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

Andreas Holzinger *, Michael D. Kickmeier-Rust, Sigi Wassertheurer, Michael Hessinger

Head of Research Unit HCI4MED, Institute of Medical Informatics, Statistics and Documentation (IMI), Medical University Graz (MUG), Auenbruggerplatz 2/V, A-8036 Graz, Austria

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.

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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 stimulus 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.
According to (Kneebone, 2005) four key areas underpin simulation-based learning: (a) gaining technical proficiency, (b) receiving expert assistance, (c) learning within a professional context, and (d) support of affective components of learning.

Interactive simulations might also incorporate the claims of research on static and dynamic media (as described above) and facilitate learning in comparison to static or dynamic, non-interactive learning material. Basically, interactive simulations allow learners to change the input variables of complex systems, to manipulate parameters of that processes, and to directly receive feedback on the changes. Additionally, the pace of changes and the order, amount, and degree of changes can be controlled by the learner. Finally, active processing might be facilitated because using interactive simulations requires constructing hypotheses and plans on the sequence and amount of parameter changes. Consequently, interactive simulations might not only be advantageous from the perspectives of multimedia learning theory but also from the perspective of instructional theories. Simulations are strongly based on the principles of exploratory (discovery) learning (Rieber, Tzeng, & Tribble, 2004), this means learners have to be actively engaged in the learning process, they have to plan the interaction with the simulation, evaluate the results, reformulate hypotheses, and compare and integrate the results in prior knowledge (Mitchell, Chen, & Macredie, 2005; Tao & Gunstone, 1999).

However, this kind of learning is demanding and research has shown several difficulties associated with learning supported by interactive simulations. For example, (Reigeluth, 1999) emphasized difficulties of learners in adequately formulating hypotheses and evaluating the results and (de Jong & van Joolingen, 1998) reported that learners often interact with simulations rather randomly instead in a planned way of testing hypotheses. Additionally, simulations are also highly demanding with regard to perceptive and cognitive encoding processes. The amount of continuously changing information and the control of the simulation might significantly increase extraneous load (de Jong et al., 1998).

Thus, research results suggested providing guidance to facilitate exploratory learning with interactive simulations. Such guidance might refer to helping a learner focusing on important parameters, creating hypotheses on relationships on various parameters, or evaluating hypotheses on the basis of simulation results (Bodemer & Faust, 2006; Bodemer, Ploetzner, Bruchmüller, & Hacker, 2005).

Bodemer, Ploetzner, Feuerlein, and Spada, (2004) argued that learning performance can be improved when static information is actively elaborated before interacting with simulations. According to these researchers, successful exploratory learning requires specific prior knowledge to use simulations in a systematic and goal-oriented way. Empirical results, however, suggest that such guidance is sparsely used by learners and consequently the effect of facilitating learning is not very robust (de Jong & van Joolingen, 1998).

Based on the results of research on using interactive simulations for exploratory learning, the combination of video instruction and subsequent use of simulations might address existing problems. Video instruction might present the most important concepts and parameters and, therefore, might facilitate the creation of meaningful hypotheses as basis for interacting with simulations. From the perspective of dual coding theory, video instruction, furthermore, might allow an associative elaboration of learning material in both verbal and visual channels.

Moreover, it may incorporate the beneficial aspects of graphics identified by Rieber (1994) that of transmitting learning content by arousing curiosity and attracting the learner’s attention.

