Teaching Information Visualization

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Abstract. Teaching InfoVis is a challenge because it is a new and growing field. This paper describes the results of a teaching survey based on the information given by the attendees of Dagstuhl Seminar 07221. It covers several aspects of offered InfoVis courses that range from different kinds of study materials to practical exercises. We have reproduced the discussion during the seminar and added our own experiences. We hope that this paper can serve as an interesting and helpful source for current and future InfoVis teachers.

1 Introduction

Education is an important aspect of any emerging and rapidly evolving discipline and this is certainly the case in Information Visualization (InfoVis) with its emphasis on the exploratory development of knowledge. Most of the researchers participating in the Dagstuhl seminar and contributing to this volume are involved in helping students graduate with competencies in visualization. The growing number of courses in Information Visualization is matched by the variety of styles of courses offered, in terms of course content, materials used, and evaluation methodologies. Attendees at Dagstuhl seminar were curious to learn about the courses others offered and the approaches and resources that were being used, and so a session on Information Visualization teaching and education was held.

To prepare for that session and benchmark current offerings, Keith Andrews from Graz University, Austria, prepared a survey about InfoVis-related courses and distributed it to the attendees. The survey was intended to gather a variety of information, mostly demographic, including teaching styles, textbooks, enrollments, teaching aids, examinations, etc. Nineteen participants completed the survey and described their courses. This paper presents the survey results and includes the perspectives of some of the participants in relation to their own teaching experience in light of these and discussions amongst colleagues at Dagstuhl.

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The survey consisted of four different parts. The specific questions included in each part are listed below.

1. General Information
   (a) Instructor name
   (b) Educational organization
   (c) Title of course
   (d) Course home page (URL)
   (e) Last taught (date)
   (f) Course level (graduate or undergraduate)
   (g) Course hours per week
   (h) Course number of weeks
   (i) Enrollment (number of students)
2. Teaching Aids
   (a) Do you use one or more textbooks (yes, no)?
      i. If so, which ones?
   (b) Do you assign papers for compulsory assigned reading (yes, no)?
      i. If so, which ones?
   (c) Do you have your own set of lecture notes (yes, no)?
      i. URL (if available)?
   (d) Do you have teaching assistants for the course (yes, no)?
      i. If so, how many?
3. Practical Exercises (Projects)
   (a) Do you use practical exercises or projects (yes, no)?
      i. If so, please describe a typical exercise or project.
      ii. If so, how do you grade the practical exercises or project?
4. Examination or Test
   (a) Do you have an examination (yes, no)?
      i. If so, written or oral exam?
      ii. If so, please describe a typical exam question.

Firstly, we briefly review the results of the survey. Section 3 summarizes the topics discussed during the interactive session on teaching at the seminar. Finally a selection of participants reflect upon how these issues relate to their own experience of teaching Information Visualization in Section 4.

2 Results

We present the results in four sections, one for each of the sections of the survey.

2.1 General Information

The first part of the survey gives an overview of the courses offered at the different universities represented by the Dagstuhl participants and provides some details about the courses themselves. Table 1 shows the responses obtained from this part. A balance of European and North-American universities were represented by participants in the survey results. The majority of courses were focused on the "core field" of information visualization (about 68%). Two courses were about visualization/computer graphics in general, and the rest were about application fields (e.g. geographic visualization) or broader topics, such as information interfaces or visual communication. This scope reflects the broad and interdisciplinary nature of Information Visualization and provides some indications as to why developing an agreed Information Visualization curriculum may be difficult.

Most of the courses (79%) had their own publicly accessible web page providing access to course related information. Nearly all the referenced courses were given in 2006 and 2007. Since all the responding instructors are active researchers in the field as well, we can assume that all these courses covered the current state of the art in information visualization. Because the detailed curriculum for the courses was not part of the survey, we do not have details about actual course content. The web pages associated with each of the courses are a rich source of information however and we used these to gather keywords associated with the curricula of each. Figure 1 shows a tag cloud generated from these keywords that gives a flavor of the variety and importance of different topics across the courses. The dominant words reflect some of the tensions in Information Visualization education, with a collective need to focus on data—its dimensionality and structure, techniques for layout and visual encoding and people and their responses to these methods and the systems through which they are accessed. Perhaps the tag cloud and the varied responses suggest a need for systematic research to learn about the range of approaches that are used in teaching Information Visualization and related topics. The session discussion, summarized in Section 3, led to more insight about this, but it was not a comprehensive examination.

Most courses were taught at the graduate level, with only two being undergraduate courses. At the bottom of Table 1, descriptive statistics about the results of questions Q1g-Q1i on course duration and size are provided. The average duration of a course and the number of hours of weekly meeting time are relatively consistent across the group. Note that most class sizes are relatively small, echoing the fact that Information Visualization is still a relatively new and growing area. Here, the undergraduate course #16 seems to be an outlier because of its large enrollment. However, this course is a compulsory course on computer graphics and visualization, and the instructor plans to divide this course into two parts in the future.

2.2 Study Materials and Teaching Aids

Textbooks (Q2a): About 72% of all the instructors (13 in total) used one or more textbooks in their courses. The most popular books were those by Colin

Table 1. Results of Part 1 of the Survey on General Information together with a brief descriptive Analysis.

