Conditions for Learning from Animations

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Abstract: Animated diagrams representing dynamic systems hold great potential for improving the way people learn. However, so far the literature failed to find clear benefits of animated diagrams. Consequently it is worthwhile to investigate conditions under which enhancement of learning occurs. In the present study interactivity of the display and spatial ability of learners were examined. Three modes of presentation were compared: static diagrams, animation with interactivity, and animation with focus, also combined with interactivity. The interactive animation condition with focus acquired more knowledge than the other two conditions while the interactive animation condition scored worst. High-spatial ability subjects performed better on the knowledge acquisition measures than low-ability subjects. The interactive animation condition with focus is particularly beneficial for low-spatial ability subjects. These results indicate that combining the conditions of interactivity *and* focus does lead to improvement in learning from animations, particularly for low-spatial ability subjects.

Introduction

In recent years there has been a trend for using multimedia applications that contain animations in combination with verbal explanations as a central means of instruction (Mayer, 2001; Narayanan & Hegarty, 2002). Multimedia is widely recognized to hold great potential for improving the way that people learn (Mayer & Moreno, 2002). A lot of research has been done to find out what the best presentation is of the working of artifacts like an engine or a human lung in action. It can be expected that users better understand dynamic systems if there is a direct correspondence between the parts of the animation and components of the dynamic system they represent. For the concept of animation we follow the same definition as Mayer and Moreno (2002). An animation is a kind of pictorial presentation and it depicts apparent movement. Animation consists of objects that are artificially created through some drawing method. In contrast video refers to a motion picture depicting movements of real objects. One assumes that an animation makes the mental model to be constructed easier to be "runnable" in that it contains information that allows the comprehender to mentally simulate a system and to generate predictions about its operation (Narayanan & Hegarty, 2002). Next to that it is a common belief that learners find animations more motivating than text and picture instruction and thus would be inclined to process the material more deeply. So an animation should work better for users' understanding than a static form. However, the empirical literature still fails to find systematic benefits of using animation over 'good old static' graphics (Lowe, 1999; Morrison & Tversky, 2001; Hegarty, Narayanan & Freitas, 2002; Tversky, Morrison & Betrancourt, 2002; Awan & Stevens, 2005; Kim et al., 2007; Van Oostendorp & Beijersbergen, 2007).

One important explanation given for the disappointing result of using animations is that viewing animations triggers passive information processing, and may mislead people into believing that they have understood (Rozenblit & Keil, 2002; Smallman & St. John, 2005). It can keep learners from doing relevant cognitive processing (Schnotz & Rasch, 2005). In this respect a recent study by Awan and Stevens (2005) is relevant. They examined the relationship between understanding and confidence of students in their understanding of animated and static diagrams. In their study it became, again, clear that there was no significant difference in students' understanding when comparing the static diagram and the animation condition. However the (over)confidence level of understanding in the animation condition was high in comparison with the static diagram group. They suggest that the mode of presentation affects how content is perceived by the viewer, and assume that higher confidence indicates lower mental effort; i.e. leading to the perception that animated material is "easy" to process. In the study mentioned above (Van Oostendorp & Beijersbergen, 2007) we tried to find direct evidence that students perceive it easier to process animations instead of static diagrams in understanding a complex dynamic system, by direct assessment of mental effort by subjects. However we could not find significant differences in perceived mental effort between a static diagram condition and an animation condition (and also no difference in learning results). Next to the above question we also considered in that study the suggestion that information overload during the animation has a negative effect on a subject's information processing. Due to the speed and visual complexity of information presented in animation, viewers experience 'cognitive or perceptual overload' (Lowe, 1999) as they are unable to attend processing all incoming information. This results in either not attending to or 'missing out' key aspects of the display. One condition in the study mentioned had an extra "cognitively designed" feature to find out if it had a positive effect on learning. In this condition a spotlight (see figure 3) pointed at the main places where changes occur during the animation (Grant & Spivey, 2003). However, even the animation with focus did not enhance learning.