### 2.3. Learning styles – learning strategies

Over the past decades, a significant amount of research has been conducted on the effects of different transmission media on learning performance. Soberly considered, the result of the research is relatively disappointing, since no clear and consistent effects were found (Cook, 2005; Hu, Hui, Clark, & Tam, 2007; Shaw & Marlow, 1999). Salient studies often attempted to explain learning performance in a differential manner, including factors such as learning styles (Ferguson, James, & Madeley, 2002; McManus, Richards, Winder, & Sproston, 1998; Moreno & Mayer, 2000; Papanikolaou, Grigoriadou, Magoulas, & Kornilakis, 2002). Following this argumentation, it seems promising to involve different learning styles and strategies when investigating the effectiveness of different learning media. Unfortunately, the “market” of theories and taxonomies is rich (Barrows, 1986; Ferguson et al., 2002; Maier & Grossler, 2000; Sun & Cheng, 2007; Yang, 2002). An early approach to learning styles was Aptitude-Treatment-Interaction (Biggs, 1976; Cronbach & Snow, 1977; Yeh, 2007). This theory outlines the relationship or interaction between learner characteristics (e.g., anxiety) and effectiveness of learning methods (e.g., highly structured transmission). Another taxonomy came from Kolb (1984), who distinguished convergent learners, divergent learners, assimilators, and accommodators. The theory of learning styles that we adopt in this work is based on a more recent approach to re-clustering different “learner types”, the HALB approach (“Handelnd-Akkustisch-Lesend-Bildlich” [acting, hearing, reading, seeing]) by Stangl (2002). This well-validated approach distinguishes four dimensions (i.e., acting, hearing, reading, and seeing) and classifies a learner along those dimensions. Research on different learning styles also has a long tradition in psychology and pedagogy. Theories essentially refer to meta-cognitive abilities and preferences of the learner and they characterize different methods, behaviors, and strategies to achieve very good or very quick learning results. An early approach came from Goldman (1972) who distinguished logically oriented and mnemonically oriented learning strategies. A good overview can be found in (Entwistle & McCune, 2004). In the present work, we refer to the Learning and Study Strategy Inventory (LASSI) by Cano (2006), Weinstein, Palmer, and Schulte, (1987). This approach classifies the learner along ten motivational, emotional, and behavioral dimensions (see Section 4.3 for details).

### 3. Technical background: the haemodynamics simulator (HAEMOSIM)

Generally, learning in the area of physiology is difficult for medical students for several reasons, which should be taken into consideration. The prerequisite for acceptance to a medical university in Austria does not include mathematics of a depth necessary to understand physiological models and the dynamics of complex mathematical rules related to these models. Moreover, learning is often without recourse to patients due to ethical restrictions (Simon, 1972). Simulations are assumed to offer various benefits, especially to novice medical students learning theoretical concepts, processes, relationships, as well as invasive procedural skills, which is extremely important within decreasing clinical exposure. Consequently, students can acquire knowledge in a safe environment (Knee bone, 2005) and apply the new knowledge in practice (Weller, 2004).
However, due to the fact that simulations are often accepted uncritically and with undue emphasis being placed on technological sophistication at the expense of underlying psycho-pedagogical theories, sometimes the benefits of simulations might not be fully utilized. The software application HAEModynamics SIMulator (HAEMOSIM) covers a variety of concepts of blood flow, which are strongly related to flow mechanics, and was designed and developed for online use. It consists of several light-weighted JAVA2-Applets, each designed to interactively present certain haemodynamic learning content (Hessinger, Holzinger, Leitner, & Wassertheurer, 2006). This enables the student to directly apply his learning to gain insight into the complex behavior of blood circulation dynamics, and most of all to simulate certain defects and the dangers of diseases, for example the steal syndrome. The application simulates solid mathematical models (Leitner, Wassertheurer, Hessinger, & Holzinger, 2006; McDonald, 1955; Pedley, 1980; Womersley, 1955) and presents these models in form of dynamic 2D and 3D visualizations. Special focus during the development was directed on user-centered design (Holzinger, 2004, 2005; Holzinger & Ebner, 2003) for example to understand the context and to adapt the various applets to the previous knowledge of the end-users.

The learning material is organized in three levels: (a) basic laws for steady flow in tubes, (b) unsteady (pulsatile) flow in straight elastic tubes under homeostatic conditions, and (c) transient blood flow in arteries. Within each level, new concepts and their limits are introduced to the learners, for example, we begin with the simple concept of a laminar flow within a straight tube. After successful mastery of each level the learners can go to the next level. For example, after introducing the law of Hagen-Poiseuille, it is essential to show medical students a practical application. To consider one tube or vessel is interesting, however for daily practice it is insufficient. Consequently, the bifurcated tubes theory application becomes more attractive and comprehensive, due to the fact that it is now possible to reproduce effects on bypassed vessels or the effects of shunts. Fig. 1 shows Applet 2 simulating a steal phenomenon, which is observed in vessel surgery when a so-called shunt is dimensioned inappropriately and, as a consequence, vascularization is impaired.

