Instructional design for effective and enjoyable computer-supported learning

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Abstract

This special issue is dedicated to a number of efforts being made by researchers – primarily in Europe – to make learning more effective AND more enjoyable. The basis of this Special Issue lies in a conference organized by two Special Interest Groups (Instructional Design (SIG 6) and Learning and Instruction with Computers (SIG 7)) of the European Association for Research in Learning and Instruction (EARLI) held July 2004 at the Knowledge Media Research Center in Tuebingen, Germany (http://www.iwm-kmrc.de).
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1. Introduction

Once upon a time, not very long ago, Henry Ford – a pragmatist, penny-pincher and visionary – coined the noteworthy phrase “You can get a car in any color you like as long as it is black”. Although the paint industry was not that limited, characteristic for such industries was that they did have only a limited assortment of
colors. The manufacturer determined the colors and types of paint available and the only consumer influence was that they could choose another brand if a manufacturer could not (or would not) deliver what they wanted. And the manufacturer could only offer a limited variety of colors and types because the processes of paint production and distribution were very costly and the reaction of the market to new paints was unpredictable. The retailer, the third party here, was also very limited. In order to offer a wide variety of paints (colors, types, manufacturers) they needed large display areas to present the different paints and large storage areas to store the stocks. Finally, stocking a wide array of colors was a financial burden and risk because the retailer never knew what would sell and what would not. Still the demands of the consumers grew, the manufacturers offered ever widening assortments of paints and the stores and storage rooms got bigger and bigger.

In the second half of the twentieth century, in a period in which technology began to allow for standardization and stability of chemical processes and for increased accuracy of measurement, someone got a creative brain wave that sounded something like this: “Why should we premix and pre-package everything for the retailer and consumer. Making paint is child’s play. You mix pigments, add them to one or more bases and voilà – colored paints.” All of a sudden it was possible to widen the variety of colors without the concomitant problem just discussed. The change was dramatic. Paint manufacturers could now offer retailers not only a line of pre-mixed paints, but also the pigments, bases, recipes and machinery to allow retailers to mix the paints themselves. Retailers no longer needed to devote meters of shelves and cubic meters of warehouse space to the presentation and storage of paints. They also no longer needed to run the risk of stocking too many unwanted colors and too little wanted ones. Customers had a lot more to say about the choice of colors, had a wider variety of choices and could even – if they were adventurous – mix their own colors, although woe be it to those who bought too little and had to try to remix the exact same color! The customer, the retailer and the manufacturer were all more satisfied.

Enter the information technology revolution with computers, color scanners, color analyzers, super accurate measuring and dosage devices, and so forth. Now, in 2005, you can take a sample of weather-beaten paint or a color that you mixed yourself – it does not matter how large – to the store. The salesperson can scan the color that you brought, analyze it, have the computer choose the exact combination of pigments and bases necessary to create an exact match, have the dosages of the pigments automatically added to the mixture of bases, shake it and deliver it. The production and retailing of paint has become more effective (and efficient) and we would not go so far as to say that painting has become more enjoyable, the job of finding the right paint has become easier and much more satisfying (i.e., the buyer does not have to settle for a compromise, although (s)he can go crazy with the wealth of possibilities).

This evolution (some might call it a revolution) has also occurred in other industries such as the auto-industry itself. Pre-producing many models, series and colors of cars was also a bulky and risky business. A car manufacturer with four models (family, sport, station wagon and compact), each with three engine sizes, two types
of transmissions (manual and automatic) and six colors requires a stock of 144 different possible cars \((4 \cdot 3 \cdot 2 \cdot 6)\) which may or may not sell. This was followed by a process where the parts (and not the cars) were warehoused with much of the standard production being done in advance and the finishing touches added on demand. We have now reached the stage of Kanban production (Kupanhy, 1995) where there are no cars on the lot, but the parameters (including all accessories) are ordered from the suppliers at the moment the deal is finalized and the specific auto is produced just-in-time, completely personalized and on-demand.