In the current study we will examine the role of interactivity (ChanLin, 1998; Hegarty, 2004; Schwan & Riempp, 2004) with similar materials and approximately the same method as van Oostendorp and Beijersbergen (2007). Being able to adapt presentation pace and sequence to one' cognitive needs may be an important condition for learning (Wouters, Tabbers & Paas, 2007). The question examined is, thus, what is the influence of providing the opportunity to adjust the presentation by the learner him/herself and to go back when needed. This form of interactivity, that is, playing, stop, rewinding and replaying the animation, allows re-inspection, focusing on specific parts and actions and in this way helps to overcome difficulties of perception and comprehension (Tversky, Morrison & Betrancourt, 2002). We restrict ourselves to this simple form of interactivity. In a more complex form it would be possible to change parameters, or data sets, e.g. varying the water inlet. The assumption is that adaptation of presentation pace and sequence to one's cognitive needs (Schwan & Riempp, 2004) might be necessary to enhance learning, even in the case of focusing attention by providing the spotlight on important locations.

Furthermore, we will include spatial ability because this ability seems to be relevant to the construction of an adequate internal dynamic mental model. Following Narayanan and Hegarty (2002) we assume that spatial visualization processes are required to construct a dynamic mental model and to make it mentally 'runnable', i.e. to generate predictions about its operation. Different opposing predictions regarding the effect of animation are possible. Spatial ability might be a prerequisite for learning from animation, so high-spatial ability students primarily benefit from animation (Mayer & Sims, 1994). In contrast, low-spatial ability subjects might learn more from animations, because animations show dynamic processes that these students have difficulty imagining for themselves (cf. Hegarty, Kriz & Cate, 2003).

Finally, on two points we wish to replicate the mentioned Awan and Stevens (2005) study somewhat stricter, with the aim to replicate the effect that mental effort in the animation condition is less, but knowledge acquisition at the same level as in the static diagram condition. One reason that the static diagram group performed relatively well in Van Oostendorp and Beijersbergen's (2007) study could be the way of presentation that was used; the phases (5 for the heart and 5 for the flush system) were separately depicted, next to each other. Maybe this already has triggered mental model construction. It might have induced mental animation (Reed, 2006), which as Hegarty, Kriz and Cate (2003) showed, could be (at least) equally effective in learning as passively viewing the external animation. A second reason for the difference in results of mental effort between both studies could be the different ways of conducting the experiment. For example, we didn't include a break session – as opposed to Awan and Stevens - between showing the representation and presenting the knowledge acquisition questions. For this reason we will now present the test at the end of the session, and not immediately after the corresponding multimedia presentation as in the first experiment.

Similar to Van Oostendorp and Beijersbergen (2007) we use three conditions: (1) static diagrams (control condition), (2) animation with interactivity, and (3) animation with focus, also combined with interactivity. For the three conditions of our representations we will use two principles for design: The 'spatial contiguity' principle, learners are better able to build mental connections between corresponding words and pictures when they are near to each other, and the 'temporal contiguity' principle, text and pictures at the same time presented are better understood than non simultaneously presented modalities (Mayer & Moreno, 2002). We will examine the research questions in two different systems (toilet flush, human heart). The reason for this is to make it possible to give a more generic answer to the research questions.

Method

Subjects

A total group of 45 subjects participated in this experiment. All subjects were higher education students. Of those 45 people, 38 subjects were men and the rest women. The subjects volunteered for the experiment and they received a reward of 6 euros. They were randomly assigned to the three conditions, 15 subjects per condition.

