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Learning performance with interactive simulations in medical education: Lessons learned from results of learning complex physiological models with the HAEMOdynamics SIMulator

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ABSTRACT

Objective: Since simulations are often accepted uncritically, with excessive emphasis being placed on technological sophistication at the expense of underlying psychological and educational theories, we evaluated the learning performance of simulation software, in order to gain insight into the proper use of simulations for application in medical education.
Design: The authors designed and evaluated a software packet, following of user-centered development, which they call Haemodynamics Simulator (HAEMOSIM), for the simulation of complex physiological models, e.g., the modeling of arterial blood flow dependent on the pressure gradient, radius and bifurcations; shear–stress and blood flow profiles depending on viscosity and radius.
Measurements: In a quasi-experimental real-life setup, the authors compared the learning performance of 96 medical students for three conditions: (1) conventional text-based lesson; (2) HAEMOSIM alone and (3) HAEMOSIM with a combination of additional material and support, found necessary during user-centered development. The individual student's learning time was unvarying in all three conditions.
Results: While the first two settings produced equivalent results, the combination of additional support and HAEMOSIM yielded a significantly higher learning performance. These results are discussed regarding Mayer's multimedia learning theory, Sweller's cognitive load theory, and claims of prior research on utilizing interactive simulations for learning.
Conclusion: The results showed that simulations can be beneficial for learning complex concepts, however, interacting with sophisticated simulations strain the limitation of cognitive processes; therefore successful application of simulations require careful *additional guidance* from medical professionals and a certain amount of *previous knowledge* on the part of the learners. The inclusion of pedagogical and psychological expertise into the design and development of educational software is essential.

1. Introduction and motivation for research

Dynamic, interactive computer simulations, designed to teach complex processes and concepts, have become very popular in all domains of science education, for example physics, chemistry and biology, as demonstrated in the high number of sales. The nature of such simulation ranges from compelling visualizations (Chittaro, 2001; Johnson, MacLeod, Parker, & Weinstein, 2004) to educational computer games (Ebner & Holzinger, 2007; Kickmeier-Rust et al., 2007). Simulations as learning tools are often engaging and, when it is assured that such tools are validated for accuracy and for learning outcome, can be valuable for medical education (Bergin & Fors, 2003; Dev et al., 2002; Hmelo & Day, 1999; Holzinger, Emberger, Wassertheurer, & Neal, 2008). Basically, a major advantage of learning with interactive simulations can be seen in the highly constructivist nature of such *exploratory learning processes.* However, we can observe in practice that, because they are technologically and graphically appealing, there is a tendency to apply interactive simulations uncritically and enthusiastically. Despite the huge enthusiasm for educational simulations generally, many questions still remain as to their effective design. Since developers are now able to include a wide range of visual and auditory elements, the complexity of design decisions is steadily increasing. This immediately raises the importance of gaining insight into the behavior of the end-users, consequently raising the appropriateness of a user-centered development (Edwards & Holland, 1992; Holzinger, 2003; Norman & Draper, 1986). Exploratory, self-directed, and goal-oriented learning with interactive and dynamic media, such as simulations, is highly demanding from the

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perspective of *limited cognitive processing capabilities* and the research on interactive simulations (Holzinger, Kickmeier-Rust, & Albert, 2008; Mayer, Hegarty, Mayer, & Campbell, 2005) has revealed that learners *need further support and guidance* when using such simulations. Finally, a further issue served as main stimulator for this work: the amount of research on simulations and its performance, which has taken place in a laboratory rather than in a real setting. For this work we used HAEMOSIM, which has been developed as an interactive computer simulation in the area of blood flow (see Section 3). Furthermore, we compared learning performance using a static text-based lesson with that of using HAEMOSIM. Additionally, we realized a third learning condition, which aimed at incorporating the suggestions of research regarding interactive simulations, as described in Section 2, by combining HAEMOSIM with additional guidance. This additional guidance was experimentally found during our end-user studies where we gained insight into the problems, requirements and demands of our end-user group. During the design we followed the principles of instructional design theories and multimedia learning. For example, Merrill (2002) identified a set of *first principles of instruction*. These principles are primarily based on the idea of problem-based learning (PBL), which is considered to be a very effective approach to learning. Merrill's principles include (a) relying on real-world problems, (b) activating prior knowledge, (c) demonstrating new information, (d) applying new knowledge, and (e) integrating the new knowledge into the *learner's world* (Merrill, 1999, 2001, 2002). A large part of existing models and theories of instructional design and strategies include the first principles of instruction, for example, *Constructivist Learning Environments* (Jonassen, 1999).