Analogously, there has been an enormous change in education and learning. At the beginning of the twentieth century you could get any type of education you wanted as long as the teacher stood in front of the class and lectured. In the 1960s, 1970s, and 1980s psychologists and fledgling educational designers began to explore how to customize and improve the traditional learning materials that were being used in the schools. David Ausubel (1960) began doing research on meaningful learning and the use of advance organizers to improve study and learning while Robert Gagne (1977) made the move from behavioral to cognitive psychology with his *The Conditions of Learning*, 3rd Edition (1977). Ernst Rothkopf (1966, 1982) and Larry Frase (1967) began their research on the effects of adjunct questions in learning texts and how/when the use of certain types of questions could affect learning in a positive way (Rothkopf called this effect *mathemagenic*, Latin for “that which gives birth to learning”). Robert Mager (1962, 1975) and Norman Gronlund (1978), in the footsteps of Benjamin Bloom (1956), produced experimental results and usable guidelines on the effects of specifying behavioral learning objectives on what/how students studied and learned. And James Hartley (1978, 1985; Hartley & Burnhill, 1977) was carrying out learning research on text layout, Rob Waller (1977, 1982) on typography, and Joan Peeck (1974, 1987) and Phillipe Duchastel (1978) were doing the same with respect to illustrations. This psychological research was augmented with educational and instructional design research on different educational models (e.g., mastery learning (Carroll, 1963), programmed learning (Skinner, 1954, 1958)) and instructional design approaches (e.g., ADDIE: Analysis, Design, Development, Implementation, Evaluation; ARCS: Attention, Relevance, Confidence, and Satisfaction (Keller, 1983, 1987) and Component Display Theory (Merrill, 1983)). The result of all of this are textbooks, learning materials and learning situations that are more varied and better suited to different types of learner groups with different needs.

As in the paint analogy used above, the field of education has also entered the computer age of mass individualization and demand driven learning. The market is being flooded by electronic learning environments and course management systems that claim to be able to match the learner and her/his characteristics (prior knowledge, goals, learning style, et cetera) with learning materials and approaches. Instructional designers and software/application engineers are allowing the use of dynamic representations (e.g., interactive visuals, dynamic visuals and animations, integrated audio and visual representations, et cetera) and the adaptive provision and utilization of learning material (e.g., just-in-time information presentation, dynamic prompting, help functions, et cetera). And researchers are going even further.
They are augmenting these systems with algorithms and agents that allow for dynamic task and material use and selection (the learner receives/can choose materials and learning tasks on-the-fly which are optimally suited to her/his performance on previous materials and tasks), simulations in multiple dimensions including augmented reality, and adaptable pedagogic agents to aid in the teaching/guidance trajectory. All of this research and development has, as ultimate goal that learning becomes more effective, efficient, interesting and enjoyable.

Now, we would not go so far as to say that educational psychology and instructional design have made education and learning an enjoyable experience for all, but we would posit the statement that strides are being made in the right direction. This special issue is dedicated to a number of efforts being made by researchers – primarily in Europe – to make learning more effective AND more enjoyable. The basis of this Special Issue lies in a conference organized by two Special Interest Groups (Instructional Design (SIG 6) and Learning and Instruction with Computers (SIG 7)) of the European Association for Research in Learning and Instruction (EARLI) held in July, 2004 at the Knowledge Media Research Center in Tuebingen, Germany (http://www.iwm-kmrc.de).

2. The contributions

This special issue comprises eight articles dealing with empirical research, followed by two analytic discussions. The authors of these contributions are from Germany, Switzerland, The Netherlands, the United Kingdom and the USA. A broad range of issues is covered, all of which are related to the overarching question of how to improve the design of computer-based learning environments in order to make them more effective and more enjoyable. Two thematic clusters can be distinguished within this collection of articles, namely the design of dynamic representations and the adaptive provision and utilization of learning material.

A first group of four articles focuses on the educational potential and on the suitable design of various types of dynamic representations that can be provided by computer-based instruction. These representations include animations, interactive tools for integrating multiple representations, dynamic three-dimensional information visualizations, and audio augmented realities. A second group of four articles is concerned with the adaptive provision and utilization of processing prompts, help functions, supportive information, or whole course materials (by means of authoring tools for designing learning environments). Both, using dynamic representations for learning as well as adaptively providing and utilizing learning materials can be assumed to improve learning outcomes and to make the learning experience easier, more effective, more interesting and more satisfying for students.

