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Towards a Survey of Interactive Visualization for Education

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Abstract

Graphic design and visualization are becoming fundamental components of education. The use of advanced visual design in pedagogy is growing and evolving rapidly. One of their aims is to enhance the educational process by facilitating better understanding of the subject with the use of graphical representation methods. Research papers in this field offer important opportunities to examine previously completed experiments and extract useful educational outcomes. This paper analyzes and classifies pedagogical visualization research papers to increase understanding in this area. To our knowledge, this is the first (work-in-progress) survey paper on advanced visualization for education. We categorize related research papers into original subject groups that enable researchers to compare related literature. Our novel classification enables researchers to find both mature and unexplored directions which can inform directions for future work. This paper serves as a valuable resource for both beginners and experienced researchers who are interested in interactive visualization for education.

CCS Concepts
•General and reference → ***Surveys and overviews;*** ***•Applied computing*** → ***Interactive learning environments;*** ***•Human-centered computing*** → *Visualization design and evaluation methods;*

1. Introduction and Motivation

Graphics based technology is used to demonstrate complex and diverse concepts and has become an integral part of many educational processes. Big data sets and complex relationships between data dimensions can make analysis and interpretation difficult for both instructors and students. Interactive visualization methods play a key role in simplifying and conveying meaningful information about complex systems. Visualization tools that assist the educational process and implementation can be extremely helpful for all types of users. In order to understand how to improve a student's learning experience, it is important to explore how to build appropriate visual systems. Literature reviews and survey papers from a range of different educational contexts are vital to study beneficial solutions.

In order to provide important trends extracted from the field of interactive visualization in education for researchers who aim to work in this area, we introduce a work-in-progress literature review of related research papers as well as conveying both mature and unsolved problems for future research. We have surveyed and categorized a selection of related research papers to explore the state-of-the-art visualization systems for educational purposes. The contributions of this work-in-progress literature survey include:

- The first survey of its kind on the topic of interactive visualization for education with a focus on evaluation
- A novel literature classification of research papers in this field
- Indicators of both mature areas of research as well as areas with unsolved problems

The rest of the paper is organized as follows: Section 2 presents related work that includes other related overview papers on technology for education. Section 3 presents reviews of advanced visualization systems used by instructors for training of students in distinct areas of study. Conclusions are presented in Section 4.

Challenges: The research papers presented here introduce methods or software that include graphical representations developed and used for educational purposes. The major challenge is to evaluate the effectiveness of the target technologies in the literature on increasing the user's understanding, with the support of interactive visualization systems. As we see in the survey, evaluating the effectiveness of any interactive visualization technique to enhance education is a non-trivial endeavour. As such this survey gives special attention to the topic evaluation when examining the literature. How and in what setting each paper carries out its evaluation is described.

Survey Scope: This survey reviews interactive visualization papers for the purpose of enhancing education and cognition. Studies that focus on teaching or understanding of material in classrooms or distance education systems with the aid of advanced of special visualization techniques are considered within the scope of this survey. Our survey includes papers which present interactive visualization software or web-based learning systems. It also includes

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Classification Subject Categories	***Classroom***	***Controlled User Study***	***Case Study***
Algorithm Cognition	Grissom *et al.* [GMN03] Schweitzer and Brown [SB07] Guo [Guo13]		Shneerson and Tal [ST97]
Perception		Velez *et al.* [VST05]	
Anatomy and Medicine	Silén *et al.* [SWK*08]		
Engineering	Contero *et al.* [CNC*05]		Sifakis *et al.* [SAMC17]
Teaching Visualization	Silva *et al.* [SASF11]		
Massive Open Online Courses			Shi *et al.* [SFCQ15]
Novel Education		Schwab *et al.* [SST*17](intvwd.)	
Active Learning & Creativity	Roberts *et al.* [RHR16] Roberts *et al.* [RRJH18]		

Table 1: *An overview of the literature in the survey classification categories. The evaluation technique that each research paper uses is categorized into classroom settings, controlled user study and case study-based evaluation methods of visual designs.*

visual representation methods for a topic taught to students rather than teaching techniques without the help of dedicated visualization methods. The purpose of each paper is to teach a subject to the audience, showing the material in a clear and effective way by exploiting interactive visualization techniques. Moreover, our decision to choose a paper included in the survey is not affected by the subject area, where, or how a teaching tool is used. A main criteria is to examine how the work studies the impact of interactive visualization techniques to educate trainees.

Out of Scope: In order to be included in the survey, more advanced, interactive visual designs are used. Sasakura and Yamasaki [SY07] present a new application for calculus that uses an adaptable model of e-learning systems and discuss authoring assistance for adaptive e-learning systems using static graphs. This paper, and others like it do not meet the our survey's scope criteria because the visualization is a standard hierarchy diagram with no interaction.