#	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q1g	Q1h	Q1i
1	Keith Andrews	TU Graz, Austria	Information Visualisation	[4]	Summer 2007	g	3	14	15
2	Jason Dykes	City University London, UK	GeoVisualization	–	Spring 2007	g	3	12	22
3	Achim Ebert	TU Kaiserslautern, Germany	Information Visualization	–	Winter 04/05	g	2	14	18
4	Helwig Hauser	TU Vienna, Austria	Information Visualization	[23]	Summer 2007	g	3	15	30
5	Jeffrey Heer	UC Berkeley, USA	Visualization	[25]	Spring 2006	g	3	16	20
6	T.J. Jankun-Kelly	Mississippi State University, USA	Information Visualization	[28]	Fall 2006	g	3	15	12
7	Daniel Keim	University of Constance, Germany	Information Visualization	[29]	Summer 2007	g	5	14	20
8	Andreas Kerren	TU Kaiserslautern, Germany	Information Visualization	[34]	Winter 06/07	g	2	14	9
9	Robert Kosara	UNC Charlotte, USA	Visual Communication in Computer Graphics and Art	[39]	Spring 2007	g	3	18	15
10	Kwan-Liu Ma	UC Davis, USA	Information Visualization	[43]	Winter 2006	g	3	10	12
11	Kwan-Liu Ma	UC Davis, USA	Information Interfaces	[44]	Spring 2007	ug	3	10	17
12	Guy Melançon	University of Bordeaux, France	Models and Algorithms for Information Visualization and Bioinformatics	–	Fall 2006	g	3	11	15
13	Silvia Miksch	TU Vienna, Austria	Information Visualization	[48]	Winter 2006	g	3	14	30
14	Tamara Munzner	UBC Vancouver, Canada	Information Visualization	[51]	Fall 2006	g	3	13	15
15	Chris North	Virginia Tech, USA	Information Visualization	[53]	Spring 2007	g	3	15	25
16	Jonathan Roberts	University of Kent, UK	Computer Graphics and Visualisation	–	Summer 2005	ug	2	12	60
17	John Stasko	Georgia Tech, USA	Information Visualization	[64]	Spring 2006	g	3	15	35
18	Matt Ward	WPI, USA	Data Visualization	[70]	Spring 2006	g	3	14	10
19	Jing Yang	UNC Charlotte, USA	Information Visualization	[72]	Spring 2007	g	3	11	9
						Arithmetic Mean	3	14	20
						Median	3	14	17
						Standard Deviation	0.6	2.1	12.1

Fig. 1. Tag cloud of course topics. Includes courses with Web pages in the English language for which a URL was provided.

Ware and Robert Spence. The following list shows all books used by instructors of InfoVis courses in descending order of popularity.

1. Information Visualization: Perception for Design. Colin Ware [71].
2. Information Visualization: Design for Interaction. Robert Spence [62].
3. Readings in Information Visualization: Using Vision to Think. Stuart Card, Jock Mackinlay, and Ben Shneiderman (Eds.) [8].
4. Envisioning Information. Edward Tufte [67].
5. Visualisierung – Grundlagen und allgemeine Methoden, Heidrun Schumann and Wolfgang Müller [58] (in German).
6. – Human-Centered Visualization Environments. Andreas Kerren, Achim Ebert, and Jörg Meyer (Eds.) [35].
   – Information Visualization: Beyond the Horizon. Chaomei Chen [9].

Some respondents noted that they also used Tufte's other books [69, 68] for specific aspects of the course or as a focused topic, rather than as a general textbook. Other courses cover more general fields, such as (Data) Visualization (#5, #18, . . .), with information visualization as part of them. In these courses, other textbooks were used, for example the VTK Book [57], *Designing Visual Interfaces* by Mullet and Sano [50], or [58, 30, 42, 16, 18]. Those teaching visualization in a particular domain (e.g. GeoVisualization (#2)) used more specific texts associated with the relevant discipline [60, 15, 49]. Figure 2 shows the usage of books for all courses listed in Table 1.

Papers for Compulsory Assigned Reading (Q2b): 68% of the courses used research papers for compulsory assigned reading. Many different papers were used so an exhaustive listing here is not appropriate. Most papers were

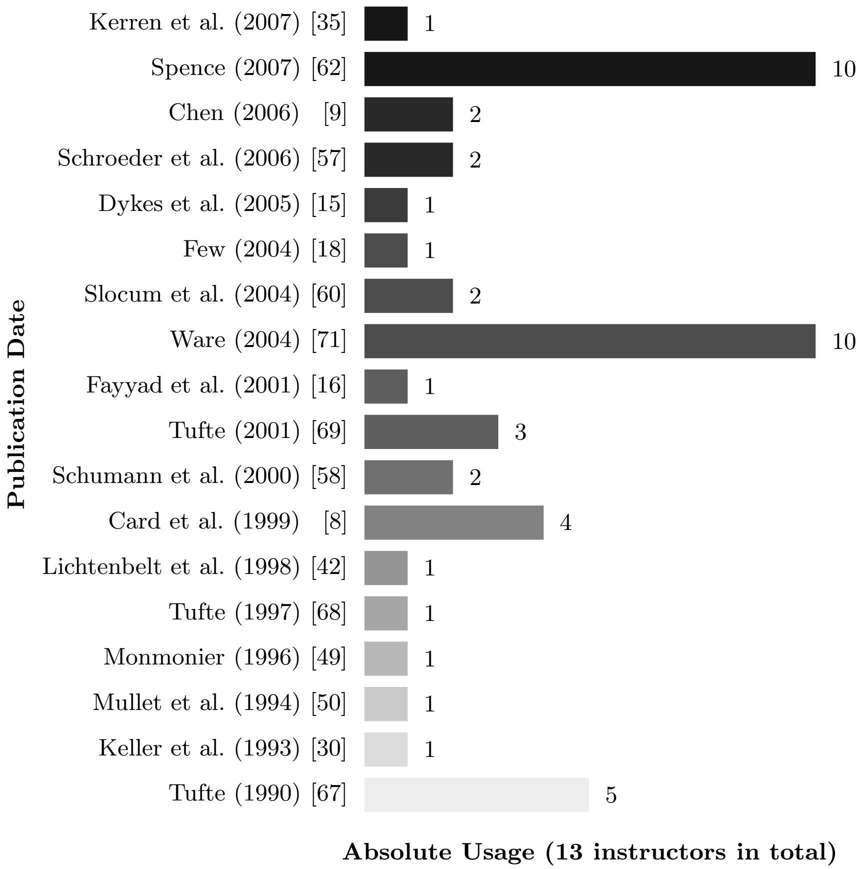

Fig. 2. Usage of books for all courses ordered by publication date.

selected from the IEEE InfoVis and Vis Conference proceedings as well as from the ACM CHI proceedings.

Students typically had to prepare a short presentation about a research paper in these courses. This helps students gain skills in oral communication (particularly if presentations are critiqued in class) and helps the courses to explore a variety of different visualization approaches and techniques in discussion. Such a presentation also could be part of a larger practical exercise or project (see Section 2.3).

Own Lecture Notes (Q2c): Interestingly, all the instructors used their own course lecture notes (many as PowerPoint slides). 58% published their lecture notes on the course web site without any restriction. We assume that the remaining instructors either offered their notes on the web with restricted access or simply used the notes to lecture from.

Teaching Assistants (Q2d): More than the half of all instructors (58%) had no teaching assistant (TA) to support their course. In these cases, we can assume that instructors also supervised practical exercises which were offered in almost all courses. Only two courses were supported by two TAs, and the rest had one TA. These figures may be due to small classes that were reported in most cases, but might be indicative of a lack of support for teaching and learning in Information Visualization, which is a very practical activity. Any such trend may be of concern to InfoVis educators.