Materials

For this experiment representations of two different systems were designed in a way that no extensive prior domain knowledge about the system was needed. One system presented was the working of the human heart. The second system presented a toilet flush and its refilling process. Off these two systems three different conditions were made. For every condition a textual description of the main steps was shown on top of the screen. The used background was made of an inconspicuous gray color. The *static* condition presents a static version of the system, flush or heart, here with the two main steps of the processes (see Figure 1). In the previous research there were five images but we decided to use just two images, more in line with Awan and

Stevens (2005). The *animation* condition was an interactive animated version that provided the users the opportunity to study the systems with the assistance of an interactive control panel on the bottom side of the screen. With this control panel the users are able to play, stop, go forward and backward in the animation every time they wish. They can make a use of the buttons to navigate through the animation or by clicking on the slide bar and dragging it forward/backward (see Figure 2). The *animation with focus* condition was also an interactive animated version but designed in such a way that every step described was spotlighted (see Figure 3). The difference between the second and third condition was that the latter system was designed in such a way that every main step described on top of the screen was highlighted in the animation to focus the subjects' attention. In both animation conditions a bullet in front of the textual description showed what main step the animation was presenting. This bullet moved to the next step simultaneously with the main changes in the animation.

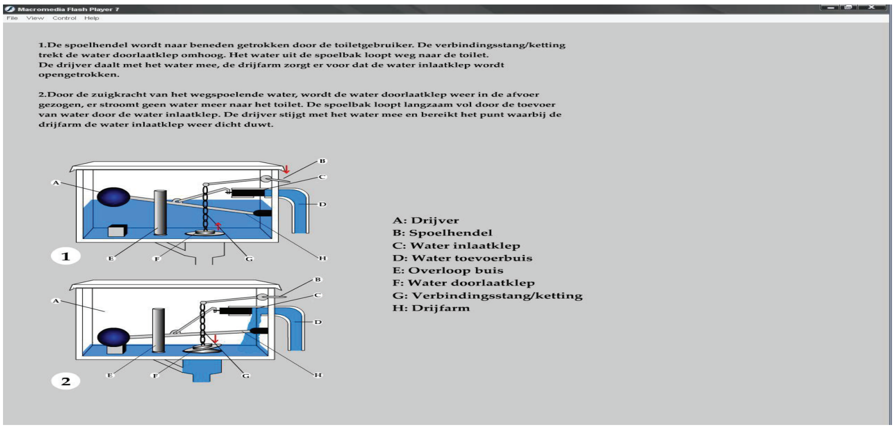

Figure 1. Static version of the toilet flush.

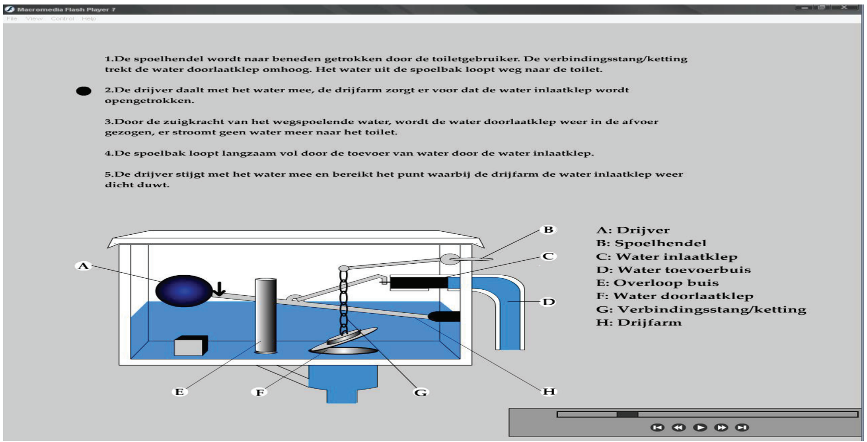

Figure 2. Frame of interactive animation of the toilet flush.

We also included a spatial ability test. After the learning phase the subject's spatial ability was measured through the "Flags" test (Thurstone & Thurstone, 1941). The Flags test requires participants to view a picture of a flag and judge which of six alternative test figures are planar rotations of the flag. The subject's task was to determine which of the test figures are rotations of the target figure as quickly and accurately as possible. They got 10 minutes to do this. For this test, the score was the number of items answered correctly with a maximum of 168 points minus the number of items answered incorrectly.