1.1. Literature Search Methodology

The literature search methodology identifies visualization papers with a focus on education for visualization. The main purpose is to examine the effects of interactive visualization methods on teaching and learning a given topic. The first step of our search browses the IEEE VIS Conference papers [IEEa]. We focus on the key words "Education", "Classroom", "Learning", "Understanding", and "Interpretation" to search for related visualization papers. We also search the IEEE Xplore [IEEb], Google Scholar [Goo], Vispubdata [IHK*18], EuroGraphics education papers [Edu], EuroGraphics Digital Library [Dig], and ACM Digital Library [ACM] using the above search terms. We also use Google Scholar's "Cited By" feature to find literature citing a given research paper. A Survey of Surveys (SoS) [ML17] is searched however we did not find any existing surveys including education. The related work section of each individual paper is also examined for sources of visualization papers in education.

1.2. Classifications

We develop a novel classification to categorize papers reviewed in this study. We classify each paper into categories based on the target subject field and evaluation methods of visual designs given in papers. As evaluation methods, we identify three categories including classroom based evaluation, controlled user study, and case study. Using this approach above, we define a matrix of categories for the classification (see Table 1). The subject areas we identify are:

- **Algorithm Cognition:** Papers use visual representations to teach algorithms with active learning. For example, algorithm visualization in computer science education and comparing the level of student engagement [GMN03].
- **Perception:** This category is about understanding visual designs by examining different spatial abilities. We cite understanding visualization through spatial ability differences [VST05] as an example.
- **Anotomy and Medicine:** This category includes research that is proposed to benefit 3D visualization and improve the study of anatomy in medical training. An example in our survey is advanced 3D visualization in student centred medical education [SWK*08].
- **Engineering:** Papers in this category aim to improve engineering education by providing interactive visualization tools. We cite improving visualization skills in engineering education, [CNC*05] as an instance.
- **Teaching Visualization:** Literature in this category intends to teach scientific visualization by taking advantage of visualization tools. For instance, using VisTrails and provenance for teaching scientific visualization [SASF11].
- **Massive Open Online Courses (MOOC):** Papers that facilitate analysing student learning performance by using video clickstreams such as visualizing video clickstream data from massive open online courses [SFCQ15].
- **Novel education:** This category includes research that presents an interactive online learning system which enables the presentation and explanation of course material using visual designs. As an example, we cite an education system with hierarchical concept maps and dynamic non-linear learning plans [SST*17].
- **Active Learning and Creativity:** Studies here describe methods which facilitate users to plan their designs and improve their skills on thinking alternative solution. We cite sketching designs

using the five-design-sheet methodology [RHR16] as an example.

Classifications are an important part of survey papers. Table 1 demonstrates how each research paper's classification is represented. We provide classification categories and each sub-category is identified by focusing on the evaluation method of the visual designs.

2. Related Work

Fouh *et al.* [FAS12] present previous visualization systems in computer science education, concentrating on projects that have positive educational impact. How computing technology influences the improvement and understanding of such visual augmentation in computer science education is presented. They start by focusing the early use of algorithm visualization (AV) in the Internet era, and the impact of engagement with AV and program visualization (PV) for computer science education. In addition, they describe several selected visualization methods which show a statistically significant difference in students' performance before and after using the visualization systems in a controlled experiment.

They introduce ten visualization systems. These systems are used to teach students computer science modules. These tools are: TRAKLA2 [LSG*05], JHAVÉ [NEN00], ALVIS [HB05], Virginia Tech Hashing Tutorial [Vir18], AlViE [Alv], Alice [Ali], Jeliot [LBAU03], ViLLE [RLKS07], jGRASP [HCIB04], JFLAP [Rod18].

Future research directions identified by Fouh *et al.* [FAS12] include creating hypertextbooks - online textbooks that connected AVs, evaluation practices, text and images. Working to produce hypertextbooks started two decades ago. Aims include developing an exhibition through a collection of technologies available through print textbooks and increasing student connection with the material to facilitate mastery. The goal is to enable instructors to modify existing textbooks and alter or take chapters from various books and merge them.

According to Rushmeier *et al.* careless generation of visual designs can cause misunderstanding [RDDY07]. Visual design of complicated data is growing and increasingly decision making is based on data-generated images. The requirement for formal education creates more questions about to whom and what to teach in visualization courses. For evaluating a visualization course, formal visualization courses are defined as including eight core topics. These core topics supply a strong base, but each refers to a significant body of further knowledge [RDDY07].

Visualization courses are required to teach a wide range of students. This is because it facilitates understanding of big data in many fields outside engineering, the natural and physical sciences. Many different areas can benefit from visualization such as history, archaeology, public policy, literature, security and intelligence in industry and daily life. Each course is based on basic themes and each has a different level of difficulty. Courses are classified as first year, upper-level/graduate courses which covers discipline-specific courses, art and design, computer science, and business.

