Eye Tracking Methods for Improving Engineering Graphics Instruction

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Abstract
The tracking of eye movements is a powerful tool used to understand the process of visual search. Recording and analyzing eye movements allow researchers to better understand how individuals make use of visual information. While eye movement research has been conducted for over 70 years, recent technological breakthroughs have made this equipment accessible to a wider range of researchers. Eye movements can be tracked across paper-based materials, computer screens, or any plane defined in 3-D space. The focus of this presentation is how eye tracking methods can be used in the design of instructional materials, particularly materials that make use of graphics for instruction. Past research on engineering graphics instructional materials presented at ASEE and similar conferences has focused on outcomes such as test scores and satisfaction ratings. Eye tracking data can build on these data sources by providing a deeper understanding of "why" a student may have or have not performed well using a particular set of instructional materials. Background will be given on the basic technologies currently employed and typical measures used to evaluate perceptual and cognitive processes involved with visualization. Next, it will be shown how this information can be used to evaluate instructional materials and provide guidance for redesign. Particular focus will be on the evaluation of graphic elements used in instruction. Finally, examples will be given of how these methodologies have been used to evaluate instructional materials in engineering and pre-engineering instruction.

Introduction

Virtually everyone involved in engineering education has at one time or another written instructional materials for their students to use. If you are involved in engineering design graphics education, you have probably prepared both text and graphic materials for you students to use. After distributing the material to your students, discussed it in your class, and evaluated their knowledge of the material, you've probably asked yourself the question: "Did they even look at that material that I gave them?" It is a perennial question educators ask and one that typically has only been answered indirectly through polling the students or testing their recall of the material. There are times, though, where it would be very helpful to know, truly, did they see what you intended them to see? For this purpose, you need eye tracking technology.

Eye tracking can be particularly useful for two broad areas of application: 1) general research understanding of how different types of students in different learning situations make use of text and graphics, and 2) applied usability research of instructional materials that will be going into publication for large numbers of students. Eye tracking technologies historically have been expensive to purchase and maintain, limiting their use to basic research. However, newer lower cost and easier to maintain technologies have made more general use in the evaluation of text and graphic materials more viable. It means that commercial publishers of both print and computer-based instructional materials have the potential of employing eye tracking in the design of their materials. Not surprisingly, eye tracking is increasingly used in the design of advertising materials[1, 2]. There is no reason why it should not also be used in what is arguably an even more important text and graphic communication application—instruction. This paper will provide a brief background to eye tracking technologies and methodologies and then provide some more specific applications to the design of instructional materials used in engineering and engineering design graphics education.

Background

Interest in where individuals "look" when reading text or inspecting a graphic is as old as the science of perception itself. Technical limitations stood in the way of accurate measurement of an individual's gaze until breakthrough work by Buswell[3] and others in the 1930's. Even still, the technology remained crude and inaccessible for all but the most dedicated researchers for much of the 20th century. However, another groundbreaking book by Yarbus[4] and growing interest in visualization of two and three-dimensional forms in the 1970's [5, 6] also led to a resurgence of interest in the application of eye tracking as a means for better understanding how individuals view and process graphic information. As eye tracking technology improved and the theoretical basis of eye tracking solidified, the potential application of this technique outside of the basic research lab has begun to show promise.

In the last ten years, numerous applied areas have opened up, including: advertising (mentioned above), transportation design (e.g., aircraft cockpits and car interiors), and web page usability studies [7]. The business interest in web and traditional print advertising has driven much of the application use of eye tracking in this area[1, 8]. From a business standpoint, it may be understandable that there has not been the logical carry-over to instructional design research, with only a few studies published looking specifically at the design of text and graphics in instruction[9, 10]. However, as the production and distribution of instructional materials continues to consolidate and the potential payoffs for well-designed materials proven to enhance learning continue to increase, there is likely to be increased interest in eye tracking technologies. Many engineering disciplines have a high spatial component and/or abstract concepts that lend themselves to the use of graphic representations. How these graphics should be designed and integrated with textual descriptions is not well understood. Work by Mayer and his colleagues[11, 12] and Sweller and colleagues[13] have provided a solid start to a better understanding how to design multimedia instructional modules. Eye tracking shows great potential to take this work to the next level in instructional areas such as engineering education.

Applied Methods

The term eye tracking covers a wide range of technologies and techniques. In almost all cases, the goal is to track where one or both eyes are looking (i.e., the gaze) and, therefore, what information is being acquired through vision. Of interest here is the gaze on instructional materials such as printed pages or computer displays. It can also include looking at three-dimensional objects, though the interpretation of this data is more problematic. The gaze trail of the eyes consists primarily of a sequence of saccades and fixations. Saccades are rapid eye movements while fixations are gazes that hold in a small perimeter area for a certain length of time. Though what defines a fixation is still a topic of scholarly debate, it can roughly be thought of as a gaze that holds in an area around 1 visual degree for 100-200 msec[7]. In fact, the eye is moving constantly, and even during a "fixation", it is undergoing a series of small, micro-saccades. During a fixation, visual information is being processed in detail and the brain plans the next movement; either a series of saccades which pick up low-level gross information about a visual scene, or another fixation to pick up more detailed information.