4. Methods and materials
4.1. Experimental design

In the present study, we compared learning performance with three types of learning conditions: a traditional textbook lesson including static images (we called this the T-group) and HAEMOSIM, an interactive computer simulation covering the same learning content (H-group). Additionally, we realized a third learning condition by combining additional material to the H-group setting, in form of a short video clip conveying a short description on how to use the simulation effectively (and called this group V-group). Our consideration was that video instruction might also enrich the interactive simulation by facilitating the creation of meaningful hypotheses, allow an associative dual coding of learning material, and incorporate the beneficial aspects of graphics (Rieber, 1994). Consequently, our null hypothesis would be that the different learning conditions do not differ in learning performance. This comparison was realized as a typical pretest and posttest 3 × 2 design (type of learning object × pretest and posttest). As dependent variables, we measured learning performance using a multiple choice test. Additionally, we assessed learning styles and learning strategies. The time for the three experiments remained always the same.
4.2. Participants

For this study \( N = 92 \) participants were recruited, all undergraduate students from the Medical University of Graz. In total, 43 of the participants were male and 49 were female. The average age was 22.33 years (SD = 3.28), the youngest participant was 20 and the oldest 35 years of age.

4.3. Material

The text-based learning object (T) consisted of a two A4 page introductory text explaining the haemodialysis shunt and the steal syndrome. Very briefly, this is a haemodynamic phenomenon, which can be defined as a reversal of blood flow in the vertebral artery ipsilateral to a proximal occlusion or stenosis of the subclavian or innominate artery. In more simple terms, a shunt is a blood vessel prosthesis and the steal syndrome describes the effect that blood might be virtually sucked out of bifurcated vessels when the shunt is dimensioned inappropriately. The text was created by a head surgeon of the Medical University of Graz and checked by several other surgeons. In the style of a typical textbook lesson, the content was suited to the prior knowledge and abilities of the students. Moreover, the text was supplemented with one static image (Fig. 2) displaying a sketch of blood vessels and shunt.

To realize the same learning objective with HAEMOSIM we used Applet 2, which covers the law of Hagen-Poiseuille (Fig. 1). We provided only a short introductory text stating the problem (i.e., in which conditions does the steal syndrome occur?) and introducing the simulation without any further assistance. In order to combine video instruction and HAEMOSIM, a short video clip was created, further elucidating the problem and providing a clear description of the parameters used within the simulation software. The video clip has a duration of slightly over 30 s. The content of this video clip roughly corresponds to Fig. 2, the static image of the textbook and explained the proper use of the simulation. This video clip was presented to the participants prior to using HAEMOSIM, however the overall time remained constant. With respect to problem-based and exploratory learning premises, in contrast to the text condition, both HAEMOSIM conditions offered free experimenting to realize a specific system status (i.e., the steal syndrome).

We referred to a pre test/post test scenario to assess knowledge and learning performance. Since the subject matter and, therefore, the learning material was very concise and controlled, we utilized a short multiple choice knowledge test including five questions about the haemodialysis shunt and the steal syndrome. Each of these questions represented an important aspect of the material and demanded a thorough understanding in order to ensure choosing the correct answer or answers, e.g., the influence of the collateral shunt area on the periphery blood circulation. All questions and answers were in German. Medical Students at the Medical University of Graz – and possibly at other universities too – are used to such tests. Each question included four answer alternatives, whereby checking none, one, or more alternatives could be correct. In one question no alternative was correct, in another question one alternative was correct, in two questions two alternatives were correct, and in one question three alternatives were correct. Thus, the guessing probability for this questionnaire was 6.25 percent. The minimum score was 0 and the maximum score was 20 (one point for every correctly answered alternative). For the pre test and post tests we used the same questions, presented in different order. Possible transfer and learning effects from pre to post test would be equal for experimental and control groups. The primary aim of this short test is to assess the participants' knowledge in the concise and well-defined learning material utilized in this experiment.

Additionally, we used the so-called HALB test (Stangl, 2002) (HALB stands for “Handeln, Akkustisch, Lesend, Bildlich” [doing, hearing, reading, seeing]), a short and economic questionnaire in German language, in order to assess learning styles. This test provides indications (in a form of percentages) to what extent a student is a reading (RD), visual (VIS), active (ACT), and auditory (AUD) learner. To assess learning strategies, we used the Learning and Study Strategies Inventory (LASSI) developed by (Weinstein et al., 1987), which includes ten scales related to learning strategies: attitude and interest (ATT), motivation (MOT), usage of time management principles (TMT), anxiety (ANX), concentration (CON), information processing (INP), selecting of main ideas (SMI), usage of learning support techniques (STA), self testing (SFT), and test strategies (TST).