Ziemkiewic *et al.* [ZOC*12] describe essential factors that influence how people perceive and understand visual designs and colors to derive common design guidelines for creating useful visual designs. Users have unique backgrounds, characteristics, and cognitive abilities which affect their thinking and means of accomplishing a task. Ziemkiewic *et al.* [ZOC*12] study visualization with respect to differences between users, by looking at individual aspects of a person such as cognition and personality.

Building a taxonomy of design factors that influences with various personality features and a good comprehension of which features are important for visualization use. Ziemkiewic *et al.* [ZOC*12] will be ready to design helpful experiments to examine how individual differences influence visualization use. Such experiments could investigate how other factors such as data influence individual performance. This long-term work agenda outcome could change understanding of visualization.

3. Interactive Visualization for Education

This section presents a collection of summarized survey papers (see Table 1). Each paper is placed in its respective classification category to facilitate comparison including related previous work and evaluation methods used.

3.1. Algorithm Cognition

The algorithm cognition section contains papers that present tools with visual designs to facilitate active learning of algorithms. Four papers in this category provide systems to visualize algorithm processes.

Shneerson and Tal [ST97] introduce a conceptual design and a system, GASP-II, used in electronic classrooms to visualize geometric algorithms. The system enables the projection and interactive examination of 3D geometric algorithms over a network [ST97]. In many other electronic classroom systems the students are entirely inactive. GASP-II enables the students to be involved in the process of learning by interacting with a given algorithm with assistance from the teacher [ST97].

A notable feature of the system is that each student can see a distinct image of the same running animation in the lecture. Students are required to modify algorithm parameters in a design panel without changing any code. GASP-II also provides every student with a control panel. This feature enables the student not control the pace of the animation but also "rewind" and "rerun", until the complex parts of the algorithm are understood completely. GASP-II follows a mode of studying in which the student is more restricted and must track the teacher during the lecture.

The majority of previous studies for algorithm animation try to improve general-purpose systems, which are designed for essential algorithms (Balsa [BS85], Balsa-II [Bro87]). Their focus on 3D geometric algorithms is restricted. The Computational Geometry Workbench [BN96] and the XYZ GeoBench [Sch91] support 2D algorithm animations, but this is not their main focus. Producing an animation is important. Mocha [BCLT96] supplies 2D algorithm animations over the internet. GASP [TD95] goes beyond these systems by assuring a rich set of 3D visualization and animation tools. There is no formal evaluation presented in the paper.

A closely related previous paper introduces algorithm visualization (AV) which illustrates the implementation of an algorithm as a series of graphical images. Grissom *et al.* [GMN03] assess the effect of different levels of student engagement with AV to study basic sorting algorithms.

Naps *et al.* [NEN00] describe an engagement taxonomy that covers six different forms of learner connection with visualization technology. The goal of this taxonomy is to supply a framework for managing experiments to measure the educational effectiveness of AV. These are: no viewing, viewing, responding, changing, constructing and presenting [NEN00]. Grissom *et al.* [GMN03] use the taxonomy provided to evaluate tests.

Previously, Jarc *et al.* [JFH00] use Interactive Data Structure Visualizations (IDSV) software to automate what students do verbally. The ISDV software poses questions to students to assess their understanding once they watch an algorithm. According to their evaluation, the students who used ISDV in the study do no better than students who do not use the system. Researchers explain this inefficacy in terms of weak students who only accept the interactive questions as a game and answer the questions simply by making predictions.

As part of evaluation of Grissom *et al.* [GMN03], 150 students are asked to answer pre-test and post-test questions on the sorting algorithms in a classroom. Students complete a pre-test which contains 7 questions before reading the information to assess students' knowledge of sorting algorithms. The post-test includes 12 questions (4 coding - 8 visual questions) about sorting algorithms and a brief survey about their experience with the learning tool. Results show AV tools can have a positive impact on students' learning and the learning improves as the level of student engagement with the AV system rises. Learning is measured by subtracting pretest from post-test scores. Improvement is observed between each level of engagement. The improvement is demonstrated between not viewing a visualization and interacting with one is statistically significant.

Schweitzer and Brown [SB07] describe the design features of visualizations which facilitate active learning, ways of using them in the classroom, and using visualization tools and their tool developing experience across different courses in a computer science curriculum [SB07]. Active learning is defined as involving students in the classroom in activities (other than listening) that are meaningful and support them in thinking about their actions [BE91].

Schweitzer and Brown [SB07] develop and use interactive classroom visualizations (ICV) in various computer science courses including algorithms, data structures, and computer graphics [Sch92] [SBC*06] [SB06]. Previous research shows that students learn more when actively involved in the learning process [CG87]. Saraiya *et al* attempted to identify key features of successful visualizations [SSMN04].