2.3 Practical Exercises

Survey analysis showed that nearly all courses (95%) had practical exercises or projects. However, a wide variety of different types of exercises were noted. One of the most common practical exercises cited was to have students use InfoVis tools and then critique them. For example, students may choose from a set of provided interesting datasets (election results, finance data, etc.) and then they examine the datasets using the different InfoVis systems to reason about analytic questions or tasks provided by the instructor or generated by the student. These exercises often conclude with a written report evaluating the tools and their effectiveness for the analysis. Alternately, some instructors give students freedom to choose/generate their own input data. From the survey results, the tools used most in such exercises are as follows:

- *Spotfire*, TIBCO Software, Inc. [63],
- *TableLens*, Inxight Software, Inc. [66],
- *ILOG Visualization Suite*, ILOG, Inc. [26],
- *Tableau Desktop*, Tableau Software, Inc. [65],
- *InfoZoom*, humanIT Software GmbH [27], and
- *KidPad*, University of Maryland [38].

The KidPad tool provides a set of zooming user interface and visualization facilities so it can be used to develop small stand-alone visualizations on individual topics. Thus, students may be asked to build a visualization on the basis of self-chosen or self-generated data sets together with some conditions, e.g., to think about designing overviews or spatial layout.

Another common approach of practical exercises is based on the idea that students should implement the fundamental idea of a research paper. As a first step, students (typically groups of at most three students) choose a paper from a list given by the instructor. Next, the students prepare a brief presentation to explain the fundamental idea and to give an overview on the planned implementation. This presentation helps to minimize the danger that the students will become too focused on low-level details. To conclude, the students present and demonstrate their tools in the classroom.

A last example of a common practical exercise is based on a special type of data in information visualization: graphs and networks. In order to help students better appreciate the difficulty of graph layout, the instructor has students draw a small graph of 10-15 nodes based on only the connectivity of the graph's vertices. Students are instructed to make their graph drawing as aesthetically pleasing as possible. When all the drawings are submitted, students view all the different efforts and vote to select the best ones. In class discussion, students explain why they voted as they did, and this can lead to a discussion of graph drawing metrics, e.g., that edge crossings and bends have a negative effect on aesthetic quality, etc. Such metrics are the basis of graph drawing algorithms that could be analyzed by the students in a second step.

Grading of Practical Exercises: One can classify the described approaches for practical exercises into two main groups:

1. implementation of a specific technique or implementation of a visualization to solve a specific problem, and
2. examination of the usefulness of a given tool or visualization approach, such as a commercial visualization system or graph drawing metrics, etc.

Grading of assignments of the first type can based on the overall quality of the implementation itself, i.e., the instructor and/or TA evaluate the needed time, aesthetic aspects, level of effort (complexity), usability, and capability provided by the tool to get more insight about the chosen data set. Both types of assignments can be combined with an oral presentation in the classroom. In this case, the quality of the presented slides, lecture style, originality, and the presentation quality itself can be used to evaluate presentation skills if these are intended learning outcomes—and it is increasingly acknowledge as desirable to incorporate the teaching and learning of skills into the subject-area curriculum rather than dealing with this independently. The survey yielded one interesting case in which the students themselves voted on the best presentation(s).

2.4 Examination

More than the half (63%) of the surveyed courses had examinations of some kind. The most common form was a written exam (37%), particularly in the United States, but a notable portion (21%) used oral exams and 5% used both. Oral examinations were used in Europe only, where there is a tradition of oral examination for advanced level courses.

The survey also gave some insight into the different kinds of typical exam questions (Q4a[ii]). There are a lot of different variants; a selection of the most asked questions includes:

- Explain technique X for the visualization of problem Y.
- Given is a concrete problem and a task to be fulfilled. Which technique would you use?
- Compare technique X with technique Y.
- Explain the construction of a Treemap, Starplot, Circle Segments, ...
- What are the advantages/disadvantages of technique X?
- What is a preattentive feature?
- What are the principles of using color?

This list only gives a rough overview about the issues that are important for the instructors. The course web pages do not provide additional detail—we found no specific exam questions or model answers when investigating methods of examination further. In general, we could observe that examiners focus not only on technical approaches or methods, but also students' capabilities for critical reflection and to demonstrate their working knowledge of human visual perception.

3 Seminar Discussions

In the seminar session about teaching, Keith Andrews first presented the initial survey result data. Next, workshop attendees discussed a variety of issues related to teaching including "best practices" and ways to improve all our courses.

Curriculum:: A common problem reported by the attendees was some uncertainty about how to logically organize the set of topics in an InfoVis course. For example, Robert Spence's 2nd edition textbook on information visualization follows the classical pipeline model of representation (data types, tree representations, ...), presentation (space and time limitations, including zooming, distortion, ...), and interaction (navigation, browsing, mental models, ...) [62]. Many alternative ways of organizing course content exist, however. One suggestion was to consider four cross-cutting dimensions: data types, domains, techniques, and methodologies. Cognitive and perceptual issues were presented as an alternative dimension of importance. The group did not come to any decisions about what the most suitable structure would be since this is clearly dependent on the orientation of the course and its learning aims. Simply being aware of alternate orderings is valuable as instructors consider alternatives however.

Study Materials: The discussion on the use of research papers for compulsory reading identified many different strategies for doing so. Many attendees echoed a frustration about the difficulty in getting students to actually read assigned articles, so many of the strategies addressed this particular issue. Several participants reported about their own experiences and ideas, a number of which are listed below.

– Papers are assigned, and students must present them. This takes place in parallel with the regular lectures. This procedure seems to be pedagogically beneficial because students learn to read actual research work, to prepare a short talk and to give a presentation in the classroom. A disadvantage is that student presentations vary greatly in quality. Some colleagues reported on students losing interest in and not learning from poor presentations—they would prefer the instructor to do all the lecturing. It is unclear if this is truly a disadvantage, however. Perhaps, the amortized learning benefit is high enough and this would justify the approach.

- The instructor gives lectures on mandatory meetings. Students can pick specific topics and lecture about a topic that the other students have not read about.
- Papers are assigned, and there are written/oral questions on readings.
- Papers are assigned, and students must write a structured critical review (about half a page) of them, i.e., a paragraph on the paper's content, an evaluative paragraph and an indication as to whether and why other students might read the paper.