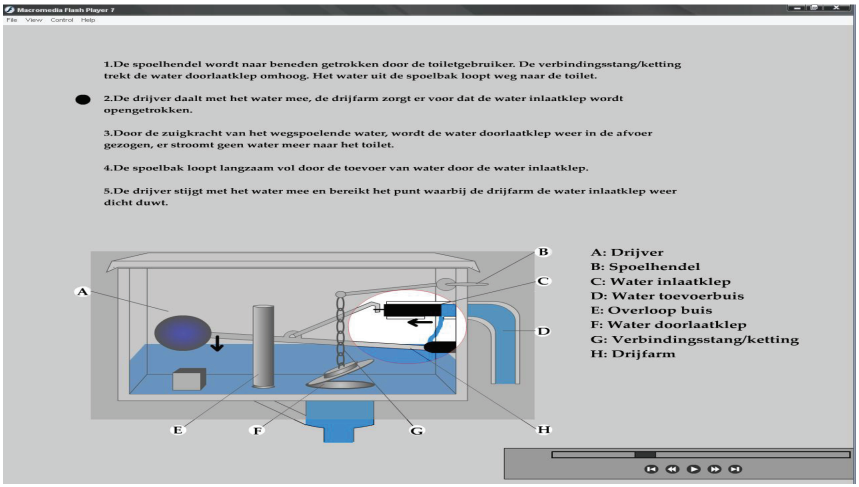

Figure 3. Frame of interactive animation with focus of the toilet flush

Knowledge acquisition measurements

To test users' knowledge acquisition of the different systems, three types of questions were constructed: retention questions, comprehension questions and transfer questions. Particularly the last two types of questions are important to get an accurate picture of the acquired mental model of students (Kintsch, 1998; Schnotz, 2001). The retention questions aimed to test subjects' ability to remember the labeled part names of the system. The subjects received one point for every part that was labeled right. For the heart representation the subjects could earn a maximum score of 9, for flush 8 (eight parts that had to be filled out). The comprehension questions consisted of five multiple-choice questions, which aimed at testing the representation at a deeper level, and involved paraphrases of explicit statements. The subjects could receive a maximum score 5 points if they answered all questions right. The transfer test for both systems consisted of four transfer- and troubleshooting questions, which involved inferring information from the conceptual model of the subjects and applying that to the problem situation (Awan & Stevens, 2005; Narayanan & Hegarty, 2002). Subjects received three points for every subquestion, resulting in a maximum total of 12.

Mental effort scales

After the subjects finished the knowledge questions, they were asked to assess the amount of mental effort they had needed for understanding the representation. These 'Mental effort' questions were based on a subjective technique where subjects were asked to scale (with 1 to 7 points) their effort after watching the representation The overall mental effort score was taken as the mean score over 8 items. The questions were selected from questions of Sweller et al., (1994), Brunken, Plass and Leutner (2003) and Paas (1993): *"It took me effort to understand the structure and consistency of the representation", " Sometimes I had the feeling that I had no idea what was happening in the representation", "The most important components and actions of the system were clear to me", "Due to the actions of, and the information around the system I knew exactly in what order I had to look at everything that was happening", "I did understand the representation very well", "I had difficulty with understanding the representation as a whole*", *"I had to take a lot of effort to concentrate on the representation to understand it",* and *"In studying the preceding problem I invested little effort".*

Apparatus

For the development of the different representations and for execution of the experiment, Macromedia Flash 8 was used. The presentations were shown on a 19" Dell Flat panel.