Productive use of ICV in an active learning system requires analysis of how the tool is introduced to students and used to improve the lecture. Schweitzer and Brown's assessment demonstrates that students rate the visual designs as a fun and effective part of the course. Students in the classroom at the U.S. Air Force Academy participated in the experiment. While they do not perform formal studies for the ICV's influence on student understanding, the positive student response and the evidence in educational literature on the impact of active learning approaches indicate that this is a effective approach.

Guo [Guo13] presents open source web-based programming tool used to teach Python in computer science (CS). Students can read lecture content and interact with code visualization within the same web-page. Students and instructors are also able to write Python programs in a web-based environment and step forwards and backwards through implementation to observe each data structure's run time states. UUhistle [SS10] and Jype [HM10] are previous examples of Python visualizers written in Java.

Professors, lecturers, and teaching assistants in many universities have used the Online Python Tutor. Class sizes spanned from 7 students in a summer Python course for non-CS majors, to more than 900 students in the Fall of 2012. Over 200,000 people used online Python tool for three years. In addition, Miller and Ranum [MR12] embedded the Online Python Tutor into their digital textbook "How to Think Like a Computer Scientist: Interactive Edition [MR12]" which draws approximately 6,000 viewers per month.

Guo [Guo13] recommends a formal study with academic partners to determine whether they should add new features to promote active interaction with program visualization. According some student feedback in discussion forums the online Python tool is particularly beneficial when debugging recursive functions and effective for understanding lists and arrays.

3.2. Perception

This section is concerned with spatial perception and how it can vary between observers. One paper is included in the perception section about comprehending visual designs by studying the different spatial abilities.

Velez *et al.* [VST05] aim to understand what causes visual designs to be perceived as difficult by examining the spatial ability differences in a varied population chosen for spatial ability variance. They concentrate on basic visualization tasks and so design a basic visualization test that asks the experimental participants to form a mental picture of a 3D object based on its 2D projections. The test is prepared like standard spatial ability tests and attempts to understand what makes a particular visual reconstruction difficult for different spatial ability levels.

Their studies find that projection and slice visualizations are not optimal for tasks like shape understanding [Tor03] and general understanding of a 3D space layout [RLF*98]. Therefore, several improvements are proposed that combine 2D and 3D methods such as clip planes of 3D volumes, cross-sections or orthogonal projections combined with 3D position references [Tor03] [RLF*98]. These studies present particular solutions that improve performance in specific tasks by modifying characteristics of the original orthogonal visualization. Previously, Shepherd and Metzler [SM71] mention that cognitive science and psychology have studied similar spatial problem-solving skills. One type of extensively studied spatial problem asks subjects to recognize 3D objects observed from different angles.

In order to evaluate variance in spatial reasoning Velez *et al.* [VST05] create a classical visual design which represents what they feel is a basic task asked of viewers in various professional fields to examine an orthogonal projection image. Their goal is to design a visualization task that is simple enough to be performed

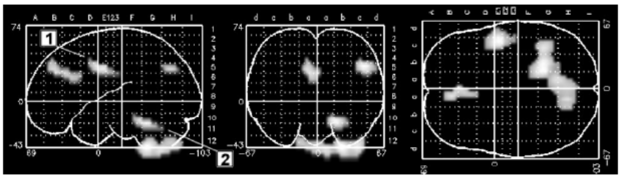


Figure 1: *A volume-based visualization task to analyze ability of a user to construct a 3D visualization from 2D image [VST05].*

by untrained users. Fifty-six students, half of them female, aged between 18-31 from a U.S. University participate in this study. Each experimental session takes approximately two hours. During the first hour, participants are given five paper-based cognitive factor tests. After the paper tests, computer-based visualization tests are administered. Subjects are seated in front of desktop computers on which the orthogonal projection test is displayed. From this experiment, we learn that for geometric objects, the number of original and hidden surfaces, edges and vertices is correlated with task accuracy. And that low spatial ability participants can interpret only simple geometrical objects such as cubes and cones (see Figure 1).

3.3. Anatomy and Medicine

This section contains research that focuses on 3D visual representations to enhance the study of anatomy in medical training. Silén *et al.* [SWK*08] examine the study of using 3D medical imaging to enhance learning and knowledge of anatomy and physiology with the assistance of 3D visualizations. The 3D imagery of high-resolution computed tomography (CT) and magnetic resonance (MR) images from clinical research are used for educational purposes. Based on supporting problem-based learning theories, 3D visualizations are applied in the medical and physiotherapy programs' schedule.

