2006-412: USE OF GRAPHICS IN MULTIMEDIA INSTRUCTIONAL MATERIALS: RESEARCH-BASED DESIGN GUIDELINES

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Use of graphics in multimedia instructional materials: Research-based design guidelines

Abstract

Engineering education, along with other disciplinary areas, uses a wide range of media and sensory modalities to communicate ideas and concepts to and between students. Put into the context of a modern classroom, text and graphic combinations are likely to come in a number of different forms. With the explosion of use of multimedia tools has come an increased interest in learning sciences research into the cognitive basis of multi-representational learning. This paper will explore current cognitive theory and the design heuristics that have been derived from it on the use of multimedia elements—especially graphics—in instructional materials. Research by the author will be presented demonstrating the use of eye tracking methods to help further understand the basic cognitive processes of multimedia learning. Findings have helped explain the interaction of text, graphics and narration. In addition, the results help provide guidance as to when it is or is not appropriate to differing combinations of these three mediums.

Introduction

Engineering education has been witness to an ever-evolving array of technologies used to communicate science and engineering concepts. While many of these communication technologies have changed over the years, others have remained relatively constant (e.g., the textbook) and—even more important—many of the underlying forms of representation have continued to be in regular use. Dominant among these forms are text and static graphics. Regardless of the medium of delivery, these two representational forms continue to play a primary role in education. If there has been a shift over the years, it has been the increased use of graphics as their production and dissemination costs have decreased. Popular engineering graphics textbooks[1] often have four or more full color graphics on a two-page spread. A survey by Roth, et al.[2] showed that there are about 17 photographs on every 20 pages of high school biology textbooks.

An increasingly popular medium for supplementing textbook instruction is slideware applications such as PowerPoint™. PowerPoint has become a mode of communication at nearly every level, from professional conferences through elementary school. Most commonly, it allows the presenter to supplement their speaking with graphics as well as highlight key points with bulleted text. An alternative approach is to use PowerPoint for self-paced instruction. In this case, PowerPoint can be used as supplement to or in place of a textbook. The PowerPoint file can be delivered as a file disk, or via a website. In addition to providing visual text and graphics, audio narration can be added to the presentation, replacing the traditional role of the presenter/lecturer. While approaches such as these are most commonly seen in various types of distance education offerings in post-secondary STEM education, it is becoming increasingly common in secondary education. Clark[3] reported that an estimated 40-50,000 K-12 students took an online course during the 2000-2001 school year.

The creators of these multimedia instructional materials must make decisions as to the appropriate interplay of text, graphics and narration. Instructional material should be trying to convey conceptual and factual information and to link these elements together into a larger, cohesive knowledge base about a subject. As such, the instructional designers need to decide whether these ideas are to be embedded in the text or graphics and whether the textual content should be delivered in visual/print form or narration or both. Tufte[4] notes that these decisions are fraught with pitfalls; more often than not, leading to a poor choice of both text and graphics to communicate the instructor's ideas.

Over the past ten years, educational researchers have been refining a set of heuristics for guiding the selection of text and graphics when developing instructional materials. While they are far from complete and do not guarantee an optimal design, they still provide robust guidance during the design process—whether you are a professional designer or just a professor. The remainder of the paper will introduce these heuristics and the theory behind them.

A Research Basis for Design

Cognitive Load Theory

Great strides have been made in the last 15 years as to how cognitive theory can be applied in the instructional settings [5, 6]. Parallel with these efforts has been development of theories of multimedia learning that apply cognitive theory to the problem of appropriate design of multiple media elements in instructional materials. Meta-analyses[7-9] cite work demonstrating that graphics can support the representation of spatial information in ways that are hard to do in textual form. If there is a singular message from this research it is that graphics can be beneficial to learning *when used appropriately.*

A broad line of research that attempts to address these issues of text-graphic relations is based on cognitive load theory [10, 11]. This theory is based on a model of cognitive architecture that includes a discrete, limited-capacity working memory component [12-14]. A part of this model surmises unique working memory processing mechanisms for auditory and visual information [13]. Two largely independent working memory processing mechanisms means information load that might overwhelm one of these processing systems can be effectively managed when divided across two of these systems. This model assumes that text delivered on a printed page would load on the same working memory system as a printed illustration while the same text delivered as narration would load on the phonological system. Multimedia researchers applied this theory to confirm advantages (in some cases) to designing instructional materials that had the text delivered as narration [15, 16].