The two groups of articles differ in how they address the issue of making learning more effective and enjoyable. With dynamic representations such as animations or audio augmented realities it is often taken for granted that they will make the learning experience more enjoyable because they arouse learner interest and motivation.
and allow engagement in stimulating, interactive, and game-like experiences. It is less clear whether this augmentation will also help to increase the effectiveness of learning. Accordingly, the first four contributions focus primarily on whether dynamic representations can foster or facilitate learning.

The article by Scheiter, Gerjets, and Catrambone on visualizing mathematical solution procedures explores the effects of different kinds of computer-based visualizations on the acquisition of problem-solving skills in the domain of probability theory. Learners received either text-based worked examples, the same text with an instruction to mentally imagine the examples’ contents, or the choice of retrieving either static pictures or animations depicting the problem statement and the problem states achieved by applying a specific solution-step. Frequently using static pictures or mental imaging both improved problem-solving performance on isomorphic problems. However, there were no positive effects of animations. Rather, the frequent use of animations led to substantial increases in learning time, with a concomitant slight decrease in performance. Thus, while the use of concrete animations to visualize solution procedures might result in a more stimulating and enjoyable learning environment, the claim that they are also helpful for conveying problem-solving skills was not borne out.

Bodemer and Faust investigate the impact of integration and external activity on an instructional support method that encourages learners to systematically and interactively integrate multiple representations in the external environment. Two experiments compared different kinds of relating representations to each other: Interactive integration of representations, interactive referencing without integration, prompted mental referencing without interactivity, and spontaneous referencing without interactivity or instruction to relate different representations to each other. Their results show that interactively integrating external representations can foster learning outcomes while interactive referencing without integrating representations externally was only just as effective as prompted mental referencing. However, this effect seems to be moderated by the difficulty or familiarity of the visual representations involved with the interactive integration tool being helpful only when learning with familiar representations.

Keller, Gerjets, Scheiter, and Garsoffky study the potential of information visualizations as learning tools. Up to now, information visualizations (i.e., interactive graphic representations of large amounts of abstract data that do not have a natural visual representation) have mainly been used to support information retrieval. The experiment reported in this special issue investigates whether information visualizations are also suitable for fostering knowledge acquisition and learning. In addition, the authors address how information visualizations, from a cognitive perspective, have to be designed to be efficient learning tools. With regard to the latter issue, the role of two-dimensional versus three-dimensional information presentation and the role of color-coding is investigated. The results show that information visualizations are suitable for fostering knowledge acquisition, that two-dimensional information visualizations are better suited for knowledge acquisition than three-dimensional ones, and that color-coded information visualizations are superior to monochromatic ones.
The article on audio augmented realities by Joiner, Nethercott, Hull, and Reid differs from the other studies on dynamic representations in two respects. First, it compares two versions of a learning environment with a focus on how enjoyable, challenging and compelling these versions are for learners. As the technology used in this study is technologically very advanced and innovative, no measures of learning efficiency have been obtained. Second, the study is not concerned with dynamic visualizations but with dynamic auditory representations. The aim of the study was to explore the design of situated educational and compelling experiences using SoundScape technology – which is an ubiquitous and pervasive technology. SoundScapes are physical spaces where digital audio files are attached to coordinates in the physical space. The users hear the audio file via a wireless LAN when they enter the designer defined area. The SoundScape technology was used in this study to captivate and intrigue learners and thereby increase the intrinsic motivation for learning. Two versions of the audio-augmented reality were compared: one that provided learners with a game-like goal and one that did not. The results show that the SoundScape with a goal was more interesting and compelling for learners than the non-goal version.

The second group of four articles focuses on the adaptive provision and utilization of processing prompts, help functions, supportive information, or whole course materials. For these studies the issue of how to make learning more enjoyable has a different meaning than for the first group of papers. The focus here is not on making learning more fun by allowing learners to interact with a stimulating and rich learning environment. Rather, the issue is how to make learning less frustrating, less overwhelming, and thus easier for them by adapting the instructional environment (to individual abilities, preferences, et cetera) and/or providing them with support (guidance, help and support information).