Previous research on student experience reveals that students have difficulty acquiring a conceptual comprehension of 3D anatomy based on more abstract content [Cot99] [Mil00] [GNS01] [DMS*02]. The 3D graphical representation of the body is constructed, such as natural skeletons and models, from scanned data, to virtual presentation, such as animated models (e.g. 3D Brain and ADAM).

In order to evaluate their work a pilot project in autumn 2005 and the main project in spring 2006 are performed within the medical programme at Linkoping University. Three questionnaires are prepared. Eleven medical and physiotherapy students in the second and third semester participate. Surveys are utilized to explore the medical and physiotherapy students' opinion of the different kind of 3D graphics and their learning experiences and attitudes towards visualization. They also look for what students find difficult to understand, the role that 3D images play and opportunities related to the self-study material. The 3D images demonstrate that students understand more and increase their awareness of biological changes and diverse organ size, spatial dimension and connection to each other (see Figure 2). The virtual dissections provide a more understandable picture than the other dissections.

Figure 2: *Volume rendering of CT heart image [SWK*08].*

3.4. Engineering

The engineering section includes two studies to improve engineering education by providing visual tools used by students and instructors.

The work presented by Contero *et al.* [CNC*05] aims to improve engineering students' visualization skill using a web-based graphics application and a sketch-based modelling system. Contero *et al.* [CNC*05] explain the importance of visualization skills in engineering education and offer two approaches to help students improve their spatial cognition. They design experiments to confirm how these approaches are advantageous to improving students' skills. Websites are used in the course which enable students to implement 3D graphical content offering richer features to improve students' visualization skills.

Michigan Technological University provides an Introduction to 3D Spatial Visualization: An Active Approach [act]. The application uses colorful shapes rendered to appear 3D. It enables students to advance their visualization skills by creating computer games. The University of Massachusetts develop several electronic tutors. The rotation tutor purposes to widen students' reasoning abilities on 3D rotation. The engineering drawing tutor promotes students in drawing orthographic and isometric views. Its goal is to facilitate students build a mental image of an object from its orthographic projections.

In previous research on a sketch-based modelling applications, eRefer [CCP*04] and eCigro [CNJC03] allow students to switch from first to third angle projections and activate or deactivate the hidden line or reference system in visual projections. eCigro [CNJC03] uses a 2D and 3D window. As the user refines the geometry, the system updates the 3D model. Students can sketch and switch the point of view to see the corresponding 3D model and continue to sketch from the new viewpoint.

A test-based experiment for engineering students is given at La Laguna University with 461 students by Contero *et al.* [CNC*05]. They select the Mental Rotation Test (MRT) and the Differential

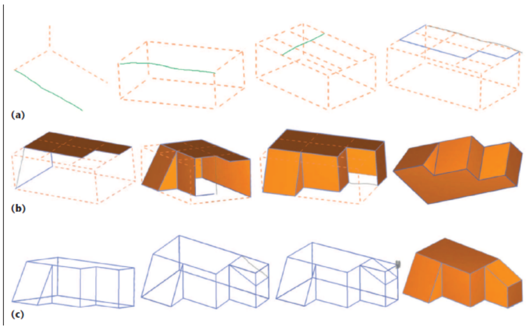


Figure 3: *An interactive input sequence for eCigro [CNC*05].*

Aptitude Test spatial relations subsection (DAT-SR) to identify the students with lower spatial abilities and to evaluate the results of three remedial courses. Three 6-hour remedial courses (courses A, B, and C) are designed, each of which is held in three 2-hour sessions. Course A focuses exclusively on paper-and-pencil exercises and emphasizes the use of standardized view problems to improve spatial vision. Course B is web-based which uses VRML models to help students complete visualization exercises. Course C focuses around the eCigro [CNJC03] application. Students are introduced to axonometric drawing using the Isometric applet [Iso] (see Figure 3). As a result of this experiment, the remedial courses have a measurable and positive effect on students' spatial ability in all three cases, as measured by both MRT and DAT tests and students' satisfaction levels are high. This study indicates that using web resources and sketch-based modelling systems in remedial courses are appropriate strategies for ensuring that students acquire a minimum spatial ability level.

In another paper, spatiotemporal processes are presented by Sifakis *et al.* [SAMC17] as a technique for conveying knowledge of physical processes in geosciences, life sciences and engineering. ViSTPro enables students to interact with given spatiotemporal models for science and engineering education, thus enabling active exploration of spatiotemporal processes in the form of scenarios written by educators and provided to students in a web-based environment [SAMC17]. A scenario contains a graphic representation of formations, movements and interactions on Google Maps. Also, ViSTPro enables learners to formulate questions and receive personalized explanations. Therefore, students can look at the representation of the processes' evolution in space and time and actively play a role [SAMC17].