Practical Exercises: Software projects or practical exercises were viewed as being very important to most attendees. These projects allow students to demonstrate/learn the difficulty of many practical problems, such as the drawing of a graph or navigation in large information spaces. Using a visualization tool (Spotfire, TableLens, ...) allows the students to interact with different visual representations and to gain experience about the advantages/disadvantages of different visualization techniques. Furthermore, students become acquainted with commercial tools. One interesting experience of attendees following this approach was that students' negative impressions of InfoVis systems mostly involved user interface or HCI issues, not the actual visualization technique(s).

One problem with such exercises is the potential difficulty in gaining commercial software for use in the projects. More vendors are making their systems freely available for educational use, however. Tableau Software is an example of a company doing so. Another issue is the challenge of finding "good" data sets to be used by the students. One suggestion was use data sets from previous InfoVis Conference contests but most attendees felt that the contest datasets are too big and complex for introductory courses. Still, the contest data sets may be suitable for advanced level courses where students have a good background in the most important techniques. Perhaps, the contest should include the production of a data subset, specifically designed for educational purposes.

Using Other Media: Workshop attendees discussed that a large and comprehensive public collection of InfoVis-related images and videos would be very helpful for instructors. Videos of interaction scenarios that show the usability and interaction capabilities of the tools would be especially beneficial. Images also could help to illuminate the history of InfoVis and illustrate different visualization techniques. Unfortunately, gathering a collection of images or videos in this way could cause copyright problems. This may be why many instructors have their own image/video archives with private access. The HCC Digital Library [24] of Georgia Tech is an example of an effort to gather a large collection of educational resources, but it is focused broadly on HCI, not just InfoVis.

Another possibility to obtain video material is to examine conference DVDs, such as the annual VIS/InfoVis/VAST DVD. Many contributions provide an additional video to clarify the usage and interaction techniques of their work. Again, it may be beneficial to encourage attendees to develop video summaries of their work, specifically for teaching and learning.

4 Personal Perspectives

In this section, three of the workshop attendees provide their own unique perspective on teaching InfoVis and InfoVis-related topics.

4.1 John T. Stasko, Georgia Institute of Technology, USA

I have been teaching a graduate course on Information Visualization at Georgia Tech since 1999. My university changed from a quarter system to a semester system then and I decided to create a course for this area that was becoming my research focus and growing in interest worldwide. Over the years I have thought of this course not merely as a teaching assignment but as a fundamental part of my academic portfolio and research mission. The course provides training for students to learn about the area and do subsequent research with me, or simply to apply their knowledge in business or government. Also, the course has directly led to a number of the research contributions made by students in the course and by my research group. Student projects from the course have won major contests [20, 54] or led to research papers [12]. Additionally, my dissatisfaction with the state of knowledge and background articles on particular course topics led to projects undertaken by my research group in those areas (i.e., analytic goals [3], user tasks [1], and interaction [73]). Below I will provide more details about the course and the projects that have resulted from it.

The Information Visualization course (CS 7450) is usually offered in the Spring semester each year. At Georgia Tech, semesters are 15 weeks long and and my course meets for 1.5 hours twice a week. The web pages for the most recent course offering can be found at `http://www.cc.gatech.edu/~stasko/7450`.

Human-computer interaction (HCI) is an important area of research in my home School—we have both a Masters degree in HCI and a doctorate in Human-Centered Computing (HCC), in addition to our undergraduate and graduate degrees in computer science. Students are drawn to the HCI and HCC degree programs from a variety of undergraduate majors, so many do not have formal computer science training. I made a conscious decision to designate the graduate HCI course as the only prerequisite for Information Visualization in order to encourage students from a wide variety of disciplines to enroll. Consequently, many students who do not have a strong background in programming typically take Information Visualization.

This fact has implications on the way that I teach the course. I do not use homework assignments in which the students must implement a visualization technique or system. Instead, assignments are more oriented toward design, critiquing and evaluation. I employ a group project where I do require that some type of software system be built, but the course demographics allow there to be at least one or two team members who are experienced programmers.

My high-level goal for the course is to have students learn the different information visualization techniques that have been created including the strengths and weaknesses of each, and to have the students become better critics of information graphics and visual systems. More specifically, the learning outcomes for the course include

- Students should gain an in-depth understanding of the field of Information Visualization including key concepts and techniques.
- Students should be able to critique visualization designs and make suggestions to improve them.
- Students should be able to design effective visualization solutions given new problems and data domains.
- Students should learn about the spectrum of commercial system solutions available in this area and how to choose one for a particular task or problem.

Perhaps the main challenge that I have faced in this course over the years is to construct a coherent syllabus and flow of topics throughout the term. Information Visualization is still a new area that is growing and maturing. Consequently, it does not exhibit a well-understood and agreed-upon set of topics that flow smoothly from one to the next. In my experience teaching the course, a number of key ideas have risen to the surface and I make these the important components of the course:

- **Data foundations** - A description and model of the different types of data that are encountered and how this data is transformed and stored for easier subsequent manipulation.
- **Cognitive issues** - A discussion of the user's goals and tasks in using an information visualization system. What cognitive benefits can visualization provide?
- **Visualization techniques** - A description of the different visual representations and interaction techniques that have been invented.
- **Interaction** - A discussion of the different types and the many issues surrounding interaction.
- **Data types/structures** - An introduction to specific types of data (e.g., time series, hierarchical, textual) and the visualization techniques that are well-suited at representing those data types.
- **Data domains** - An examination of different domains (e.g., software engineering, social computing, finance and business) and the visualization techniques that are helpful to people working in those areas.
- **Evaluation** - A dialog about the challenges of evaluation in information visualization and a review of different evaluation techniques that have been used in the area.

Some of these topics are fundamentally interwoven so the flow of concepts is not clearly self-contained and independent. For instance, certain visualization techniques are best used for specific data types (e.g., treemaps for hierarchical data). In organizing the course content, I feel this tension and often struggle with which topics to teach first. Nonetheless, my course uses this progression of topics as its organizational framework.

The course is lecture-based but I try to engage the students in discussions about the different concepts being studied. I have used Bob Spence's textbook some terms augmented by selected papers, and other terms I have used only research papers. I have settled on having students read one or possibly two research papers for each class. Typically, the paper is an important one for that topic or it is a good overview of the issues involved. When I have assigned more papers than this, I find that the students often do not adequately prepare and read all the papers. To cover more recent research, I typically select two or three recent articles on the topic of the day and I assign two or three students who must recap and describe their particular paper's key ideas to the class in less than five minutes. I believe that experience giving presentations like this is important and valuable to the students. All of my lecture slides can be found at the course website and in 2007 I created in-studio video versions of each lecture. These videos can be found at the website `http://vadl.cc.gatech.edu`.