Procedure

Upon arrival subjects were first asked to fill in how much they knew about the working of the human heart and the toilet flushing system. The subjects always received the same condition of the two systems, but the representations could differ in order. The presentation had a fixed duration (5 minutes). After running the application of the first system (flush or human heart) for five minutes, they received the second system, also for five minutes. After presentation of the systems, the spatial ability test was presented (the Flags test), for maximally ten minutes. Next they were asked to start answering the knowledge acquisition questions. After the subjects had given answers to knowledge questions, and rated their mental effort, the whole process was repeated for the second system (flush or human heart). The subjects had fifteen minutes to complete all questions after studying the tutorial. They were instructed beforehand that they had a limited amount of time and had to answer some questions after studying the presentations.

Results

Knowledge Acquisition

In table 1 we have shown the means (and standard deviations) for the three conditions on both systems for the three types of knowledge acquisition measurements.

Table 1. Knowledge acquisition, mean scores of correct answers and sd's.

	Static condition (1)		*Animation condition (2)*		*Animation with focus (3)*	
Knowledge Acquisition	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Heart						
Retention of part names (0-9)	6.6	2.1	5.53	3.02	7.53	1.6
Comprehension questions (0-5)	3.6	0.91	3.33	1.54	4.1	0.8
Transfer of knowledge (0-12)	4.37	1.45	4.43	1.95	4.53	1.87
Flush						
Retention of part names (0-8)	6.73	1.22	6.27	2.43	7.73	0.46
Comprehension questions (0-5)	4.27	0.6	3.73	1.03	4.6	0.63
Transfer of knowledge (0-12)	6.1	1.91	5.3	2.4	6.23	2.45
Total average score (0-1)	0.67	0.10	0.60	0.18	0.74	0.07

To correct for the effects of prior knowledge, we did analyses of covariance with the prior knowledge of the subjects as covariate, and condition as factor. We found an effect of condition on the retention questions on both systems (Flush: $F(2,41) = 3.25$, $p < .05$ and Heart: $F(2,41) = 4.16$, $p < .02$). The post hoc analyses showed that in both systems the subjects of condition 2 scored the worse and the third condition had the highest scores. We also found a (weak) significant effect on the comprehension questions (Flush: $F(2,41) = 4.66$, $p < .02$ and Heart: $F(2,41) = 2.84$, $p < .07$). The post hoc analyses showed that the condition 2 scores the worse on e both the heart and flush comprehension questions and condition 3 scored the best. The analysis of covariance didn't result in significant differences for both systems on the transfer questions (Flush: $F(2,41) = .93$, $p = .40$ and Heart: $F(2,41) = .44$, $p = .65$). A similar analysis on the total average scores showed a significant effect of condition ($F(2,41) = 6.37$, $p < .00$). The total average score is based on the proportional score of each test, and taking the average of all 6 tests. Also here, based on a post hoc analysis, we noticed that animation condition 2 has the worst scores and the animation with focus condition (3) did much better than the rest.

Spatial ability

On basis of the median Flags test score (median = 120), low and high-spatial ability subjects were distinguished. It appeared that condition 1 had 6 low and 9 high-spatial ability subjects, condition 2 9 low and 6 high respectively, and condition 3 6 low and 9 high-spatial ability subjects. In Table 2 the means (and sd's) on the overall –total average – knowledge acquisition scores are presented.

Table 2. Total average knowledge acquisition scores for low and high spatial ability subjects, means and sd's.

	Static condition (1)		*Animation condition (2)*		*Animation with focus (3)*	
Total Knowledge Acquisition	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
High-Spatial Ability	.73	.06	.74	.11	.77	.04
Low-Spatial Ability	.58	.09	.51	.17	.69	.08

Analysis of covariance with spatial ability and condition as factors, and prior knowledge as covariate did show a significant effect of spatial ability ($F(1,37)=27.74$, $p<.001$) and a significant effect of condition ($F(2,37)=7.43$, $p<.01$). The interaction effect was not significant ($F(2,37)=1.77$, $p<.18$). Figure 4 shows the patterns. High-spatial ability subjects acquire a higher score on the total average knowledge measure than low-spatial ability subjects, and the interactive animation with focus condition (3), as we already saw above, scores best while the interactive animation condition (2) scores worst.

