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ORIGINAL RESEARCH

The moderating role of additional information when learning with animations compared to static pictures

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Abstract

In research on learning with animations compared to static pictures usually very short and narrowly defined topics are chosen. However, in school contexts such topics are often extended by additional information (i.e., information that is related to a given topic, but not essential for this topic). In the current study, that took place in a school context, it was investigated which role additional information would play when learning with animations compared to static pictures. It was hypothesized that there would be a beneficial effect of the animation, that additional information would impede learning the original topic and that the beneficial effect of the animation compared to the static picture would be even more pronounced when additional information is presented compared to when no additional information is given. A 2×2 between-subject design, with visualization format (animation vs. static picture) and additional information (present vs. absent) as independent variables, was used ($N=199$ high school students). Learning outcomes were analysed by means of a focal contrast analysis that corresponded to the stated hypotheses. Results revealed that the hypotheses were not met for factual knowledge tasks, but for transfer tasks: Additional information hindered learning, and the advantage of the animation over the static picture was more pronounced when additional information was presented. However, it should be noted that learners receiving additional information performed better on questions about the additional information than learners without additional information. Implications of these results are discussed.

Keywords Multimedia learning · Animation · Static picture · Additional information · Coherence principle

Introduction

When considering the research about multimedia learning in general, and animations compared to static pictures in particular, usually in these studies very short and narrowly defined topics are chosen (Berney and Bétrancourt 2016; Mayer 2009). However, from a more ecological valid and practical point of view, for instance when considering school

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contexts, such narrowly defined topics are seldom conveyed alone, but in connection with additional information that may also be part of curricular content. The impact of such additional information on different design principles concerning how to present multimedia instructional materials, and specifically with respect to learning with animations compared to static pictures is, however, unclear. It may be argued, that such additional information hinders learners to understand the core topic (e.g., Mayer and Jackson 2005). Hence, especially when additional information is conveyed, it may be even more important to use instructions that foster a deeper understanding of the core topic. For the current study, this was investigated by using for the core topic a well-designed instructional animation that, in comparison to a static picture, was supposed to support learning.

Learning with animations compared to static pictures

When comparing the effects of animations to static pictures with regard to learning, the pattern of results is rather mixed (e.g., Berney and Bétrancourt 2016; Höffler and Leutner 2007; Lowe and Schnotz 2014; Schnotz and Lowe 2008; Tversky et al. 2002). This may—at least partly—be attributed to the characteristics of the used animations and their associated processing demands (e.g., Hegarty 2004; Lowe and Schnotz 2014; Tversky et al. 2002).

On the one hand, animations can be overwhelming (cf. Lowe 2004; Schnotz and Lowe 2008) and may hamper learning. These overwhelming demands can be caused by the transience of an animation (e.g., Ayres and Paas 2007; Castro-Alonso et al. 2014; Lowe and Schnotz 2014) and/or its visual complexity (e.g., de Koning et al. 2011; Kühl et al. 2012; Lowe 2004). In the context of Cognitive Load Theory (CLT; e.g., Paas and Sweller 2014; Sweller et al. 2011), such unnecessary demands that are detrimental to learning, are termed extraneous cognitive load (ECL). Next to the concept of ECL, the CLT distinguishes the concepts of intrinsic cognitive load (ICL) and germane cognitive load (GCL). ICL refers to the load that is caused by the complexity of a given instructional material, while GCL refers to the investment in germane resources that contribute to a deeper understanding of the content. The abovementioned overwhelming demands do not necessarily hold true for every animation: The drawback of transience does not apply when a movement is frequently shown (Kühl et al. 2011, 2018a, b; Schnotz and Lowe 2008). Similarly, the drawback of visual complexity does not apply when solely one element in an animation is moving (cf. Kühl et al. 2018a, b; Lowe and Schnotz 2014). On the other hand, a potential advantage of animations is that they can directly depict dynamic features, such as changes in the velocity of an object (e.g., Kühl et al. 2011; Lowe 2004). These dynamic features can directly be read off from the animation, thereby giving the opportunity to deeper understand the depicted content. Since this information cannot directly be read off from a static picture, it may be demanding for learners to reason about and understand these dynamic features when receiving static pictures.