Another cornerstone to cognitive load there is that meaningful learning is often linked to integrating multiple pieces of information from multiple representations [17-19]. These pieces of information often are divided between graphic and textual components—sometimes redundantly encoded in these different sources. How these elements are encoded and spatially, temporally, and modally arranged can influence the cognitive load required to process and integrate this information. This condition, often referred to as the split-attention effect, predicts that spatial or temporal separation of visual media elements

that need to be integrated will create additional load since information will have to be held in working memory until the disparate elements are integrated into long-term memory [20, 21]. These additional demands leave fewer cognitive resources available for learning.

As noted above, working memory load is tied, in part, to how the learner's attention is allocated. Information in the visual field is scanned both pre-attentively and attentively [22]. Pre-attentive processing helps initially organize information in the visual field and happens in parallel with little effort. Attentive processing, though, is done with effort in a serial manner. The working memory efficiency advantages of coding information in more than one modality or as printed text and graphics will be lost if excessive resources are needed to search the visual field for information to coordinate with, say, the narration. Numerous studies have demonstrated the effects on learning when the information elements are not designed for effective integration [15, 23, 24]. The design of the information elements with regard to color, shape and texture can affect the degree to which this information can be organized pre-attentively so that cognitive resources can be directed to the most relevant material.

Multimedia Learning Theory

In parallel with the work done by cognitive load theorists, Mayer and colleagues have been developing a related theory of multimedia learning [24, 25]. In addition to using Baddeley's theories of working memory, Mayer also made use of Paivio's[26] dual-coding model, which surmised unique processing of textual and graphic elements. Mayer's [27, 28] work applied this theory to multimedia learning and demonstrated in more detail the interplay between text, graphics and narration and under what conditions which combinations might be best applied. As with the cognitive load researchers, Mayer provided a definition of learning to guide his research. Learners will actively scan and acquire textual and graphic material that they feel will be most relevant to their current cognitive task [29]. Meaningful learning will take place when learners can integrate relevant information into coherent memory structures that are integrated with allied structures of knowledge. Learners need to be able to later retrieve this information when it is relevant and supportive of the task at hand. The goal is to provide an instructional information structure that lowers cognitive load and minimizes the utilization of working memory capacity in the acquisition and processing of graphic and textual information.

An interesting extension of this work has demonstrated that inclusion of both printed text and narration can sometimes lead to poorer performance than using only narration to support the textual portion of the information [21, 30, 31]. This effect is explained, in part, by both the visual (print) text and graphics competing for short term memory resources. In addition, this interpretation surmises that the disruption comes from both the visual text and auditory narration competing for unique semantic short term memory stores where printed text is "verbally" processed prior to encoding into long term memory [32, 33].

Mayer and colleagues also conducted a number of experiments that looked at the role of animations, as opposed to static graphics, in multimedia learning [30]. Animations, by their nature, present multiple images over time. In doing so, a stroboscopic effect is created that allows viewers to perceive dynamic phenomena much as they would in the physical world. These virtual dynamic events can be grounded in events seen with the unaided human eye, but in the classroom—more often than not—they represent

phenomena that unfolds very slowly or very rapidly or is an abstract concept not directly connected to physical objects. As such, animations will be most powerful in representing concepts where change over time is a critical component [34]. An extension of this is weighing the alternatives of representing change over time via stroboscopic motion of elements in an animation versus using one or more static images presented serially or in parallel depicting the same change. Similarly, motion in a static image can also be inferred through the use of graphic devices such as arrows or transparency [35]. A critical consideration when choosing the appropriate form of representation is the form and accessibility of the information deemed necessary for learning and the processing required to access that information [36].