I use a number of relatively small homework assignments in the course, along with one larger homework and a group project. I will frequently employ a midterm or final exam as well. The small homeworks often involve a visualization design exercise (on paper) given a data set. Of course, such assignments do not engage the interactive component of information visualization that is so important, so they are fundamentally limited.

The larger homework assignment is a commercial tools critique. Students are given five example datasets and asked to choose the two that they find most interesting. Before using any systems, the students examine the datasets and generate questions about them. Next, the students use a few information visualization systems to explore the data and try to answer those questions. I also alert the students to note any serendipitous findings that occur during exploration. Finally, the students must write a report in which they critique the different systems used, the visualization techniques each employs, and whether the systems led to insights and discoveries. I have used systems such as Spotfire, SeeIt, Advizor, Eureka (Table Lens), InfoZoom, InfoScope, and Grokker over the years. I find this assignment to be extremely valuable to the students as it allows them to gain hands-on experience with sophisticated systems and shows them how visualizations can (or cannot) be helpful in analysis and exploration.

This particular assignment even led to an interesting research contribution by my group. We studied the analytic queries generated by students over many years of the course and clustered these inquiries into different low-level analytic tasks that visualizations may assist. Our taxonomy of these tasks was presented at the 2005 Symposium on InfoVis [1].

I also employ a group project in the course in which students design and build a visualization system for a particular problem and data set. Teams of three or four students work together for most of the term and find a client with a data analysis problem or they simply choose a data set and envision the kinds of analytic queries that one would expect on it. The students explore different visualization designs, then they choose one to implement. In the past, student teams have often chosen to work on the contest datasets from the IEEE InfoVis or VAST Conferences. In fact, student teams from my course have won these contests on multiple occasions or have had competitive entries in the contests [20,54]. Group projects have even led to full papers at the InfoVis Symposium as well [12].

One ongoing tension with the group project is simply when to begin the assignment. By initiating the project early in the term, students have more time to work on it and make better progress. However, at that early point, students have engaged very little course material and so their understanding of information visualization concepts and ideas is not as rich. I have found that the simple topic chosen for the project can have a profound impact on the results, and better knowledge of the information visualization area leads students to make better choices in project topics. This has led me to wait until the midterm point to distribute the project in some semesters, but then the students have much less time to work on it.

Overall, the Information Visualization course has been valuable to me in many different ways. Perhaps most importantly, the process of preparing lectures and course material has made me reflect on the topics that I would be discussing and question "accepted" knowledge in the domain. I believe that this has made me a better researcher and it has generated ideas for new projects and investigations.

4.2 Andreas Kerren, Växjö University, Sweden

My experiences in teaching Information Visualization go back to the year 2003. At this time, I was a temporary assistant professor at the Institute of Computer Graphics and Algorithms of the Vienna University of Technology, Austria. The institute offered one course on InfoVis and several other related courses. In this environment, I had the opportunity to give several lectures on Software Visualization and domain-specific visualization, such as visualization in Bioinformatics. In 2005, I moved to the University of Kaiserslautern in Germany. There, I was responsible for the annual InfoVis courses. Based on my experiences from Vienna and current flows in research, I designed a completely new syllabus for this course. Originally, this syllabus provided 15 lectures (one semester at TU Kaiserslautern) plus practical exercises for Masters level students; each lecture took 1.5 hours once a week. As I have been appointed for a faculty position at Växjö University (VXU), Sweden, in 2007, some modifications were needed to address the different course and teaching system at this university. Web pages (in English) for the most recent InfoVis courses at VXU can be found at `http://cs.msi.vxu.se/isovis/courses/`. In this section however, I will focus to my experiences with my courses given at TU Kaiserslautern from 2005-2007, because the details of my last course there (in the winter semester 2006/2007 (WS06/07)) reflect my particulars within the Dagstuhl survey.

My general learning aims for the course are more or less identical to John Stasko's four learning outcomes at Page 76. Therefore, I don't want to repeat them at this place. It was very important for me to give students the opportunity for critical reflections and to show the newest directions in research. Furthermore, my course covers basic principles from cognitive psychology that have influence on InfoVis, such as human visual perception or Gestalt laws. As a result of this position, each technical approach and tool was discussed with respect to its value (please compare [17] in this book), its usefulness, and—if existent—its usage in

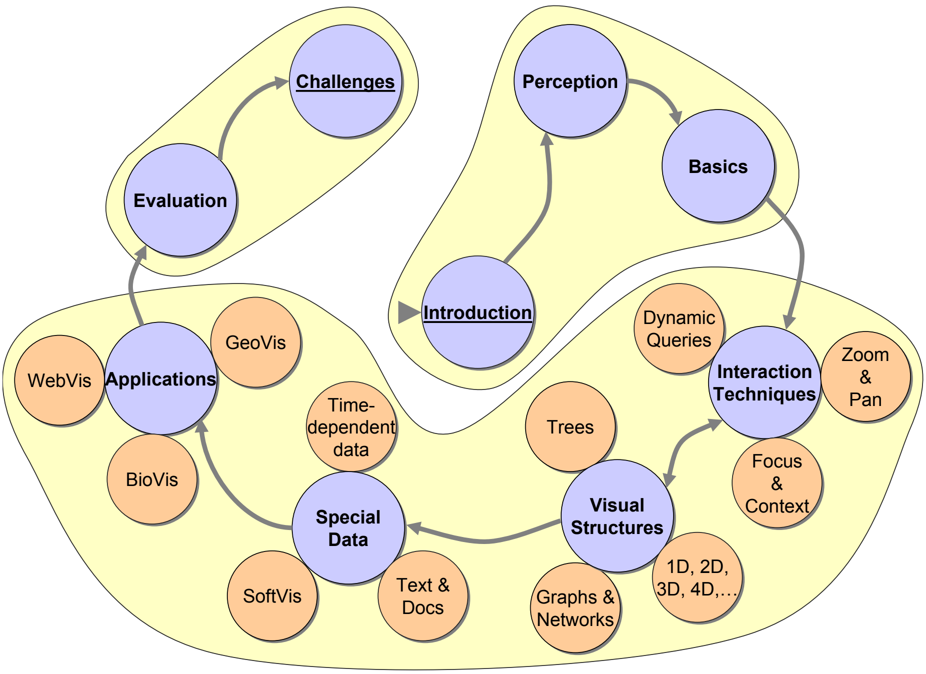

Fig. 3. Course structure of the WS06/07 InfoVis course given by Andreas Kerren at TU Kaiserslautern.

commercial products. Of course, this was a challenge and sometimes a little bit subjective because of missing quality metrics or missing evaluations of tools and techniques.