For the current study, we used a focused instructional animation where the drawbacks of transience and visual complexity did not apply, but where the advantage of depicting dynamic features was present. Thereby, the animation possessed a clear informational advantage (i.e. depicting dynamic features) over the static picture. Accordingly, it has been shown in two previous studies that this animation was beneficial for gaining a deeper understanding of the topic (Kühl et al. 2018a, b), particularly for transfer tasks as well as factual knowledge about the dynamic features, but not for knowledge that was not related to the dynamic features. These studies took place in laboratory settings and used a very short and narrowly defined topic. However, from a more applied point of view, like in school contexts, such narrowly defined topics are seldom conveyed alone, but in connection with additional information. Such additional information may, in turn, impact whether animations compared to a static picture might be less or even more suitable for learning.

The role of additional information

Additional information is information that is associated with the contents of the core topic at hand, but that is not directly relevant for understanding the core topic. Such additional information may, for instance, consist of formulas and their verbal descriptions (i.e., quantitative details) that are additionally given to a qualitative explanation of physical principles (cf. Mayer and Jackson 2005; Verkoeijen and Tabbers 2009). It should be noted though that additional information may not inevitably only consist of formulas and their verbal descriptions, but may also consist of other types of associated information, that in turn is not essential for understanding the core topic.

When teachers convey new topics, it may be appealing for them to convey at the same time additional information of associated contents. In doing so, it is supposed that this additional information—even though it is not essential—provides a context that supports the understanding of the original topic (cf. Kilpatrick et al. 2001). However, and opposed to this view, according to the coherence principle (cf. Mayer 2009), additional information that do not directly contribute to the core topic should be excluded and is considered as extraneous instructional material that may strain cognitive resources and increase ECL. Thereby, the additional information is supposed to increase the difficulty of an instructional material. In consequence, the additional information is supposed to impede learning the original content (Mayer and Jackson 2005; Verkoeijen and Tabbers 2009)—but might, of course, nevertheless support learning the additional information itself.

The interplay of additional information on learning with animations and static pictures

As outlined above, a well-designed animation, where the crucial information can directly be read-off, possesses an informational advantage over a static picture. Thereby, such an animation is better suited to gain a deeper understanding of the dynamic interrelations of a content than a static picture (Kühl et al. 2018a, b). When additional information is given—as is often inevitable in teaching new contents in the classroom, also because the additional information may be a further instructional goal—the demands of learning an instructional material are more challenging, and may be straining the cognitive resources more, than when no additional information is presented (cf. Mayer 2009). It can be argued that under such circumstances where the cognitive resources for deeper engaging are already strained, especially learners with static pictures may be overwhelmed to carry out the demanding processes of reasoning about and understanding the dynamic interrelations. With animations on the other hand, the strained cognitive resources may be less problematic, since the crucial information about the dynamic features can directly be read off from the animation. Therefore, the instructional advantage of the animation over the static picture might become even more evident when additional information is given. When on the other hand no additional information is presented, the benefits of the animation over the static picture might also be evident, but not as strongly pronounced compared to when additional information is presented.

The present study: hypotheses and research questions

The aim of the present study was to examine the potential benefits of an animation compared to a static picture in a more applied scenario, namely in the classroom. Thereby we investigated the influence of additional information—which may rather reflect common practice in a classroom lesson when conveying a new topic—in learning with an animation compared to a static picture. We used instructional material that is in the curriculum of (German) schools. The whole instructional material was considered as appropriate by the subject teachers. The core topic of the instructional material was short and narrowly defined. It dealt with Kepler's second law, which is about how the velocity of a planet changes when orbiting the sun on an ellipse. The core topic was visualized either by an animation or by a static picture. The instructional advantage of the animation over a static picture could be shown in previous studies for learning outcome measures that addressed an understanding of the dynamic interrelations, namely transfer tasks as well as factual knowledge that was related to the dynamic features, but not factual knowledge that was unrelated to dynamic features (Kühl et al. 2018a, b).