In previous work, Buschbeck *et al.* [BJS11] develop the system GLOCAL, that depicts complex events structured hierarchically with the use of sub-events. Users examine the structure of the event and focus on single events by applying filters and to observe related images. Prestopnik and Foley [PF12] improve an educational tool for the visualization of historical battles. Entities are represented as points, classified by name, and color mapped according their group. The visualization contains a timeline synchronized with the animation of the battle presented. Additionally, the user can start, pause, control the playback speed and determine the type of information that is introduced.

To demonstrate the use of ViSTPro a crisis management incident a firefighting emergency in Chania is selected. A fire ignites in the field of the Sebronas, Platanias. This scenario is modelled after a rural forest fire report of the incident and is based on information supplied by the chief firefighter related to operation. The VisTPro scenarios are based on 4 activities to represent processes such as inception, intervention, control, and full control. These scenario activities have also sub-activities to represent more details. However, there is no controlled experiment presented.

3.5. Teaching Visualization

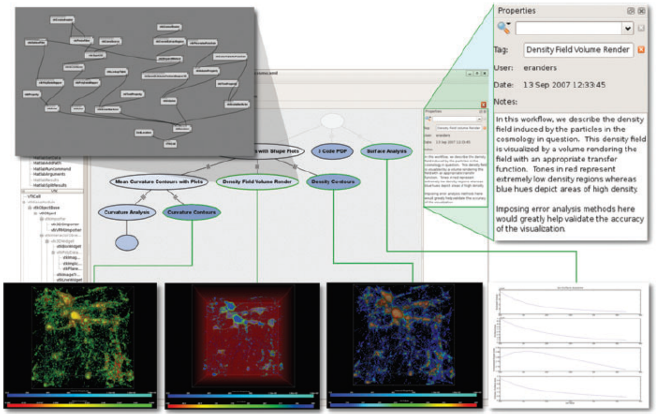
A study is found in this category is indented to teach scientific visual designs using a unique visualization tool.

Silva *et al* [SASF11] focus on experiences using VisTrails as an environment to teach scientific visualization. VisTrails is an open-source tool designed to assist research on computational tasks such as data analysis and visualization. Moreover, provenance records information about the steps used to generate a given visualization result and the set of tasks that produced it. VisTrails provides visual interfaces for exploring the provenance information and supporting knowledge to use it again [SVK*07]. Students can take advantage of the detailed provenance in examples to prepare themselves and more easily understand the visualization tasks required of them during the course. Because VisTrails supplies utilities including query-by- example and refinement-by-analogy [SVK*07], students can quickly find and apply previously investigated visualization pipelines to the task at hand.

Prior to this, the Application Visualization System (AVS) [UFK*89] is one of the earliest and most effective visualization environments developed in the 1980s. It is based on a dataflow model and it is aimed at providing an easy to use system for supporting the filter/map/render pipeline. The IBM Data Explorer (DX) [IBM] and the IRIS Explorer [IRI] are two other systems from the same period. These tools are still widely used today for over 20 years after first relase.

In order to evaluate VisTrails, 30 students taking a visualization course are selected. Each student in the course is required to complete six separate, and increasingly complex tasks using VisTrails, VTK [SLM03], and Matplotlib [Mat]. Students are asked to create layouts of the cosmology data (from Los Alamos National Laboratory [AAH*08]) in the last assignment. Providing students with the provenance collected during the examples in class enables them to reproduce the examples as well as to experiment with variations and facilitate better understanding of the main properties of various visualization techniques. Students respond positively to this method of instruction as it enables them to explore the advantages and disadvantages of different techniques more easily.

VisTrails enables the students to focus on the visualization tasks, instead of having to spend substantial effort developing user interfaces. Besides simplifying the building of pipelines, the provenance method also streamlines the exploratory process required to produce the designs, and enhances interactions between students, instructor, and teaching assistants. Another benefit of using VisTrails from an assignment perspective is that students submit the complete history of the process they followed to create those results instead of submitting just the final layouts. It can be very useful for the instructors to better assess their teaching effectiveness and identifying students in need of help (see Figure 4).



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Notes:

In this workflow, we describe the density field induced by the particles in the cosmology in question. This density field is visualized by a volume rendering the field with an appropriate transfer function. Tones in red represent extremely low density regions whereas blue hues depict areas of high density.

Imposing error analysis methods here would greatly help validate the accuracy of the visualization.