2. Theoretical background

2.1. Static and dynamic media in education

Research on the impact of new media on learning performance has a long tradition. Consequently, the body of empirical results is rich. Generally, previous research revealed that the mode of presenting learning content significantly affects learning processes and, therefore, learning performance. An important focus of research was often on the comparison of static media (e.g., text or illustrations) and dynamic media (e.g., animations or videos). Repeatedly, it was assumed that dynamic media might be the most successful method for presenting learning content about complex dynamic systems (e.g., blood flow or combustion engines) and that such dynamic media might significantly facilitate learning; past research, however, yielded inconsistent and sometimes contradictory effects (Mayer et al., 2005; Tversky, Morrison, & Betrancourt, 2002).

The most prominent theoretical frameworks for explaining the effects of different learning modalities are the *theory of multimedia learning* (Mayer, 2001, 2005) and the *cognitive load theory* (Paas, Renkl, & Sweller, 2004; Sweller, 1988; Tuovinen & Sweller, 1999; Valcke, 2002). Mayer's theory is based on *three* assumptions. First, it is assumed that visual and auditory information is processed via *different channels.* This assumption goes back to ideas of the *dual coding theory* (Paivio & Csapo, 1973; Paivio & Desrochers, 1980; Thompson & Paivio, 1994) which states that human memory consists of *two separate but interrelated channels* for processing information. These channels are verbal and visual systems and they can be activated independently but there are interconnections between the two systems allowing dual, and therefore more efficient, coding of information (Rieber, 1994). The *second* assumption of Mayer's theory is that the *processing capacity of each channel is limited.* Only a small portion of information can be processed at one time. Finally, the *third* assumption interprets learning as an *active process,* for example by constructing mental representations of learning material and *integrating it into existing knowledge structures.*

Cognitive load theory (Sweller, 1988) basically states that a learner's attention and working memory is limited. This limited amount of attention can be directed towards intrinsic, germane, or extraneous processing. *Intrinsic* processing describes a learner's focus on the learning content and its key features; it is determined by the intellectual demands of learning content. *Germane* processing describes a deeper processing of the content by its organization to cognitive representations and its integration into existing representations. Finally, *extraneous* processing describes cognitive demands during learning, which do not foster the actual objectives of the learning material, for example cross-references or navigation elements.

On the basis of this theoretical framework, Mayer (2001) defined the static and dynamic media hypotheses. In brief, the *static media hypothesis* assumes that static media, such as text or images, facilitate learning processes by shifting attention and processing capacities from extraneous processing to germane processing. This is achieved by providing only *relevant* information (for example only important steps of a dynamic process) and by encouraging learners to construct mental representations of the learning material. Moreover, static media allow learners to control the pace and order of attended learning content. The *dynamic media* hypothesis, on the other hand, assumes that dynamic media, such as animations, might facilitate learning by reducing extraneous load and encouraging germane processing by reducing the efforts of constructing mental representations and by attracting interest and by increasing motivation.

The current empirical data favor neither the static nor dynamic media hypotheses. Mayer et al. (2005) reported that in a series of experiments static media resulted in significantly higher, or at least equal, learning performance than animations. On the other hand, these researchers conclude that dynamic media might be superior to static media when learners with low spatial ability are engaged or with increasing complexity of learning content. Furthermore, Narayanan and Hegarty (2002), argued that dynamic media might be superior when learning content concerns processes, which are not observable in the real-world (for example computer algorithms).

Existing research on static and dynamic media indicates that it is necessary for learners to be enabled to control the pace and order of animations; to provide them with guidance during the most important steps and to facilitate active processing, for example by answering questions during learning (Mayer et al., 2005).

2.2. Dynamic, interactive simulations in education

A number of studies indicated that interactive, dynamic computer simulations have been successfully applied in promoting exploratory learning of new concepts as well as in changing existing mental representations (*conceptual change*; see for example: (Hewson, 1984)) in various scientific areas (Alparslan, Tekkaya, & Geban, 2003; Langley, Ronen, & Eylon, 1997; Windschitl, 1998; Zacharia & Anderson, 2003).

According to (Jimoyiannis & Komis, 2001), interactive simulations might bridge prior knowledge of learners and the learning of new concepts through an active reformulation of misconceptions.