectures and exercises are mixed throughout the course.

3.4. Problems and recommendations

Series of problems and recommendations were recognized that are important to take into consideration. A problem that was mentioned in several cases was the difficulty of finding datasets to be used by the students. Datasets are often large and complicated (Kerren, Stasko, and Dykes 2008, 74), and cleaning and preparing existing datasets can take much of the course. Associated with this point "[t]oo often, students think of data as pure, unmodifiable fact" (Wolfe 2015, 357). Therefore, it is necessary to teach students that the process of reading and preparing the data includes subjective actions that can open to different interpretations. Another common problem is that some authors faced difficulties in getting students to read the readings assigned to them. (Kerren, Stasko, and Dykes 2008, 74). Regarding the tools, it was observed that students could spend much of their time learning new tools instead of addressing the course content (von Landesberger et al. 2016) and some tools are only available through the payment of a license.

Among the recommendations collected, some authors emphasized the importance of starting projects as soon as possible (Lo, Ming, and Qu 2019, 12), this contributes to developing learning by doing and PBL strategies. Some authors recommended staying flexible in order to monitor the speed with which conditions around the teaching of these topics change (Kerren, Stasko, and Dykes 2008, 86). While others pointed out that the course requires a balance between freedom–so that students can explore and progress–with the activities and requirements that keep them busy in a regulatory framework that guarantees reaching the proposed objectives (Burch and Melby 2020, 896). Lo, Ming, and Qu (2019, 12) also recommended using tools with minimal setup to be useful to students with different backgrounds. On the other hand,

Kammer, Stoll, and Urban (2021) point out that "[s]tudents should work scientifically and individually acquire knowledge about a specific topic" and that the instructor should prioritize the adaptation of existing materials.

Two important recommendations that emerged from the review of these cases have to do with the nature of the studied topics and its communication process. Regarding the topics, it is recommended that students "ask questions that have meaning for themselves and their communities" which contributes to their motivation (D'Ignazio and Bhargava 2018), but also promotes the communication of relevant and pertinent information.

In the same sense, Lo, Ming, and Qu (2019, 12) recommend using "non-trivial, manageably sized, real-world and engaging datasets" since the information is authentic and contributes to stimulating students. For example, Battista and Conte suggest selecting a social justice issue with "clear implications for the politics of gender, race, class, sexuality, or geography" (Battista and Conte 2017, 149).

Regarding communication, Ryan et al. (2019, 99)–who reviewed thousands of job offers associated with data visualization–noted that 47% also required communication skills, which is usually an important differentiating aspect among candidates, since only 10% said they have this skill. Precisely, the central axis of data visualization is to face the communication difficulties that authors and institutions are having with rapidly diversifying media (Chong 2012).

4. CONCLUSIONS AND PROPOSED COURSE

This research has contributed to update and understand the current existing knowledge around teaching data visualization. More specifically, a series of interesting conclusions can be defined from the proposed questions. First, two main trends in data visualization courses have been identified, those focused on coding and directed to data scientist and those multidisciplinary courses where a broader range of tools are used, and design tends to have a predominant role. These trends showed complementary and both necessary. Second, data visualization interest in higher education has been growing exponentially, recognizing the need to prepare the work force in this requested skill. The review found documented cases from different countries since 2008, but most of them were published in recent years. Third, an incredibly predominant number of the data visualization courses prioritize practical exercises over theoretical content. Using approaches such as learning by doing and PBL some of them organize a series of shorts exercises while other focus only in one or a couple of them. To these, lectures, tutorials, and discussions are complementary. Fourth, the difficulties that some of these courses found are also common to other disciplines such as lack of interested in readings or students without experience in the required tools. Other were much more specific such as the difficulty of finding datasets to be used by the students. Fifth, among the clearest and most common recommendations the authors pointed at looking for interesting topics for the students to promote their engagement that also are relevant for the society in other to get meaningful results. In the same way, the authors also recommended to start the visualization process as soon as possible and spend the least possible time on learning tools. Some of them recommended to also include the development of complementary skills for data visualization such as communication.

Starting from these findings, a three-credits, graduate and upper-level undergraduate professional elective was created under the title *Visualization Research*. The course is offered by the School of Architecture but

open to all the students in the College of Arts and Design at Louisiana State University, which includes Architecture, Arts (Art History, Digital Art, Graphic Design, and Studio Arts), Landscape Architecture, and Interior Design.

Following the recommendations of most of the examples studied, *Visualization Research combines content-oriented sessions* and *project-oriented sessions*, but practical learning by doing and PBL exercises are predominant. For this reason, two thirds of the contact hours have been formulated in studio format, where the students can work in class with immediate feedback from the instructor and their peers. While the first sketches of the visualizations begin the first week of the course, to encourage learning by doing and make the best possible use of the time available.