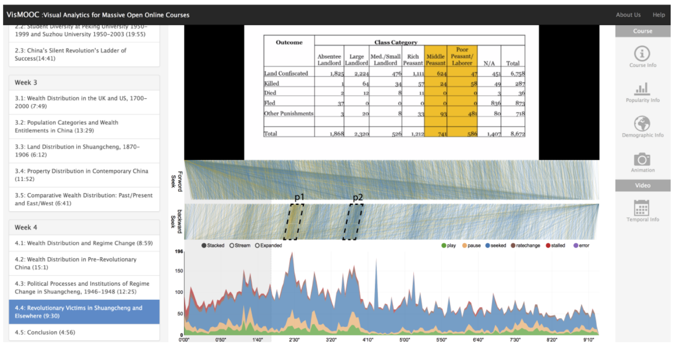
Figure 4: *An exploratory visualization example to work celestial structures derived from cosmological simulations using VisTrails [SASF11].*

3.6. Massive Open Online Courses

This section contains research that uses video clickstreams of popular online course platforms to examine student learning performance.

Shi *et al.* [SFCQ15] present a visual analytic system, VisMOOC, to facilitate analysis of student learning performance by using video clickstream data collected from MOOC (Massive Open Online Courses) platforms such as Coursera [Cou] and Udacity [Uda]. While thousands of students are watching course videos, large amounts of clickstream data are generated and recorded by the MOOCs systems for each course. Such a huge data supply an important chance for teachers and analysts to obtain ideas about online learning approaches on a large scale.

In previous related work, a course administration system, CourseVis [MD07] purposes to inform the educator on social, behavioural and cognitive condition of students. Visual designs such as a 3D scatter plot are used to demonstrate learners' web log data. Hardy *et al.* [HAB04] describe a set of visual representation tools that help to display and analyse student's interaction with online course platforms. They primarily focus on student access of the course material and the navigation path that a student takes throughout the course.



Outcome	Class Category							
	Absentee Landlord	Large Landlord	Med./Small Landlord	Rich Peasant	Middle Peasant	Poor Peasant/ Laborer	N/A	Total
Land Confiscated	1,825	2,224	476	1,111	624	47	451	6,758
Killed	1	64	34	57	24	58	49	287
Died	2	12	8	11	0	0	3	36
Fled	37	0	0	0	0	0	836	873
Other Punishments	3	20	8	33	93	481	80	718
Total	1,868	2,320	526	1,212	741	586	1,407	8,672

Figure 5: *VicMOOC's user interface which includes list view on the left, content-based view in the middle and dashboard on the right [SFCQ15].*

For evaluation, Shi *et al.* [SFCQ15] conduct an experiment with instructors to assess utility and effectiveness of their system in the Chrome Web browser and provide insights obtained from the experiment. During investigation, the instructors are asked to explain the reason for the patterns found and to refer any course materials used during lecture. Overall statistics provide users a first impression of the data with popularity and demographic distributions of course videos. Also, specialists examine the clickstream data with the content of the video. Another method uses coordinated analysis to study complex patterns. VisMOOC is found by instructors as an easy to use system for data collection and can enhance understanding of student interests and facilitate preparation of course materials and to develop learning engagement (see Figure 5).

3.7. Novel Education

The novel education section includes a paper that describe an online system which provides presentation of course material using visual designs.

Information hierarchies are difficult to explain in linear presentations such as in books and courses. Schwab *et al.* [SST*17] provide a web-based environment called booc.in which enables linear and non-linear presentation and content such as lecture slides, book chapters, and videos. An interface facilitates creating hierarchical structures. Schwab *et al.* [SST*17] present an interactive online learning system that collocates notions and their dependency tree into hierarchical, circular layouts. Demonstrating the typically-expansive dependency trees using hierarchical circular orders makes the design compact and enables context. Linear representation of the material is displayed as a learning plan that runs "around the clock face" of the hierarchical concept circles. Non-linear learning plans shortcut material and run inside the hierarchy of circles.

Previously, online learning platforms, such as edX, Coursera, or Udacity, enable learners to understand a given topic by combine the content into stack or groups, which help recall by adding structure [Bad92] [FGZ92]. This enhances learner performance and satisfaction [ZZBNJ06] especially with active learning and interactive content. Many web-based tools provide hyperlinks to different resources to facilitate learning of complex topics by giving multiple perspectives.

For an evaluation experiment, 12 participants were selected randomly. Seven were current students of the course, and five had taken course named "Govt. 2001-Advanced Quantitative Political Methodology" at Harvard University the year before. Each student is interviewed for 60 minutes with little-to-no knowledge about the software. The students are accustomed to a typical course web-page containing a hierarchical concept list organized by topic with hyperlinks to access course videos and PDFs. Students are asked to find material on a specific concept by using the existing web-pages and are directed to their webpage to search for learning materials. After completing the task by exploring the features of their web system, students are interviewed to understand their impression and experience using the booc.io. According to the results, the majority of participants provide positive feedback of booc.io (see Figure 6).