The additional information was associated with the core topic. The additional information addressed information about the solar system, how an ellipse is defined and composed, the corresponding terminology of the components of an ellipse as well as how certain properties of an ellipse can be calculated. This additional information is not essential to understand the original content: It is neither necessary to know the planets of the solar system, nor the components and terminology of an ellipse, nor how certain properties of an ellipse can be calculated to understand how the velocity of a planet changes when orbiting the sun on an ellipse.

The amount of the additional information was approximately twice as much as the core topic. At this, we extended the narrowly defined core topic and came somewhat closer to the complexity and demands of contents within a lesson. Thereby, we chose a trade-off to, on the one hand, be able to study the impact of learning with different visualization formats under more ecological valid conditions, and on the other hand to be still able to convey the whole instructional material with a multimedia learning environment in a controllable experimental setting.

To conclude, the following hypotheses for learning outcomes were derived: First, animations should be more beneficial for learning than static pictures for this instructional material, especially for test questions that ask for an understanding of the principle of the dynamic process explained in the core topic (here: factual knowledge about the dynamic features as well as transfer). Second, additional information should impede the understanding of the original content. Third, because an animation that possesses an instructional advantage may be even more beneficial when the understanding of the original content is impeded, the benefits of learning with animations compared to static pictures might be more strongly pronounced when additional information is present compared to when additional information is absent (where the beneficial effect of the animation should also be still observable).

Furthermore, as a subordinate goal, we also assessed subjective measures of cognitive load. In contrast to the learning outcome measures, assessing cognitive load served rather exploratory purposes. Thereby, we wanted to explore whether these subjective measures may mirror the learning results and hence may contribute to our understanding.

Since this study took part in a more ecologically valid setting, we intended to increase the statistical power (i.e., decrease in Type II error) by a) using a comparatively larger number of participants (for an experimental setting) and b) by using a predefined contrast in the analyses of the knowledge test about Kepler's second law that corresponded to the abovementioned hypotheses.

Method

Participants and design

Two-hundred-and-one students from 9th and 10th grades of five different high-schools in Germany (Gymnasium) participated in the study. To be able to take part in this study, students were required to have parental permission (parents had to sign an informed consent, which the students had to hand out to their respective teachers). The data of two students had to be omitted from further analysis (one student could not watch the entire learning environment due to a computer crash, one student could not finish the knowledge test but had to leave the classroom). Of the remaining 199 students, 101 were female and 98 were male (average age: $M = 15.27$ years, $SD = 0.81$). They were randomly assigned to one of four conditions, which resulted from a 2×2 between-subject design with additional information (present vs. absent) and visualization format (static picture vs. animation) as independent variables. Forty-eight to 52 students served in each condition.

Instructional material and apparatus

The core topic was distributed among three computerized pages and consisted of the contents (a) Kepler's first law, (b) Line segment joining a planet and the sun, and (c) Kepler's second law and its implications. This core topic comprised altogether about 190 words and took about 210 s (system-paced). Note that the information about Kepler's first law and the line segment joining a planet and the sun are necessary to be able to understand Kepler's second law.

Kepler's second law states that "A line segment joining a planet and the sun sweeps out equal areas during equal intervals of time". Because a planet is orbiting the sun on an ellipse, and the sun is not centered in the ellipse, Kepler's second law has implications on the planet's course of velocity. More precisely, to coincide with Kepler's second law, the planet travels faster when closer to the sun. This implication was also mentioned in the text.

The conditions including additional information consisted of seven computerized pages, in total, and altogether of approximately 560 words, which were system-paced and took about 550 s (i.e., four additional pages contained additional information with overall about 370 words and took about 340 s). The four additional pages that contained the additional information dealt with: (i) Planets in the solar system (i.e. the names of the eight planets of our solar system and that they can be divided in two groups with respect to their proximity to the sun); (ii) Composition of an ellipse (i.e. the terms for center (semi-)minor axis and (semi-major) axis as well as for the nearest and farthest distance to the sun (perihelion and aphelion); (iii) Focal Points of an ellipse (i.e. the definition of the focal points and how they can be constructed as well as formulas of how they can be calculated); (iv) Eccentricity of an ellipse (i.e. the concepts of linear and numerical eccentricity and its relation to the shape of an ellipse). The order of the seven computerized pages was: (1) Planets in the solar system, (2) Kepler's first law, (3) Composition of an ellipse, (4) Focal points of an ellipse, (5) Eccentricity of an ellipse, (6) Line segment joining a planet and the sun, and (7) Kepler's