How dynamic elements are presented over time and space, what other information sources need to be integrated to fulfill the learning goal and the characteristics of the learner are also all crucial issues in the use of animations. These factors are parallel to many of those considered with static graphics in multimedia instructional materials, but require increased design sensitivity due to the increased cognitive demands of animations over static graphics [37,38]. Central to this increased load is the transience of the images in an animation. While a static image is likely to be re-inspected numerous times [39-41], the image elements of interest in an animation are likely to change shape, location, etc. or disappear altogether as the animation plays. There may also be an issue as to whether cognitive processing can keep up with the rate of presentation [37, 42].

Guidelines

Derived from cognitive load theory and multimedia learning theory are a number of guidelines that find broad support among researchers. As with any heuristic, there are always exceptions and cases of interactions with other elements that cannot be predicted *a priori*. So, with that caveat, here are some guidelines that are both regularly violated and, if followed, are likely to improve learning:

1. Make use of multimedia elements when they provide the sources of information relevant to the learning goals. In particular, use the mode of delivery best suited for the type of information. For example, if the information is spatial in nature or requires a holistic integration of elements that need to be accessed in parallel, then graphics may be more suitable than text. Animations may be appropriate when displaying phenomena that change over time. On the other hand, lists of information and detailed descriptive information may be better presented as text. Purely decorative graphic elements add nothing to conveying key information and may distract the learner.

2. Information that needs to be integrated should be placed near each other in time and space. That is, information needed to derive understanding of a specific concept or idea should, ideally, all be available in the visual (or auditory or both) field(s) at the same time. Serial presentation of information that needs to be integrated means that either the chunks of information need to be rehearsed and held in short term memory until the other information is available or integrated and then retrieved from long term memory. However, this information may not be readily accessible from long term memory if the learner cannot relate it back to the concept being learned. Similar to serial presentation of

information, if the material is spread out in the visual field, effort is needed to search out and fixate on the different pieces of information sequentially.

3. Coordinate pieces of information that need to be brought together. Visual search can be reduced if related pieces use a consistent and coherent scheme for labeling and referring to elements. This can be done through the use of color, textual, or numeric coding. Similarly, text should explicitly reference a graphic or elements of a graphic when they help understand the textual material. Finally, when sequences of illustrations are used, locate graphic and textual elements in a consistent spatial pattern, so the learner can find information with a minimum of visual search. Related to this is the consistent use of the same terms and design of graphic elements so that when they are re-encountered, they can be easily identified and associated with their past appearance.

4. Use narration to relieve load on the visual system. When both graphics and printed text are used, visual attention has to be divided between the text and graphics, often requiring information elements from both sources to be managed in the limited capacity short term memory. By shifting printed text to narration, some of the load put on short term visual memory is relieved. Text presented as narration means the eyes can stay on the graphic as the coordinated narration refers to elements in the graphic. This can be particularly powerful when the narration is coordinated with an animation so that text is presented at the appropriate time as events unfold in the animation.

5. Be careful when providing redundant information. Current research indicates parallel presentation of identical content as both printed text and narration may be detrimental to learning. When presented this way, the learner devotes additional cognitive resources to coordinating the printed and narrated text to the detriment of integrating graphic information. There are not, however, clear guidelines as to how to use combinations of printed text, graphics, and narration when the text and narration do not overlap word for word.