The design of the syllabus was partly influenced by courses given at Georgia Tech and TU Vienna in 2005 as well as by the textbooks of Spence [61], Ware [71], a pre-version of the textbook of Kerren et al. [35], and many research papers. The course is divided into three parts which are illuminated by Figure 3:

1. In the first part, I discuss basic knowledge that is important for the design or analysis of InfoVis concepts. As a first step, I introduce the field itself, give motivations for the need, and present several traditional and modern examples, mainly from Tufte's [67, 69] and Spence' books. Important is the differentiation between InfoVis and SciVis, also, if that is not so easy in some cases. After this introduction, a larger discussion on perception and cognitive issues is given. Here, I provide information about the perception of colors, textures, etc., preattentive features, and Gestalt laws. This course component is mainly based on the book of Ware, but also on a lot of examples and animations that can be found in the WWW. The last lecture of this first part describes basics, such as the InfoVis Reference Model (data tables, visual mapping, interaction, etc.) or data types and dimensionality. These issues are mostly based on the book of Card et al. [8].

2. The second part is the largest one of my course. Here, I discuss the most important interaction techniques at first, for example Dynamic Queries, Zoom&Pan, and several Focus&Context related techniques. This component is more or less geared to the InfoVis Reference Model [8], i.e., I distinguish interaction by means of data transformations, visual mapping, and view transformations. I use actual research papers to exemplify the different approaches. From a didactic point of view, this is a little bit tricky, because I presume some knowledge in visual representations or structures to explain my examples. I decided to discuss interaction at first and the visual structures for different data types after this. One advantage is the possibility to refer later to discussed interaction techniques directly with less additional explanations. My experiences with students show that they accept this order, and that they have no problem in understanding the differences/correlations. But this should be communicated previously.

   As described before, a discussion of the most important visual structures for more basic data types follows the interaction component. Here, I introduce visualization techniques for multivariate data, hierarchies and graphs mostly on the basis of research papers as well as the books of Spence and Kerren et al. Individual solutions for special kind of data types, e.g., time-series data, text, or software, follow this component directly. The second part finishes with visualization techniques for different data domains, such as BioVis, WebVis, GeoVis, etc. During the past years, I vary this part of the lecture a little bit depending on my current research interests or hot-topics. Resources for these lectures are current papers and articles, but also the second part of the textbook [35].

   Each course component of this second part is accompanied by short video or tool demonstrations. From my perspective, this is absolutely needed, especially for the different interaction techniques and their interplay with visual structures. It is fun to keep an eye on the students during such demonstrations, and as a result they are motivated to ask deeper questions. One interesting and traditional example is the claim to preserve the mental map in dynamic graph drawing. Only with the help of a video or demo it is possible to illustrate the difference between morphing or other techniques, such as foresighted layout [14]. However, the usage of video or tools is not always possible because of unavailability.

3. My course concludes with 1-2 lectures on possible evaluation techniques and the most important InfoVis challenges for the next years. Because of the missing time at the end of the semester, I focus on specific aspects of these issues. For example, the intended learning aim is to impart students an overview knowledge of basic evaluation techniques and—perhaps more important—an impression of the difficulties to perform such an evaluation. The final discussion of the most important challenges gives an idea about the current state of the field and leads to take part of it, for example, by working on a thesis in my research group. A good source for these issues are the corresponding chapters in Kerren et al. [35].

Another important part of the course are the assignments. They are composed of a brief presentation, of a software implementation, and of a short software demonstration at the end of the semester. Each student or student group (consisting of maximal two students) chooses a specific research paper from a list given on the course web page. I take care that the papers' topics and the presented approaches are not too complex. The final aim of the assignment is that the *main idea* of a paper should be implemented in any programming language. It is not needed that all features or interaction possibilities are implemented. But a GUI is mandatory in order to give me and the other students the chance to load another input file etc. Data sets depend on the paper topic, e.g., if the paper presents a new treemap layout then the students can choose their own input, such as the hierarchical file system on their own personal computer. All these topics should be discussed in the first presentation in the middle of the course. In a first step, each student or group prepares a presentation (10 minutes plus 3-5 minutes of discussion) about the chosen paper followed by a working plan. In this way, I can steer the processes, give hints, and prevent nasty surprises. At the end of the course, all implementations are presented and discussed in class. I have found that this division into two presentations and demos respectively helps students to think about important concepts. Furthermore, they have already learned the most important theoretical concepts during the course before they start to program. My overall impression of this practical project is very positive. At the beginning, the students often had doubts because it appears time-consuming and complex, but they had a lot of fun in the progress of the semester. The results were mostly really great; for me it is important that they learn to see the difficulties and to carefully reflect about the paper, not so much the result itself. Often, however, the resulting programs were amazingly good. My pedagogical concept, especially for the assignments, clearly follows moderate constructivistic learning approaches, as described in the following written by Jason Dykes or in some of my papers on learning concepts in context of using Software Visualization techniques [33, 32, 59].

The course evaluation by my students led to very good results for this course. They liked the way I structured the course, the motivating examples and videos, and they had the subjective feeling that they have learned a lot of interesting things. At large, it was not difficult to motivate students for InfoVis. It is a very interesting field also suitable for the solution of practical problems. Therefore, it was sometimes not so easy to explain why people cannot find more InfoVis in standard software products. This leads to a problem that is discussed in paper *The Value of Information Visualization* [17] of this book.

I would like to discuss one further issue that is important to me: Finding a good balance between giving a good overview of the field as compared to explaining the details of specific visualization techniques is pretty difficult, especially in the frame of 15 course lectures. Some students liked to get more overview knowledge of InfoVis, but they also disliked that some topics were only briefly covered. For instance, I used 1-2 lectures for the visualization of graphs. It is enough time to explain the most important things, but not enough time to explain the different graph drawing techniques in detail. Thus, I abstracted in many cases, but some students would like to learn more. The level of detail/abstraction in teaching InfoVis is not obvious. In general, my solution for this problem is to offer a seminar back-to-back after the InfoVis course, where interested students can choose a specific topic and prepare a presentation on it. This allows for more deeper discussions. Additionally, such a seminar is a good starting point for subsequent thesis work.