Schwonke, Hauser, Nückles, and Renkl investigate how adaptive prompts can be used in self-guided learning. The cognitive and metacognitive prompts used in this study are adaptively selected based upon a diagnosis of the students’ strategic deficits and are intended to counteract these deficits. In the experiment the students revised a learning protocol and were supported either by adaptive prompts, randomly selected prompts, or no prompts. Adaptive prompts were not only experienced as more supportive than random ones, but they also improved the quality of the learning protocols and fostered the acquisition of declarative knowledge and comprehension.

The article by Kester, Lehnen, Van Gerven, and Kirschner investigates whether the best time to present different types of auxiliary information for mastering a complex procedure (e.g., supportive conceptual information, schematic overview) is before or during practice. Providing auxiliary information during practice can, on the one hand, help minimize cognitive load by avoiding temporal split attention. On the other hand, processing auxiliary information during practice can be rather demanding for learners if they have to simultaneously engage in solving practice problems and processing supportive information. The experiment reported in this special issue uses a $2 \times 2$ factorial design with the factors supportive information (before or during practice) and schematic representation (before or during practice) to investigate whether auxiliary information on concepts and theory as well as a
schematic overview of a topic are best presented before or during practice in order to ensure efficient learning. Efficiency was obtained in terms of learning outcomes relative to the amount of task demand, effort investment and frustration experienced by the student. The results show that providing auxiliary information according to a “supportive during, schema before” format or according to a “supportive before, schema during” format was more efficient that providing both kinds of auxiliary information either before or during practice. Thus it seems that certain ways of presenting auxiliary information to students make learning at the same time more effective and more enjoyable.

Bartholomé, Stahl, Pieschl, and Bromme are interested in the effectiveness of learners’ use of help facilities in computer-based interactive learning environments. They study how learners’ utilization of a context-sensitive help function and of a glossary function depends on different learner-related factors, including prior knowledge, motivational orientation, interest, self-estimated competence, and epistemological beliefs. Additionally, they investigated whether help-seeking behavior was helpful in fostering effective learning. The results yield a positive effect of help-seeking on learning outcomes. In addition, learners with a low level of prior knowledge used the context-sensitive help function more often and therefore performed better than learners with a high level of prior knowledge. Whereas motivational orientation and interest had no impact on help-seeking there was a curvilinear relation between self-estimated competence with overconfident or underconfident learners showing less help-seeking behavior than intermediate learners. Finally, results confirmed that epistemological beliefs play a prominent role in help-seeking. The belief that knowledge is unstructured and constructed led to a higher amount of help-seeking and improved learning outcomes. As providing help functions per se is not effective to improve learning without learners utilizing them this research stresses the important role of learner-related factors.

The final study by Ainsworth and Fleming is on the adaptive provision of whole course materials. Beyond addressing the issue of whether an individualized composition and presentation of course materials will increase learning outcomes, this article also investigates whether an authoring tool (REDEEM) which was used to individuate instruction is also sufficiently usable from the perspective of the intended author population (e.g., classroom teachers). The REDEEM authoring tool was developed to allow teachers – without programming knowledge – to design computer-based learning environments (i.e., simple Intelligent Tutoring Systems) in a time-effective manner. The article reviews a 5-year program aimed at assessing the strengths and, just as importantly, the weaknesses of this approach to developing computer-based learning environments. The authors conclude that REDEEM is both effective for learners and easy for teachers to support and to integrate into their classroom practice.

3. Conclusion

As stated, this Special Issue presents the cutting edge of empirical research – primarily in Europe – on how to improve the design of computer-based learning envi-
ronments in order to make them more effective and more enjoyable. The foci were the design of new types of dynamic instructional materials making use of various types of representations and the on-demand adaptive provision and utilization of learning materials for students.

We, as editors, hope that this Special Issue will serve a double function to its readers. First, we hope that it will contribute to their understanding and practice with respect to effectivity AND enjoyment. Second, we hope that the articles themselves are experienced by the readers as effective AND enjoyable.

References