6. Carefully monitor overall cognitive load on the learner. Good and bad cognitive load need to be distinguished from each other. Extraneous load resulting from poor design decisions discussed above robs the learner of cognitive capacity that could be directed towards learning. However, learning requires cognitive capacity to be used to challenge the learner to acquire new information, connect these elements together to generate insight and integrate them into long term memory. Optimal learning occurs when the learner is maximizing their ability to engage in these tasks. Equally undesirable as burdening the learner with extraneous load is underwhelming the learner and not making use of their cognitive resources to learn. Since each learner is unique—optimal load will be different for everyone—instructional materials and the instructors (human or computer) guiding the learner need to respond to changes in load over the course of a lesson or course.

Current Research

Work by our research group has conducted investigations extending and exploring the heuristics presented above. One line of work has used eye tracking technology to

investigate the interaction of graphics, text, and narration. Eye tracking is a particularly powerful tool to quantify how visual attention is distributed over time and space as a learner interacts with instructional material. By recording eye movements, how much time is spent on different learning elements and in what order can be recorded and analyzed.

An initial study by Slyhkuis, et al.[43, 44] showed that graphics in a PowerPoint slide attracted visual attention regardless as to its relevance to the content presented in the text. While irrelevant graphics garnered substantially less attention than their relevant graphic counterparts, they still were viewed—usually at the beginning. The other finding from this study was that narration interacted with graphic relevance. Narration tended to equalize the ratio of time spent looking at the text and graphic between the relevant and irrelevant graphics. A follow-up study [45] reinforced these findings and extended them to cases when the graphics were animations. An additional finding from this second study was that increasing density of text on the slide increased the difference seen in the text to graphic ratio when narration was added. That is, there was a marked increase in the time spent looking at the graphic when narration relieved the viewer of reading text. In both the studies, narration "paced" the viewer such that they spent considerably more time looking at both the text and graphic elements on the slide.

In a pair of studies looking at the visual representation of DNA replication, Patrick, et al. [46, 47] used eye tracking and interviews to study how both novice middle school students and experts (science teachers) extracted information from a sequence of four graphics of DNA replication. These studies provide more information of the role cueing can play and the importance for coordinated textual support for graphics. While graphic design techniques such as color coding and shape were equally effective at drawing attention from both novices and experts, without additional support for generating understanding, the novices were not able to make sense of what they were looking at. That is, while the novices were able to use universal cues of color and shape to cue in on key elements of the graphic (as determined by the designers), the graphics were not "self-explanatory" and needed additional text support to generate meaning from the graphic elements.

Spatial tasks are particularly sensitive to representation. A study by Carroll and Wiebe[48] documented the difference in performance in an origami paper folding task between those using video instructions and those using traditional printed graphic and text instructions. Those students viewing the dynamic representations of folding (a highly spatial task) outperformed those having to create the folds from static text and line drawings. However, once the task became very difficult for the novices attempting the folds, neither format showed an advantage.

This and other studies have pointed to the importance of measuring the level of cognitive load learners are under. Prior experience is just one of many individual differences that can affect load and, in turn, affect choices in instructional design. Work underway in the lab is looking at validating better instruments for measuring cognitive load.