4.4. Procedure

First, the participating students were asked to provide us with biographical data, to complete the learning styles and strategies questionnaires and to complete the pretests to assess prior knowledge in this particular field. Subsequently, they were randomly assigned to one of the three groups (i.e., text-based learning T; simulation-based learning H; a video instruction with simulation-based-learning V). The participants in the group assigned to condition T (group T) were only provided with a print-out of the two-page lesson, while the participants assigned to condition H (group H) were seated in front of mobile computers and given access to the HAEMOSIM software, including a
short list of basic functions on-screen. Finally, the group assigned to condition V, were shown the initial video clip on a computer screen, and subsequently were given access to the HAEMOSIM software including the basic function introduction. All three groups were given exactly the same amount of time to learn, i.e., 6 min, and were instructed to learn as much as possible within this fixed period of time. This time frame was recommended by surgeons of the teaching hospital as typical and realistic. Generally, these medical students are required to learn an extensive amount of content during their clinical practice and, therefore, the time applied for learning a specific, limited topic is clearly restricted. Thus, an important question is, whether interactive simulation can be sensibly utilized in such a limited time frame. After another short break, the students were asked to complete the posttests. The whole test procedure took about 45 min in all three experimental settings, which corresponds exactly to a standard clinical learning module.

5. Results

The results regarding learning performance are very interesting. As expected, in the pretests no differences were found between the three experimental conditions (Table 2). In group T, the mean score in the knowledge test was 11.26 (SD = 2.56), in group H the mean score was 11.29 (SD = 2.05), and in group V the mean score was 10.00 (SD = 2.53). These results are true for males as well as females. In group T, the females achieved a mean score of 10.42 (SD = 2.45), males a score of 12.17 (SD = 2.41). In group H, females achieved a score of 11.63 (SD = 2.03) and males a score of 10.93 (SD = 2.09). Finally in group V females achieved a mean score of 10.29 (SD = 2.75) and males a mean score of 9.50 (SD = 2.38).

As displayed in Fig. 3, we found distinct results regarding knowledge in the field of the steal syndrome in the posttests (Table 2). While the results of conditions T and H did not differ significantly, condition V resulted in a clearly higher mean score than both other conditions. Summarizing, in condition T the mean score was 14.28 (SD = 2.38), in condition H the score was 14.48 (SD = 3.04), and in condition V the score was 17.82 (SD = 1.72). These results were found to both males and females. In condition T females achieved a mean score of 14.15 (SD = 2.44), males a score of 14.42 (SD = 2.36). In condition H females achieved a score of 14.00 (SD = 3.58) and males a score of 15.00 (SD = 2.36). In condition V females achieved a mean score of 17.43 (SD = 1.90) and males a mean score of 18.50 (SD = 1.29). The descriptive results are summarized in Fig. 3. For statistical analyses we computed the learning performance (i.e., score in posttest – score in pretest). An univariate analysis of variance (ANOVA) yielded a significant effect of the learning condition (F(2, 86) = 13.47, \( p < .001 \)) while gender did not result in significant differences (F(1, 86) = .85, \( p = .361 \)). Interestingly, a significant interaction of condition and gender was found at the 5%-level (F(2, 86) = 3.47, \( p = .036 \)). As shown in Fig. 4, females performed better in condition T while males achieved slightly higher scores.

![Fig. 3. Mean test scores in knowledge tests depending on learning conditions and gender (the minimum score is 0, the maximum score 20).](image1)

![Fig. 4. Average learning performance (i.e., difference of scores in pre and posttests) depending on learning conditions and gender. Condition H resulted in significantly higher learning performance than both other conditions. Although the factor gender did not cause statistically relevant differences, we found a significant interaction between gender and learning condition.](image2)
in conditions H and V. A post-hoc Scheffé test for learning conditions indicated that condition V resulted in significantly higher scores ($p < .001$) than both other conditions. Conditions T and V did not result in different scores ($p = .966$).

Besides scores achieved in the pre and posttests regarding knowledge, we asked participants how satisfied they are with existing offers of multimedia learning objects for their courses. The average rating on a percent scale was 61.74 (SD = 20.50) where 100 means absolutely satisfied. We found a moderate negative correlation with the score in the posttests regarding knowledge in learning conditions H ($r = -.28$) and V ($r = -.32$) while for condition T no correlation was found ($r = .06$). Similar results were found for the question regarding the participants' wish for more multimedia objects supporting learning in their courses. The average rating on a percent scale was 57.24 (SD = 25.70). We found remarkable correlations between the ratings for this question and the posttest scores regarding knowledge in learning conditions H ($r = .63$) and V ($r = .59$) while for condition T only a slight correlation was found ($r = .23$).