The content sessions include lectures, criticizing provided visualizations by groups, and in-class exercises oriented to develop specific skills, practice new tools, or address common difficulties. At the beginning of the course, content sessions are devoted to topics such as finding reliable information, formulating research questions, and introduction to the basics of the scientific method. Subsequently, among the broad range of topics considered in the analyzed courses, *Visualization Research focuses on the* visualization process, visualization techniques, color usage, visual perception, accessibility, and copyrights in order to better respond to the students' design background. In the same line, the course defined four learning outcomes: Learners will be able to identify and organize useful data for visualization; Learners will understand the fundamental design principles and different types of data visualization; Learners will understand how to apply their design skills to represent and communicate data; Learners will be able to design compelling, complex, and diverse data visualizations.

Several authors mentioned that the students should be exposed to all the stages of the process, thus *Visualization Research* requires working individually to make a visualization from the beginning to the end. This process is divided into four stages: Research, First visualization, Second visualization, Final visualization, and Portfolio. The first stage is dedicated to defining the topic and searching for the data to be used. As recommended by several studied research, the definition of the theme is free, so the student can find a topic of interest, but it must be pertinent to the local context, improving its relevance.

As many authors had issues with students don't reading the given materials, in this case they are provided with a selection of videos from existing internet resources. They only had to read the documents that contained the data needed to develop their visualizations. Following other comments, to avoid having to deal with complex raw databases, the use of clean and organized data presented in reports from recognized organizations or scientific publications is prioritized.

Also considering the results obtained during the review, the course emphasizes communication as a commonly needed skill for data visualization experts. As example of this effort, the course was certified in the LSU's Communication across the Curriculum program, in which the university organizes courses where this skill in profoundly taught and developed. To get this certification, the course fulfilled the following objectives: instruction and assignments emphasizing informal and formal visual and technological communication; teaching of discipline-specific communication techniques; use of feedback loops for learning; 40% of the course grade rooted in communication-based work; and practice of ethical and professional work standards (LSU's Communication across the Curriculum program n.d.).

Visualization Research has been taught twice, both in 2022. First, in a 16-weeks spring semester (in-person with 17

students) and then in a 5-weeks intensive summer (online with 6 students). Below, two examples of the students' work (Fig. 2 and 3). The course is still under development and its results are still to be analyzed.

Finally, the results of this review and the proposed course are expected to be useful to other similar initiatives. Looking forward, this research will focus on further developing the Visualization Research course. As first step, it plans to evaluate the preliminary results obtained until now to contrast them with the conclusion defined from the scoping review to continuously refine and improve the learning experience. At the same time, the research expects to delve into issues that have not been included in this publication, such as the differences between the objectives and tools defined in the analyzed courses.

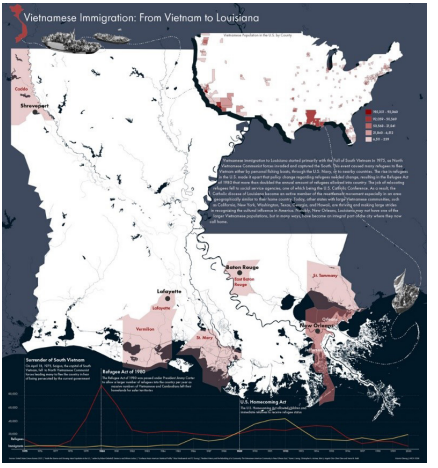

Figure 2. Vietnamese Immigration: From Vietnam to Louisiana. Student: Victoria Cheung

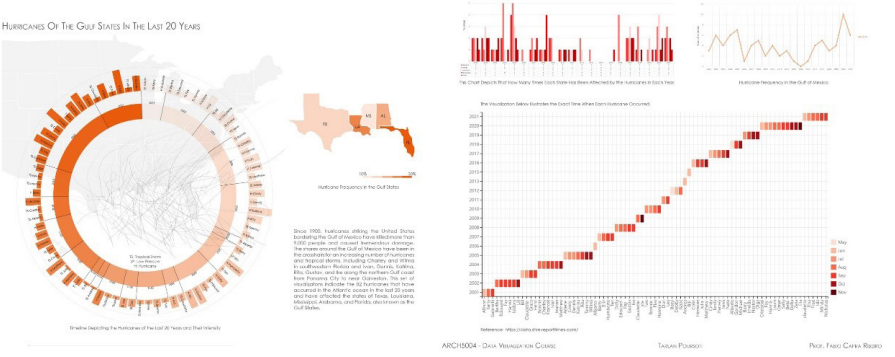

Figure 3. Hurricanes of the Gulf States in the last 20 years. Student: Tarlan Poursoti

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