References

1. Bertoline, G.R. and E.N. Wiebe, *Fundamentals of graphics communication*. 5th ed. Irwin Graphics Series. 2005, New York, NY: McGraw-Hill.
2. Roth, W.-M., G.M. Bowen, and M.K. McGinn, *Interpretation of graphs by university biology students and practicing scientists: Toward a social practice view of scientific representation practices.* Journal of Research in Science Teaching, 1999. **36**(9): p. 1020-1043.
3. Clark, T., *Virtual Schools: Trends and Issues. A Study of Virtual Schools in the United States*. 2001. Report. Distance Learning Resource Network, WestEd. URL: www.WestEd.org/online_pubs/virtualschools.pdf
4. Tufte, E., *PowerPoint is evil: Power corrupts. PowerPoint corrupts absolutely*, in *Wired*. 2003.
5. Pellegrino, J.W., N. Chudowsky, and R. Glaser, *Knowing what students know: The science and design of educational assessment*. 2001, Washington, DC: National Academy Press.
6. Bransford, J., A.L. Brown, and R.R. Cocking, *How people learn : Brain, mind, experience, and school*. 2nd ed. 2000, Washington, D.C.: National Academy Press. xxiii, 319.
7. Vekiri, I., *What is the value of graphical displays in learning?* Educational Psychology Review, 2002. **14**(3): p. 261-312.
8. Peeck, J., *The role of illustrations in processing and remembering illustrated text*, in *The psychology of illustrations: Basic research*, D.M. Willows and H.A. Houghton, Editors. 1987, Springer-Verlag: New York. p. 115–151.
9. Carney, R.N. and J.R. Levin, *Pictorial illustrations still improve students' learning from text.* Educational Psychology Review, 2002. **14**(1): p. 5-26.
10. Paas, F., et al., *Cognitive load measurement as a means to advance cognitive load theory.* Educational Psychologist, 2003. **38**(1): p. 63-71.
11. Sweller, J., J.J.G.v. Merrienboer, and F.G.W.C. Paas, *Cognitive architecture and instructional design.* Educational Psychology Review, 1998. **10**: p. 251-96.
12. Newell, A. and H. Simon, *Human problem solving*. 1972, Englewood Cliffs, NJ: Prentice Hall.
13. Baddeley, A., *Human memory*. 1999, Boston, MA: Allyn & Bacon.
14. Miller, G.A., *The magical number seven plus or minus two: Some limits on our capacity for processing information.* Psychological Review, 1956. **63**: p. 81-97.
15. Tindall-Ford, S., P. Chandler, and J. Sweller, *When two sensory modes are better than one.* Journal of Experimental Psychology-Applied, 1997. **3**(4): p. 257-287.
16. Penney, C.G., *Modality effects and the structure of short term verbal memory.* Memory and Cognition, 1989. **17**: p. 398-422.
17. van Someren, M., et al., *Learning with multiple representations*. 1998, Amsterdam: Pergamon.
18. Kozma, R., *The material features of multiple representations and their cognitive and social affordances for science understanding.* Learning and Instruction, 2003. **13**(2): p. 205-226.
19. Larkin, J.H., *The role of problem representation in physics*, in *Mental models*, D. Gentner and A.L. Stevens, Editors. 1983, Erlbaum: Hillsdale, NJ. p. 75-98.
20. Mayer, R.E. and R. Moreno, *A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory.* Journal of Educational Psychology, 1998. **90**(2): p. 312-320.
21. Kalyuga, S., P. Chandler, and J. Sweller, *Managing split-attention and redundancy in multimedia instruction.* Applied Cognitive Psychology, 1999. **13**(4): p. 351-371.

22. Treisman, A.M. and G. Gelade, *A feature integration theory of attention.* Cognitive Psychology, 1980. **12**: p. 97-136.

23. Jeung, H.J., P. Chandler, and J. Sweller, *The role of visual indicators in dual sensory mode instruction.* Educational Psychology, 1997. **17**(3): p. 329-343.

24. Mayer, R.E. and R. Moreno, *Nine ways to reduce cognitive load in multimedia learning.* Educational Psychologist, 2003. **38**(1): p. 43-52.

25. Moreno, R. *Who learns best with multiple representations? Cognitive theory implications for individual differences in multimedia learning.* in *ED-MEDIA 2002 World Conference on Educational Multimedia, Hypermedia & Telecommunications.* 2002. Denver, CO.

26. Paivio, A., *The empirical case for dual coding*, in *Imagery, memory, and cognition*, J.C. Yuille, Editor. 1983, Erlbaum: Hillsdale, NJ. p. 307-332.

27. Mayer, R.E., *The promise of multimedia learning: using the same instructional design methods across different media.* Learning and Instruction, 2003. **13**(2): p. 125-139.

28. Mayer, R.E., *Elements of a science of e-learning.* Journal of Educational Computing Research, 2003. **29**(3): p. 297-313.