Typically, my courses terminate with an oral examination. Regarding our survey results, this is consistent with the examination practice of many colleagues coming from Europe, cp. Section 2.4.

4.3 Jason Dykes, City University London, UK

Introduction and Context: My background is in geography and the geosciences, where there is a strong tradition in the use of maps and graphics. Traditionally undergraduate courses in geography have taught and assessed manual skills in cartography and mapping activities and projects remain at the core of many geology degrees. Increasingly these activities are being augmented or replaced by learning that involves Geographic Information Systems (GISystems) and other digital techniques, but a focus on cartographic principles for designing effective maps and communicating geographic information effectively is still regarded as important.

My 'Visualization' Module. I have been teaching a Masters level module in 'GeoVisualization' for eight years. The postgraduate module was originally developed to provide Geographic Information Science (GIScience) students with skills in creating, evaluating and using maps and graphics in their analysis and communication of geographic information. It replaced a cartography module and updated this with recent advances in the use of dynamic and interactive graphics for exploratory analysis.

During this time the GIScience community and GIScience students have become more aware of Information Visualization. Equally students from non GI programs have wanted to learn about cartography and visualization. It is challenging to develop a coherent module that is relevant to this range of students whilst embracing Information Visualization and a traditional cartography syllabus.

My module consists of 12 sessions with 3 hours contact time and 7 hours guided individual study. Students are expected to spend another 30 hours participating in assessed activities. The module is thus designed such that an average student spends 150 hours studying for 15 credits—-it uses a shared credit framework that does not conform to the requirements of the Bologna process [5]. The module is available to distance learners through a managed learning environment and digital resources ensure distance learners have an equivalent experience those who attend campus.

Many students go on to do research projects in visualization involving data sets and applied problems that feed my research and are subsequently used in teaching. This effective feedback loop is important in perpetuating bi-directional links between research and teaching.

Teaching Issues in Information Visualization at Dagstuhl: I don't know the content or culture of InfoVis or Computer Science education. This is one of the difficulties associated with having interests that lie between rapidly developing disciplines. But the Dagstuhl discussions and survey suggest that many of those involved are facing similar issues with which I am familiar. The survey draws attention to a range of approaches, topics, academic disciplines, text books involved.

There is great variation in the approaches and syllabuses of the courses reported in the survey. 'Information Visualization' is the most popular title, but course names that begin: 'Models and Algorithms for ...'; 'Data Visualization'; 'Computer Graphics and ...'; 'GeoVisualization' are evidently situated in different ways and will require different emphases. This is evident in Figure 1—a tag cloud showing relative occurrences of topics listed in courses included in the Dagstuhl survey.

Despite this texture, some consistent themes emerge from the survey and particularly the discussion at Dagstuhl. Three particular themes resonated with me and related to my experience. They are also evident in a report produced following an open workshop at IEEE Visualization 2006 in which I graphically depict the relationships between related courses with an Information Visualization emphasis [56]:

1. a trend/desire for evaluative and critique-based learning that can draw from a range of related disciplines;
2. an emphasis on 'learning through doing' as opposed to a transmissive approach to learning;
3. some concern about developing appropriate exercises and assessment for visualization classes.

I'll briefly consider these key issues and reflect upon their relationship with my teaching. Doing so may provide some synergies in the cross disciplinary educational mash-up that is developing in Information Visualization.

Critiquing: Critiquing involves students applying and developing their knowledge through evaluation and review. Robert Kosara argued convincingly for a critique-based approach to Information Visualization at Dagstuhl. He describes this as a 'highly interactive and human-centered way of designing things' [40]. An approach that evaluates graph drawing algorithms and evaluation criteria is documented in the Dagstuhl survey and described in Section 2.3 above.

As a learning device, critiquing may involve evaluating existing work, software or graphics, but importantly should involve the practical application of theory. I ask students to critique existing graphics, those that they have developed and software systems using a number of criteria, such as:

- Graphical integrity, graphical excellence and Tufte's 'theory of data graphics' [69]
- Using appropriate symbolism [6, 10]
- Map symbolism [45, 60]

– Map design [7]
– Use of colour [22]
– Interactivity and functionality [11, 41]
– Animation [21, 55]

Each of these sources provides useful criteria to structure critiques and against which judgments can be made. Amar and Stasko's framework [2] also offers opportunities and Dagstuhl has drawn attention to the scope for using more knowledge from InfoVis in developing critiquing criteria.

Paper Summaries. Presenting summaries of research papers is clearly a core activity in InfoVis teaching and learning. This fits the critiquing trend if the work is evaluative and assessed against existing theory and criteria. Tamara Munzner's generic 'what makes a good InfoVis paper' criteria as presented and discussed at the Dagstuhl seminar [52] could prove useful in this kind of learning activity.

The validity of critiquing depends upon the level of learning being supported. In the UK some of the more advanced levels of knowledge, such as those developed through critiquing, relate to the more advanced levels of learning. Masters level and level-3 courses require students to evaluate and so the approach is particularly appropriate. It can be used to provide feedback and for assessment. I've found that extended abstracts work well as a focus for quick and informal 'in class' critiquing that breaks up a learning session.

Learning by Doing:

> "I hear and I forget, I see and I remember, I do and I understand" (Chinese proverb).

Participants in an Information Visualization seminar are likely to be persuaded that seeing is a powerful learning device. But 'learning by doing' may be even more effective. It is a form of active learning that is popular in education and there is particular opportunity for using this approach in visualization education. Doing can involve summarizing information, developing graphics or software or analyzing data sets and the Dagstuhl participants provide plenty of examples of these activities in their courses as we have seen in this paper.

Fieldwork is used to provide opportunities for learning by doing in the geosciences and has an important role in education [31]. There are parallels between the kind of observation, interaction and exploration that occur in fieldwork and those associated with the kind of exploratory analysis that visualization supports. I have explored some of these parallels and opportunities when developing learner-focused activities that emphasize learning by doing. The constructivist approach emphasizes learning through an interpretive, non-linear and recursive process in which active learners interact with their surroundings and the resources that are provided to help [19]. Such methods are regularly used in geoscience fieldwork and may result in 'deep understanding' of the kind experienced when researchers use visualization to interact with complex structured datasets. They seem particularly suited to visualization education.