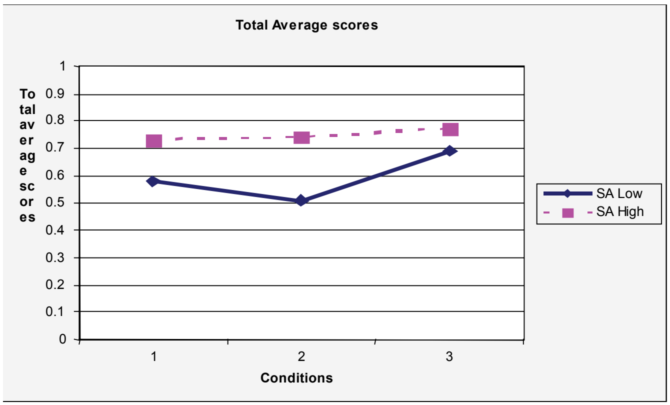

Figure 4. Mean total average knowledge acquisition scores for low and high-spatial ability (SA) subjects.

In Figure 5 and 6 we have depicted the results on the knowledge acquisition measurements where there was a significant interaction effect between condition and spatial ability. That was the case for the Flush retention test ($F(2,38)=15.98$, $p<.01$) and for the Heart comprehension test ($F(2,38)=5.16$, $p<.01$).

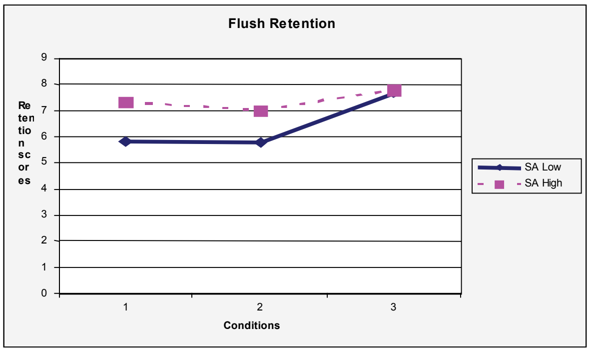

Figure 5. Flush retention scores for high and low-spatial ability subjects.

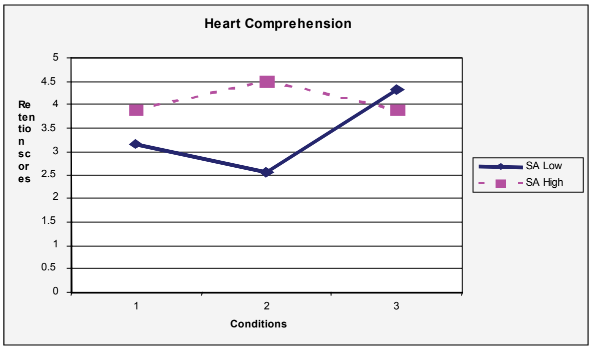

Figure 6. Heart comprehension scores for high and low-spatial ability subjects.

The common result in Figure 5 and 6 is that low-spatial ability subjects show a significantly better performance in the interactive animation condition (condition 3) compared to the focus condition (condition 2); for high-spatial ability subjects there is no significant difference between the animation conditions, and control condition.

Mental effort

Finally we also examined differences in mental effort of the subjects, with one-way ANOVA tests. We couldn't find any significant difference between the three conditions (See Table 3). All Fs were not significant ($p>.05$).

Table 3. Means and sd's of mental effort scores.