For the applied researcher using eye tracking equipment, fixation location and duration becomes the key raw data from which most other measures of interest are derived.Other measures of interest might be: 1) number of fixations within a particular region in a visual scene, 2) total fixation time within a region, 3) interfixation distance (i.e., distance between fixations), and 4) scanpaths—the sequence of fixations in a scene. The first two of these measures has something to say about what the viewer thought was important to look at and how difficult it was to process the information. The last two measures have something to say about a viewer's strategy; what should be looked at in what detail and in what order. This, of course, is a considerable over-simplification of eye tracking data interpretation, but it provides an idea of what kind of data is available for better understanding how a viewer is making use material they are looking at.

Applied researchers are primarily making use of two basic types of technologies: "bright-eye" and "dark-eye" trackers[7]. Bright-eye trackers use an infrared light shining into the eye to create two reflections, one through the pupil and off of the back of the retina and one off of the surface of the cornea. An infrared-sensitive camera records these two reflections, using image processing techniques to size and locate these two reflections in the image at a rate of 30-60 Hz. The relative position of these two reflections is then used to tell where the eye gaze is. The retinal reflection looks large and bright in this video image, thus its common name. Dark eye trackers use a similar image processing approach using visible light and often visible landmarks other than the corneal reflection. In this more standard video image, the pupil looks dark. In order to associate the relative locations of eye landmarks with a gaze point on the material of interest, a calibration procedure must be conducted. The location of the eyes to the material viewed is measured and the viewer is asked to look at a series of calibration points of known location while their eye reflections are recorded. Since subsequent movement of the head can affect this calibration, the researcher has a number of options to insure reliable data collection. At one extreme, the viewer's head can be restrained in a chin rest or similar device. Alternately, a magnetic head tracker can track and compensate for head movements. Or, finally, the video image processing can attempt to compensate for recorded movement of the head/face. These options roughly fall along a continuum of higher to lower precision while also going from more restrictive to more natural viewing environments.

Example Applications

While the technical details of eye tracking methods may appeal to some, of broader interest to the engineering education community is how eye tracking can be used to improve instruction. As in most applied research, eye tracking should be one of many tools the instructional researcher uses to help better understand how a learner acquires and processes visual information. In the opening section, more traditional research tools were alluded to: surveying students and measuring performance through testing. While these approaches help with measuring outcomes, it doesn't tell us much about why one got the measured outcomes one did. Eye tracking has the potential to help get answers these "why" questions.

The eye tracking measurements mentioned earlier can directly tell the researcher what was looked at and for how long. While it is likely that everything in a scene is viewed and processed at a very low perceptual level, one or more fixations will indicate that this area was of particular interest to the viewer and processed at some level of depth. Eye tracking equipment is precise enough to resolve fixations to the level of a single printed word or the vertex on a pictorial line drawing of an object. Eye tracking data can help the researcher correlate what the instructional designers thought was the most important information to view on a page/screen with what individuals actually spent time on. Similarly, analysis of the sequence of fixations can lend insight into the order in which information is processed. Fixations are not random and are guided by an ongoing processing of information. Fixation sequences can help understand whether textual or narrative elaboration of a graphic helped guide the viewing of this graphic, or whether specific graphic elements proved to be “distracting”, continually drawing the gaze.

Looking at engineering design graphics education, there has been an ongoing interest in which types of representations are best for helping students visualize two and three-dimensional form[14-16]. As noted above, eye tracking was an important thread in the visualization research in the 1970’s [6]. Eye tracking research can continue to be part of our discipline-specific instructional research as we explore the use of static and animated representations of 3D forms, line drawn versus shaded/rendered representations, and the use of annotations such as coordinate axes, vectors, or text.

Almost invariably, the published instructional materials used in engineering design graphics education contains a mixture of text and graphic representations[17]. Even as instructional materials move from printed form to multimedia platforms such as PowerPoint™ and Blackboard™, there is still a healthy mix of text with static graphics and animations. If text is being displaced, it is with the spoken word through narration replacing text. In all of the these cases, previous work using eye tracking to look at the interplay of text and graphics[9] along with the development of more general heuristics for the use of multimedia elements provides a starting point for using eye tracking to look at the specific issues in engineering graphics and its very heavy reliance of graphics and visualization.

Ongoing research at the eye tracking lab at North Carolina State University is looking into many of the issues listed above. Current studies include looking at the effect narration has on making use of both printed text and graphics in PowerPoint presentations. Another line of work is comparing simplified 2D schematic representations and complex 3D representations of DNA replication in biotechnology instruction. Finally, work is also ongoing to better understand how to best represent terrain for students trying to visualize 3D land forms. The laboratory looks forward to taking a closer look at how other spatially challenging information such as mechanical devices are represented and how animation affects how graphic information is acquired and processed.

Acknowledgements
This work was supported in part by a grant from the NC GlaxoSmithKline Foundation.

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Biography

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