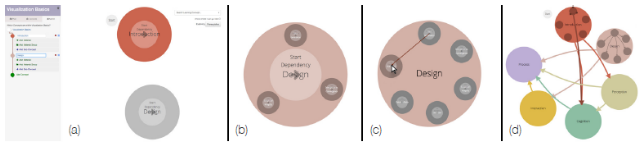


Figure 6: *Parent concepts (a) and child concepts (b), dependencies from point to point (c), final dependency graph (d) [SST*17].*

3.8. Active Learning & Creativity

In this section, two studies are presented that describe methods which enable users to plan their designs and develop their skills on considering alternative directions.

Roberts *et al.* [RHR16] describe a method which helps users plan their visual design for data mapping ideas. They recommend generating ideas starting with a comprehensive brainstormed list and prioritizing them from best to worst. The Five Design Sheet Methodology (FdS) is a five-stage process that features a brainstorm (idea) sheet, three design sheets and realization at five steps. The FdS model enables the user to consider multiple perspectives and discuss designs to explore a variety of visual solutions.

An example of the five FdS sheets was produced for an assessment of an information visualization module in MSc Computer Science program. Fifty-three students who take an information visualization module on an advanced computer science course participate in the evaluation and analyze data that describes performance indicators of a range of universities and contains data on expanding participation and disability support. The students follow the FdS method, and develop a prototype tool in Java. The five FdS sheets demonstrate how the students discover different potential visual descriptions of the data before completing a chosen design.

In follow-up work, Roberts *et al.* [RRJH18] define 6 components (of an active learning framework): research, report, design alternatives, plan, develop and reflect, that are split into three stages. These are:

- Stage 1: Establishing Fundamental Knowledge: The main goal is to increase and assess knowledge. Students need to perform research, take notes and then write up the findings in a well-structured, written report.
- Stage 2: Design and Plan: The aim of this stage is to investigate alternative design ideas and to increase creative skills. After some initial lectures, there are practical activities to upskill creativity, including exercises to practice the Five Design-Sheets method [RHR16] and story boarding techniques.
- Stage3: Develop, Reflect and Present: The goal of the final stage is to develop an implementation from the final design from sheet [RHR16] and the organization of the story from the storyboard sketches. After that, the students reflect on their work, give a presentation and demonstrate their explanatory visualization.

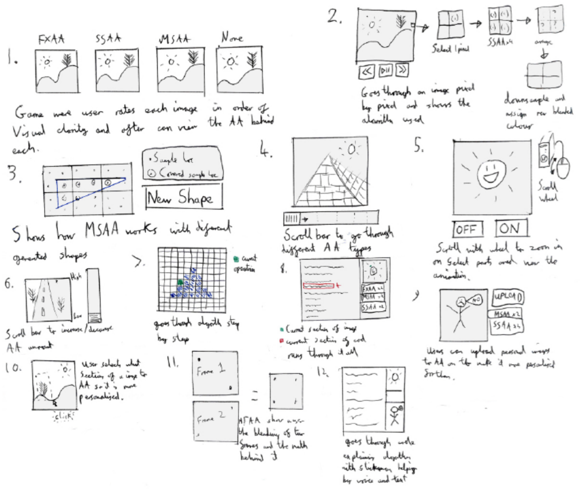


Figure 7: *An example from student sketch on their Fds Sheet which includes 12 different ideas [RRJH18].*

There is remarkable similarity between these and previous instructional models such as ADDIE [BRC*75] (analysis, design, development, implementation and evaluation) and Jonassen's eight stages [Jon97]. The data visualization community have created several models that help developers consider and build visualization tools. Models such as Munzner's nested model [Mun09], McKenna and Meyer [MMAM14] (understand, ideate, make, deploy) and the nine-stage design-study model by Sedlmair and Munzner [SMM12] can be used in teaching scenarios.

Teaching creative skills in Higher Education has many benefits; the most important being that the students develop their skills in thinking through problems, having alternative approaches and creating more effective solutions. Roberts *et al.* [RRJH18] guide students to think through the explanatory visualization task, consider alternative solutions and demonstrate their design, implementation choices, and actions. The framework is aimed to supply a good balance between promoting creative thinking and providing planned guidance. Students are tasked with creating explanatory visualizations of computer graphics. By creating their own explanatory visualizations, students learn and develop their creative and communication skills (see Figure 7). The informal evaluation is based on using the method directly in a classroom.

4. Conclusion and Future Work

This work-in-progress paper contributes a literature review in visualization for education. We provide a novel classification of pedagogic papers that enable researchers to explore published literature that demonstrate the influence of visualization methods on users' training. The natural subject-based classification enables readers to identify areas of open research subjects in interactive visual representation for education. This paper presents a classification table which provides a first step to start studying in this field. We also believe that this overview is a beneficial for both new or experienced researchers interested in visualization and education. Future work includes adding more related literature to the survey, developing the classification further, and adding more comparative meta-data from the literature.

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