Multiple perspectives are important in constructing knowledge and so group work is often employed in such activities. In this context, symbolic and graphical representations of knowledge and ideas and can be important in negotiating, mediating and constructing shared meanings [19]. This is particularly so if the graphics can be manipulated in an exploratory context as knowledge is derived. Consequently strong arguments exist for using software that is interactive and exploratory to develop opportunities for learner-centered constructivist activities [74].

I have developed exploratory visualization software for use in fieldwork in this context. It encourages 'learning by doing' through a series of linked cartographic, statistical and photographic views of a study area and a highly interactive interface through which these can be manipulated. It forms part of a learner constructed activity - the software is one of a series of resources made available to students who are expected to develop an approach to a problem relating to land cover and land use. The contrasts with passive or transmissive education are emphasized by the exploratory, student-led visualization and the ability to add data recorded in the field into the software for analysis [46]. Our evaluations show that the software and the constructivist activity that it supports are an effective learning device [47].

The Dagstuhl survey suggests that a number of similar activities may be taking place. It certainly seems that there is scope for using exploratory graphical software to support constructivist learning methods in visualization that give students the opportunity to learn actively.

A Portfolio Approach to Assessment: The issue of exercises and assessment was discussed at Dagstuhl primarily because some teachers were finding it difficult to set and assess meaningful exercises. Critiquing and 'learning by doing' provide scope for effective objective assessment that encourage active learning. My experience with portfolio-based assessment has been very positive in this context and compliments these methods well.

Portfolios involve students developing and collating annotated evidence of their capabilities throughout a course. They receive formative feedback on their work and use selected work to demonstrate that they have achieved a set of learning outcomes. Portfolio-based assessment can spread workload for staff and students, offers the opportunity for developmental feedback and review, and provides a synoptic view of what has been learned. It also results in a tangible end-product that students can show to colleagues and prospective employers—potentially—bringing learning to life and engendering pride.

I use portfolio-based assessment in the GeoVisualization module. Students participate in a practical exercise associated with each learning session that requires them to 'learn by doing'. Their work is discussed and improved. Selected work is submitted for formal formative feedback. At the end of term students are asked to submit a portfolio of three exercises and a reflective essay that uses these as items of evidence to demonstrate that module learning outcomes have been achieved. Amongst other competencies, outcomes require that students are able to ...

– explain the complex issues associated with GeoVisualization with clarity and from an informed perspective by drawing upon recent academic research;
– design maps and data graphics that are effective, informative and consistent and that exhibit graphical excellence and graphical integrity;
– use data graphics, maps and visualization tools to present and explore multifaceted data sets in a manner that is professional, informed and ethically sound;
– evaluate data graphics, maps and visualization tools by drawing upon principles and theories of design.

The approach seems to work nicely and addresses some of the issues discussed at the Dagstuhl meeting. It may be useful for those wishing to help students learn to critique and assess their developing skills. I have received favorable feedback from students and internal and external evaluators.

It seems particularly appropriate for developing skills in graphicacy where Tufte's concept of 'redesign' is a key element. Portfolios or long-term developing group projects that provide opportunities for feedback and critique can be very beneficial here. It should be noted that portfolios are frequently used in the arts where critiquing and redesign are key learning activities.

Conclusion: These arguments are personal perspectives, developed through reflections on discussions at Vis 2006 and the Dagstuhl seminar and the Dagstuhl survey, in the light of my teaching experience. I suggest a focus in Information Visualization education not on curriculum (which may vary to suit particular disciplines and student groups) but on general qualities and competencies that can be applied across a range of curricula. I've identified what some of these might be and presented some ideas on how they might be supported and assessed through the example of my GeoVisualization module.

The critiquing and 'doing' themes support the notion that underlying skills in the use and evaluation of graphics are broadly (I hesitate to say 'universally') valuable. They may be a way of helping Information Visualization educators bridge the multiple multi-disciplinary divides and certainly help justify the approach taken on my GeoVisualization module.

They may also help us deal with change—we are in a discipline where the specifics of curricula change very rapidly. Perhaps we're moving away from a text-book based model of teaching as disciplines change so quickly and student's expectations and abilities to access information increase. This is good news from the perspectives of information sharing and efforts to link research and teaching, which many are evidently doing very effectively, cf. Section 4.1. The bad news is that we need more flexibility in terms of course content and perhaps structure. This is no bad thing in itself, but is difficult to achieve when the levels of documentation that are expected by students and (in the UK at any rate) required for quality assurance and to gain approval for changes in provision are considered. Guided approaches in which links to a selected set of papers and examples are used to support learning against broad aims and outcomes provide a way forward. It is well worth using the URLs listed in the Dagstuhl survey to learn from colleagues who use this approach (see Stasko, Munzner and Heer's courses for example). The kinds of repositories of examples and teaching materials discussed and suggested in Section 4.1 will help, as will a focus on generic methods of teaching such as those that involve critique and active learning rather than developing monolithic curricula that will age rapidly in response to new developments. Portfolio-based assessment that involves the focused combination of a series of activities supports this flexible approach.

Adoption of the ideas discussed here would continue to move visualization education away from core Computer Science. Doing so will continue the trend of enabling more students to participate in visualization education and help address the difficulties associated with multi-disciplinary domains - how do we focus simultaneously on the concepts listed in our tag cloud of the scope of Information Visualization education (Figure 1)—computer science and algorithms, the science of perception and cognitive studies and concepts derived from the arts such as composition and design? The Dagstuhl survey has certainly helped inform my approach to visualization education. Perhaps this discussion will help the community when considering the nature of Information Visualization education and how to best it might be supported and developed. I'd certainly be delighted to debate the ideas and their relevance further.

5 Conclusion

This paper describes the results of our teaching survey based on the information given by the Dagstuhl attendees. It covers several aspects of offered InfoVis courses that range from different kinds of study materials to practical exercises. We have reproduced the discussion during the Dagstuhl Seminar and added our own experiences. In this regard, we have found that teaching InfoVis is challenging because it is a new and growing field. There exist a lot of open questions regarding the syllabus, a consistent theory, or the abstraction level of single topics. In consequence, it is also a great subject for teachers, not only for students: we are convinced that teaching InfoVis also leads to a better reflection on the topics and to new ideas which can induce new projects. Finally, we hope that this paper can serve as an interesting and helpful source for current and future InfoVis teachers.

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