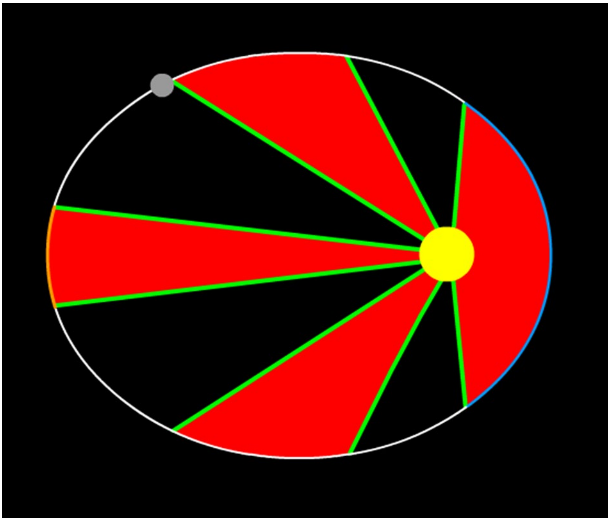

Fig. 1 Used instructional visualization concerning Kepler's second law of the static picture condition. (Color figure online)

second law and its implications. At this, the pages (2) (6) and (7) presented the core topic. The additional information was related to the movement of the planet on the ellipse, but not essential for gaining understanding.

Each page contained an illustration that was always presented above the corresponding written text. Each page was shown for a certain amount of time on the computer and then was automatically forwarded to the next page (system-paced). Thereby it was assured that all students had the same amount of time for those pages that were essential for the understanding of Kepler's second law.

The animation conditions differed to the static picture conditions solely for the last page of the computerized learning environment (namely Kepler's second law). In the static picture conditions, a picture depicting Kepler's second law was shown (see Fig. 1). This picture depicted the orbit, the position of the planet and four equal areas (red color). The animation conditions were identical to the static picture conditions with the exception that, additionally, the changes in the velocity of the planet were depicted (as an inherent property of the animation). In this animation, the planet needed approximately ten seconds to orbit the sun and thus this movement was shown approximately 15 times.

Measures

The measures consisted of (1) one spatial ability test, (2) a participant questionnaire including items on self-reported interest and prior knowledge, (3) items assessing cognitive load experienced during the learning phase, and (4) knowledge tests to measure learning (concerning Kepler's second law as well as the additional information). Additionally, an evaluative questionnaire was given. The spatial ability test and the self-reported prior knowledge were administered as control variables.

Spatial ability

To assess spatial ability, a shortened version of the Paper Folding Test (PFT; Ekstrom, French, Harman, and Dermen 1976) was applied. The shortened version consists of the first part of the PFT and includes ten items. Each item has one correct solution and four distractors. Based on the original procedure for the PFT (Ekstrom et al. 1976), participants were instructed that they have three minutes to work on the PFT. Moreover, participants were instructed that one point would be subtracted for each item in case of an incorrect answer, in order to prevent participants from guessing. We followed this procedure, which resulted in a minimum of −10 and a maximum of 10 points.

Interest and self-rated prior knowledge

Five items were assessed: Two items asked for students interest ("I am interested in the topic physics", and "I am interested in the topic planetary motion (astronomy)"), which had to be rated on a seven-point Likert-scale ranging from 1 (not at all) to 7 (very much). These two items were summed up to an interest score. Three items asked for students' self-rated prior knowledge ("How do you rate your knowledge about physics?" ("How do you rate your knowledge about Kepler's second law (astronomy)?", and "How do you rate your knowledge about ellipses?"), which had to be rated on a seven-point Likert-scale ranging from 1 (very low) to 7 (very high). These three items were summed up to a self-rated prior knowledge score. All items were presented on the computer. Due to problems with log files recording, the data of two students are missing.