29. Mayer, R.E., et al., *Maximizing constructivist learning from multimedia communications by minimizing cognitive load.* Journal of Educational Psychology, 1999. **91**(4): p. 638-643.

30. Mayer, R.E. and R. Moreno, *Animation as an aid to multimedia learning.* Educational Psychology Review, 2002. **14**(1): p. 87-99.

31. Kalyuga, S. and J. Sweller, *Measuring knowledge to optimize cognitive load factors during instruction.* Journal of Educational Psychology, 2004. **96**(3): p. 558-568.

32. Freedman, M.L. and R.C. Martin, *Dissociable components of short-term memory and their relation to long-term learning.* Cognitive Neuropsychology, 2001. **18**(3): p. 193-226.

33. Martin, R.C., M.S. Wogalter, and J.G. Forlano, *Reading comprehension in the presence of unattended speech and music.* Journal of Memory and Language, 1988. **27**(4): p. 382-398.

34. Ainsworth, S. and N. VanLabeke, *Multiple forms of dynamic representation.* Learning and Instruction, 2004. **14**(3): p. 241-255.

35. Bertoline, G.R., et al., *Engineering graphics communications.* 1 ed. Irwin Graphic Series, ed. G.R. Bertoline. 1995, Chicago, IL: Richard D. Irwin.

36. Larkin, J.H. and H.A. Simon, *Why a diagram is (sometimes) worth ten thousand words.* Cognitive Science BF311 .C552, 1987. **11**: p. 65-99.

37. Lowe, R.K., *Extracting information from an animation during complex visual learning.* European Journal of Psychology of Education, 1999. **14**: p. 225–244.

38. Lowe, R.K., *Animation and learning: selective processing of information in dynamic graphics.* Learning and Instruction, 2003. **13**(2): p. 157-176.

39. Wiebe, E.N., L.A. Annetta, and D.A. Slyhkuis. *Eye tracking students' use of science related PowerPoint presentations.* in *NARST Annual Meeting Proceedings.* 2005. Dallas, TX: NARST.

40. Hegarty, M., *Mental animation: Inferring motion from static displays of mechanical systems.* Journal of Experimental Psychology: Learning. Memory, and Cognition, 1992. **18**: p. 1084-1102.

41. Carpenter, P.A. and P. Shah, *A model of perceptual and conceptual processes in graph comprehension.* Journal of Experimental Psychology: Applied, 1998. **4**: p. 75-100.

42. Bodemer, D., et al., *Supporting learning with interactive multimedia through active integration of representations.* Instructional Science, 2005. **33**: p. 73-95.

43. Slyhkuis, D.A., L.A. Annetta, and E.N. Wiebe, *Eye-tracking students' attention to PowerPoint photographs in a science education setting.* Journal of Science Education and Technology, in press.

44. Slyhkuis, D.A., E.N. Wiebe, and L.A. Annetta. *Eye tracking students' use of science related Powerpoint presentations.* in *Annual meeting of the National Association for Research in Science Teaching.* 2005. Dallas, TX.

45. Wiebe, E.N. and L. Annetta. *The Influence of Narration on Attentional Distribution in Multimedia Instructional Materials.* in *AERA Annual Conference Proceedings.* in press. San Francisco, CA: AERA.

46. Patrick, M.D., G. Carter, and E.N. Wiebe, *Visual Representations of DNA Replication: Middle Grades Students' Perceptions and Interpretations.* Journal of Science Education and Technology, 2005. **14**(3): p. 353-365.

47.   Patrick, M.D., G. Carter, and E.N. Wiebe. *Visual Representations of DNA: A Comparison of Salient Features for Experts and Novices*. in *NARST Annual Meeting Proceedings*. in press. San Francisco, CA: NARST.
48.   Carroll, L. and E.N. Wiebe. *Static versus dynamic presentation of procedural instruction: Investigating the efficacy of video-based delivery*. in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. 2004. New Orleans, LA: HFES.