Finally, participants were asked to complete questionnaires regarding learning strategies (LASSI) and learning styles (HALB). The results are summarized in Table 1. To analyze how far the different learning strategies and styles affect learning performance, we computed the correlations between LASSI and HALB scores and learning performance. As shown in Table 1, we generally found very moderate correlations. Interestingly, scores in LASSI’s concentration and attention scale (CON) was negatively correlated with learning performance in condition H ($r = -.44$) but positively correlated with learning performance in condition V ($r = .34$), while for condition T, no correlation was found ($r = .10$). Equally interesting is the correlation of LASSI’s information processing scale (INP) and learning performance in condition V ($r = .65$), while for conditions T and H no correlations were found ($r = .10$; $r = .18$). Additionally, the more technical conditions H and V yielded moderately negative correlations ($r = -.30$; $r = -.43$) with test strategies and preparation for tests (TST) while no correlation was found for condition T ($r = .04$). Similar to the LASSI learning strategies, we found distinct correlations within the HALB learning styles and learning performance. While only slight correlations were found between reading, visual, and auditory learning styles and performance, an active learning style was negatively correlated with learning performance in conditions T ($r = -.30$) and V ($r = -.36$) while a moderate positive correlation was found for condition H ($r = .31$).

6. Discussion

In the current work, we introduce HAEMOSIM, an interactive, dynamic computer simulation in the area of medical education, which covers concepts of blood flow. These concepts are of highly mathematical and technical nature, strongly depending on the laws of flow mechanics. Thus, undergraduate students, especially in the area of human medicine, have learning difficulties. With the current investigation we sought to investigate learning performance with HAEMOSIM (H) in comparison to a traditional text-based lesson including a static image (T). Moreover, on the basis of claims of previous research regarding the utilization of interactive simulations, for example, providing prior knowledge and guidance (Bodemer et al., 2004, 2005), we investigated the effects of combining video instruction with HAEMOSIM (V).

The results of the present study yielded some remarkable results. As expected, in the pretests no differences were found between the three learning conditions, although the rate of correct responses, and consequently the amount of prior knowledge in this very specific area, was higher than expected in all conditions. On average, participants achieved scores between 9 and 12 (Fig. 3), which is a rate of slightly above 50 percent. This percentage is clearly above the probability of guessing (i.e., six percent) in the applied knowledge tests. Also in the posttests no differences were found for conditions T and H, although the average learning performance was lower than one would expect. These results can be interpreted in favor of either learning condition. On the one hand, one can argue that the less costly (in terms of development costs) text-based lesson resulted in equal learning performance than the much more “expensive” HAEMOSIM simulation. On the other hand, exploratory learning can be viewed as generally more time-consuming than reading through an educational text because
learners have to generate hypotheses and test these by changing various parameters and evaluating the results. Thus, the learning performance achieved with HAEMOSIM within the small time frame provided in the current study indicates a promising potential for learning when more time is available for exploring the underlying concepts. Still, both conditions appeared to be little efficient. More remarkable are the results of condition V. The combination of initially providing an introductory video instruction and subsequently utilizing the HAEMOSIM simulation resulted in significantly higher learning performance than both other learning conditions, for males as well as females. This finding supports previous research which argued that simulations can be most successful used for learning when guidance is provided that helps focusing on important concepts and parameters and when a basis of relevant knowledge is available prior to using interactive simulations (Bodemer et al., 2004, 2005).

In terms of Mayer’s multimedia learning theory (Mayer, 2001, 2005), learning with interactive simulations, either in combination with video instruction or not, positively affect coding and elaboration of information in multiple channels, which is considered to be most effective for learning. Additionally, interactive simulations support processes of actively developing mental representations of complex concepts. On the other hand, interactive and dynamic media are cognitively more demanding than the static media. In terms of cognitive load theory, interacting with the options and functions of simulations indicates a high extraneous load. In the current study, however, we did not find evidence that this “limited capacity model” negatively affected learning performance because no differences were found between conditions T and H and, furthermore, condition V resulted in significantly higher learning performance than both other learning conditions.

A further interesting result is an interaction of learning performance with gender. As shown in Fig. 4, males generally performed better in the more technically learning conditions which included interactive simulations (i.e., H and V), while females performed better with the traditional text-based lesson. This finding confirms results of similar previous research (Cooper & Stone, 1996; Ong & Lai, 2006; Mayer-Smith, Pedretti, & Woodrow, 2000), yielding that females might have a smaller bias towards rather technical learning material and different visual input preferences.