Subjective ratings of cognitive load items and interest

Subjective ratings of cognitive load were assessed by four items. At this, one item referred to invested mental effort ("How much mental effort did you invest?"; cf. Paas 1992), which may be seen as an indicator of the overall cognitive load. The other three items were developed by Cierniak et al. (2009): One item referred to content complexity and was supposed to measure ICL ("How difficult was the learning content for you?"), one item referred to difficulty and was supposed to measure ECL ("How difficult was it to learn with the material?"), and one item referred to concentration and was supposed to measure GCL ("How much did you concentrate during learning?"). Moreover, one item that is not directly related to cognitive load referred to interest ("How interesting or boring was the learning content for you?"). These items were presented at the computer, on one screen, and had to be rated on a seven-point Likert-scale ranging from 1 (not at all) to 7 (very much).

Knowledge test about Kepler's second law

The knowledge test was handed out after the learning phase ended. On the introduction page of this knowledge test, students were instructed that this test would be about Kepler's second law, and that Kepler's second law was the last page of their learning environment. Learning outcomes were measured by a paper-based *factual knowledge* test as well as a paper-based *transfer* test. The factual knowledge test, in turn, was divided in contents that asked for (1) knowledge comprising non-dynamic features of the content (non-dynamic factual knowledge) and for (2) knowledge comprising dynamic features of the content (dynamic factual knowledge).

The factual knowledge test consisted of one retention question and one drawing task. For the retention question, students were asked to write down everything they could remember about Kepler's second law within three minutes. According to a coding scheme, the retention question was scored by assessing how many of the core idea units are included in a student's answer. These answers were divided on the one hand in answers that addressed non-dynamic features, for instance that the orbit is an ellipse or that a line joining a planet and the sun sweeps out equal areas during equal intervals of time, and on the other hand in answers that addressed changes of the planet's velocity (i.e., dynamic features of the content). For the paper-based drawing task, students had to draw Kepler's second law (with a time limit of two minutes), with the planet, the sun, the orbit and two areas. The score for *non-dynamic factual knowledge* was obtained by summing up the answers to the retention question that addressed non-dynamic features and the paper-based drawing task. The score for *dynamic factual knowledge* on the other hand was obtained by summing up the answers to the retention question that addressed dynamic features.

The paper-based transfer test consisted of four tasks, in which Kepler's second law had to be applied to new scenarios. The four questions were asking for (1) the influence it would have when the planet is circling on an even more elliptic orbit (compared to a similar but less elliptic orbit); (2) the influence on the course of the velocity of a planet it would have, when the sun is closer to the center of the ellipse; (3) how the orbit would look like, when the velocity of the planet is constant, but Kepler's second law would hold true (and to draw the answer); (4) the impact it would have on the area (that the line joining a planet and the sun sweeps out during equal intervals of time), when the orbit is an ellipse, but Kepler's second law would not hold true. For solving each transfer task there was a time limit: five minutes for transfer task one, three minutes for transfer task two, three minutes for transfer task three and five minutes for transfer task four. For each transfer question, there was also a list of possible correct answers according to a predefined coding scheme. The final score for transfer was determined by summing up the points from all four transfer questions ($\alpha = 0.74$).

The open questions of the knowledge test were scored by two independent raters. Interrater agreement (cf. Hayes and Krippendorff 2007) was good for non-dynamic factual knowledge (Krippendorff's $\alpha = 0.81$), and very good for dynamic factual knowledge (Krippendorff's $\alpha = 0.91$) as well as for transfer (Krippendorff's $\alpha = 0.96$). The final score for each test was calculated by the arithmetic mean of the scoring of the raters.

Knowledge test about additional information

Moreover, there was a paper-based knowledge test about the additional information, which can be considered as a kind of manipulation check. Even though this additional information was exclusively presented in the conditions including additional information, students who did not receive additional information had to also take this test. This knowledge test consisted of six multiple-choice questions with four alternatives to choose from, with one or two correct answers. For each correct answer, one point was assigned and for each wrong answer one point was subtracted. No negative points were carried over, leading to a minimum score of zero and a maximum score of eight points for this knowledge test.