	Static condition (1)		*Animation condition (2)*		*Animation with Focus condition (3)*	
Mental effort	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Heart (1-7)	2.76	1	2.5	1.07	2.64	0.67
Flush (1-7)	2.13	0.56	2.18	1.23	2.37	0.88

General conclusions and discussion

The main results concerning the knowledge acquisition are that the interactive animation with focus condition (3) is significant better than the other two conditions, and interactive animation (condition 2) is worst (for the transfer questions no differences were found, probably due to the small amount of questions). Furthermore spatial ability plays a significant role (the correlation over all 45 subjects between the Flags score and total average knowledge acquisition score is .79 (!), $p<.001$). High-spatial ability subjects perform better than low-spatial ability subjects. Finally, subjects with low-spatial ability profit significantly from the interactive animation presentation when that is combined with focus. Regarding the mental effort scores, again no significant differences between conditions were found as in the previous experiment (Van Oostendorp & Beijersbergen, 2007).

As mentioned in the introduction (plain) animation still hasn't been proved being more beneficial than static diagrams for understanding and retaining knowledge of a dynamic system. From our previous results (Van Oostendorp & Beijersbergen, 2007) we concluded that plain animations are not preferable over 'good old static graphics' (for both systems), even not when focus is included. In both animated conditions used in our tests the overall knowledge acquisition results were not significantly better than in the static condition. It is worthwhile to note that we did not find an effect of animation on any level of representation (Kintsch, 1998), neither on a surface or textbase level, nor on a mental model level.

By asking the mental effort questions we tried to find more *direct* evidence for the possibility suggested by Awan and Stevens (2005) that mental effort could explain the difference in confidence between the test groups. However, also the more direct indication of this mental effort spent on processing the presented information did not show any significant difference between presentation modes. In the previous and current experiment we did not find any significant difference in perceived mental effort. The reason for this difference between our studies and their study is hard to explain. One could reason that the difficulty of the questions was not high enough and the easy questions could have resulted in no effect between conditions. But even if this is true, the scores on the open transfer of knowledge questions indicate a large range in scores, thus no ceiling effect, and also here we don't find an effect of condition. We also wanted to find out to what extent information overload forms the bottleneck for information processing. Since the processing of an animation requires heavy perceptual and cognitive processing (Lowe, 1999), we designed a presumably less mental effort taking condition (animation with focus condition) by focusing subjects' attention and so reducing the subjects' perceptual and cognitive load. We did not find any significant differences in knowledge acquisition between the three conditions in the previous experiment (Van Oostendorp & Beijersbergen, 2007). This result indicates that focus in itself is not a sufficient condition for learning from animations.

In the current study the first main research question concerned the role of interactivity. We can conclude on the basis of both experiments that interactivity and focus alone are not sufficient conditions to enhance learning from animation. Condition 2 and Condition 3 in previous experiment and condition 2 in the current experiment were not better (sometimes even worse) than Condition 1 (static diagrams) in terms of knowledge acquisition. However, combining the conditions of interactivity *and* focus did lead to improvement in learning from animations. Also, here we found similar results for both systems (heart and flush). Apparently, directing the focus of attention to important locations during the animation *and* being able to adjust the animation and going back when needed, are both necessary when interacting with the multimedia systems.

Our second main research question involved the role of spatial ability. We saw that high-spatial ability subjects got much higher knowledge acquisition scores than low-spatial ability subjects, confirming results of Hegarty, Kriz and Cate, 2003. That was the case in our study in the interactive animation condition but also in the static diagram condition. It seems that high-spatial ability subjects are able to mentally animate static diagrams as well as to profit from animation, both leading to better performance compared to low-spatial ability subjects. Furthermore particularly low-spatial ability subjects had a significant advantage of the focus feature when interacting in their own way with the system. This suggests that low-spatial ability subjects need more support on how to isolate and integrate different aspects of the motion of objects in the animation, even when they can adjust the presentation pace and sequence. Only when these conditions are met, animation can benefit low-spatial ability learners.

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Acknowledgement

This research has been supported by the GATE project, funded by the Netherlands Organization for Scientific Research (NWO) and the Netherlands ICT Research and Innovation Authority (ICT Regie).