In the present study not only correlations between learning performance and learning conditions were of interest but also the relationship to the estimation of the quality of existing learning material and the wish for more multimedia learning material. Generally, the participants rated the quality of existing learning material at their universities slightly above average (62 percent) and also the wish for more multimedia learning material was in an average area (57 percent). This is somewhat unexpected because we expected a smaller rating of quality and a higher interest in multimedia support of learning. These findings, however, are very heterogeneous which is indicated by the large standard deviations (i.e., 20.50 and 25.70). These results suggest that the lower the quality estimation of existing (mostly static) learning material and the higher interest in more multimedia learning material the better performed participants with the more technical and dynamic learning conditions H and V.

The present results also suggest that there are no, or only small, relationships between learning strategies and styles and learning performance (Table 1). The results indicate that in such short learning events learning strategies and styles do not substantially affect learning performance and, thus, the inconsistent results are difficult to interpret. Still, the average scores of both LASSI learning strategies inventory and the HALB learning styles questionnaire were, as expected, in medium areas. A distinct exception was the LASSI information processing scale (INP); here an average score clearly above average was found. Summarizing, the correlations suggest that learning strategies and learning styles did not influence learning with static text-based material because for this condition we found no correlations throughout the different scales. A reason for this finding might be that learning with static material is well-trained throughout the educational career and it is not very demanding in terms of cognitive load. For learning with HAEMOSIM and its combination with video instruction we found slightly different results. An interesting correlation was found, for example, between LASSI concentration scale (CON) and learning performance. In condition H we found a negative correlation \( r = -0.44 \) while for condition V a positive correlation was found \( r = 0.34 \). A possible explanation of this effect might be that concentrating on a particular concept might be fruitful for video instruction in order to focus on the main concepts and subsequently evaluate these with HAEMOSIM, the concentration on a particular concept, however, might be disadvantageous for exploring blood flow effects using only an interactive simulation. A further interesting correlation was found between learning performance and the LASSI information processing scale (INP) in the V condition. Here we found a positive correlation \( r = 0.65 \). This scale corresponds to the assumption that learning means an active construction of mental representations and its integration into prior knowledge (Mayer, 2001, 2005). Thus, a possible explanation might be that learners who perform well in constructing such mental representations with the video instruction and subsequently evaluate these concepts with HAEMOSIM are superior in learning with that combination. Finally, an interesting result is that learning with static material as well as learning with the combination of video instruction and HAEMOSIM was negatively correlated with an active learning style, while learning with HAEMOSIM only was positively correlated. This result might reflect the fact that an active learning style significantly facilitates active, exploratory learning, while it is disadvantageous for more passive learning. In consideration of these results, future work must address the relationships of learning with different types of material and different cognitive traits.

The results of the present study, however, have some limitations. Exploratory learning by interacting with a complex simulation like HAEMOSIM is a more time-consuming process than reading through a static text-based lesson including a static image. In the present study, however, the time frame of learning was rather short. The idea was to investigate learning in probably realistic setting within which students are able to spend only a limited amount of time on learning a certain delimited topic. Thus, future research might address effects of different learning times. Additionally, further comparison is needed regarding learning with video instruction only or further combinations (e.g., text and HAEMOSIM).

An important consideration for future experiments, which sparsely was integrated in research so far, is long term memory effects. A hypothesis is that even if learning performance with HAEMOSIM is not higher than as learning with static text, the amount of forgetting might be smaller over time because learning might be deeper.

7. Conclusion

This study corroborates that research on multimedia learning must not only investigate isolated learning modalities and their impact on learning performance but also integrate pedagogical ideas. Learning must take place in a meaningful, problem oriented setting and tech-
nology must adapt to this. Results of this study confirm claims of previous research on exploratory learning using interactive simulations, however, it is essential to provide additional help and guidance on the proper use of a simulation before beginning to learn with the simulation. Providing this support, using additional instructional material, conveying the necessary information to use the simulation effectively and providing a hint on the main goals, resulted in significantly higher learning performance than isolated (static and dynamic, interactive) learning conditions, although this experimental group were not given more time than the other groups. The results showed that, with few exceptions, these effects are independent of individual learning strategies and learning styles but not necessarily of gender. Consequently, gender aspects, both cognitive and affective (attitude to technology), must also be taken into consideration when designing educational simulations. Finally, this work shows a further successful example of combining Psychology, Pedagogy and Computer Science.

References