Evaluative questionnaire

This questionnaire contains retrospective evaluations concerning the learning phase as well as the knowledge test (e.g., students had to evaluate whether they found the given learning time adequate, whether they found the given time for solving the knowledge test adequate, how helpful they considered the text as well as the visualization about Kepler's second law, how they perceived the reading flow, how well they could perceive the changes in velocity [in case they received an animation], etc.). This questionnaire was designed to get deeper insights in students' comprehension problems to be able to further develop the learning environment for future studies. The results were not explored in this article.

Procedure

Within their classes, students were first randomly assigned to one of two groups: With additional information or without additional information. These groups were tested in parallel in separate computer labs, in order to insure that students did not become aware about the factor additional information (as it might happen when students would realize that the time for studying the learning material was different between individual students). Within these two groups, students were randomly assigned to either the animation condition or the static picture condition. Students were tested in groups of up to seventeen persons per session in the computer labs of the respective school. Each student was seated at an individual computer. The procedure of the experiment was briefly described to the students. First, students had to fill in the items about interest and prior knowledge. Then, the learning phase began. After the learning phase ended students had to rate their cognitive load experienced during learning. Subsequently, the knowledge test about Kepler's second law was handed out. Students were told that after time ended for a task, they had to stop writing and in case a student should have finished a task before the time ended, it was not allowed to already start with the next task, but they had to wait until time was over. Also it was not allowed to review the previous tasks. The paper and pencil based knowledge tasks about Kepler's second law were given in the following order: retention task, pictorial task and transfer tasks. Thereafter, all students had to answer the knowledge test about addressing the additional information. After the knowledge tests were finished, the evaluative questionnaire had to be filled out. Thereafter, students were thanked for participation and the scope of the study was briefly explained. The whole study lasted approximately 45 min. The PFT was assessed approximately one week after the study was conducted (in another lesson).

Not all data are available for the variables cognitive load, knowledge test about additional information and the PFT: For one student, no cognitive load data are available, since the computer crashed after the learning phase ended. Nevertheless, this person could work on the paper-based knowledge test. One other student left earlier and did not fill out the knowledge test about additional information (or the evaluative questionnaire). Eleven of the 199 students did not fill out the PFT (because of various reasons such as that they were not present in this other lesson, when the PFT was assessed). This loss of data is treated as missing values for the respective variables, meaning that the cases were not removed entirely, but solely for the analyses of the respective variables.

Results

Data analyses were conducted according to the following procedure: Two-factorial ANOVAs (2×2 between-subject ANOVAs) with the independent variables visualization format and additional information were performed 1) for the control variables to check whether students' prerequisites (control variables) could be considered equal across experimental conditions, 2) for the dependent variables of cognitive load, and 3) for the knowledge test addressing additional information.

Since there were specified hypotheses for the main dependent variables, namely the knowledge test concerning Kepler's second law, these data were analyzed using contrasts, thereby following the suggestions made by Abelson and Prentice (1997) as well as Niedenthal et al. (2002). Compared to a conventional ANOVA, contrasts have the advantage to provide greater statistical power without increasing type I error (Buckless and Ravenscroft 1990). Other than for a two-factorial ANOVA, in a contrast analysis the two main effects and the interaction are not presented and reported separately, but en bloc, meaning that the hypothesized pattern of results is analyzed as a whole. For learning the essential of Kepler's second law, we hypothesized (1) an overall advantage of an animation over a static picture (2) additional information to hamper learning and (3) that the advantage of an animation over a static picture should be especially pronounced when additional information was given, but less pronounced when no additional information was given. These specified hypotheses of two main effects and an interaction are completely represented by, and incorporated, in the focal contrast A (1 5−71; with the value "1" for static picture without additional information, the value "5" for animation without additional information, the value "−7" for static picture with additional information, and the value "1" for animation with additional information). Given that there were four experimental groups, two additional orthogonal contrasts had to be created that captured the residual systematic variance between the groups (B: 1 0 0 −1; C: −3 4 2 −3). These two orthogonal contrasts need to be applied to rule out statistical artefacts, particularly in case the focal contrast is significant. More precisely, when the focal contrast is statistically significant, but the two remaining orthogonal contrasts, as a set, are not statistically significant, it can be concluded that the observed data of the respective dependent variable correspond to the hypothesized pattern of results (here: the hypothesized two main effects and the interaction). To apply the most conservative test for the two residual contrasts, we tested the variance explained by these two contrasts using one degree of freedom (Niedenthal et al. 2002). All three contrasts were entered in a multiple regression analysis.

Means and standard deviations are reported in Table 1. Partial eta-squared (η^2_p) is reported as a measure of effect size. For eta-squared, effect sizes of 0.01, 0.06, and 0.14 correspond to small, medium, and large effect sizes respectively (Cohen 1988).

Control variables

For the control variables, 2 × 2 between-subject ANOVAs with visualization format (static picture vs. animation) and additional information (present vs. absent) as independent variables revealed neither differences for visualization format, nor for additional information, nor for the interaction for any of the control variables: spatial ability (all Fs < 1, all ps > 0.44), interest (all Fs < 2.05, all ps > 0.15) as well as self-rated prior knowledge (all Fs < 1.75, all ps > 0.18).

Cognitive load and interest

For the four cognitive load items as well as for the interest item, 2 × 2 between-subject ANOVAs revealed no main effect for the independent variable visualization format (all Fs < 2.03, all ps > 0.15) and no interaction (all Fs < 1, all ps > 0.34). For the independent variable additional information, there was no main effect for concentration or interestingness (both Fs < 1, both ps > 0.68), but a main effect was observable for the dependent variable content complexity, $F(1, 194) = 10.90$, $p = 0.001$, $\eta^2_p = 0.053$, for difficulty, F(1,

Table 1 Means (and SD) as a function of additional information and visualization format

Visualization format	Static picture		Animation	
Additional information	Absent ($n = 52$)	Present ($n = 49$)	Absent ($n = 50$)	Present ($n = 48$)
Control variables				
Spatial abilities[a]	4.71 (3.32)	4.91 (3.20)	4.22 (3.33)	4.74 (3.21)
Interest	8.81 (2.90)	8.35 (2.91)	7.90 (2.89)	8.06 (3.08)
Self-rated prior knowledge	7.94 (2.78)	6.98 (2.79)	7.60 (3.09)	7.42 (3.54)
Cognitive load[b]				
Content complexity	2.54 (1.43)	3.17 (1.16)	2.32 (1.08)	2.90 (1.42)
Difficulty	2.37 (1.19)	2.77 (1.15)	2.08 (1.05)	2.73 (1.32)
Concentration	5.00 (1.24)	4.90 (1.51)	4.74 (1.40)	5.00 (1.32)
Effort	4.48 (1.75)	5.15 (1.44)	4.10 (1.58)	4.90 (1.40)
Interestingness	4.67 (1.37)	4.50 (1.29)	4.36 (1.24)	4.44 (1.40)
Learning outcomes				
Non-dynamic factual knowledge (max. 11 points)	4.98 (1.41)	4.94 (1.47)	5.05 (1.16)	4.98 (1.10)
Dynamic factual knowledge (max. 2 points)	0.52 (0.77)	0.39 (0.64)	0.98 (0.79)	0.76 (0.84)
Transfer (max. 14 points)	6.85 (3.75)	5.73 (4.25)	7.67 (3.73)	7.49 (3.49)
Knowledge about additional information (max. 8 points)[c]	2.83 (1.45)	5.41 (1.73)	2.36 (1.24)	5.40 (1.48)

[a]The following data of the PFT are missing: One student of the condition "static picture & absence of additional information (SA)", four students of the condition "static picture & presence of additional information (SP)", four students of the condition "animation & absence of additional information (AA)", two students of the condition "animation & presence of additional information (AP)"

[b]No cognitive load data are available for one participant of the condition SP

[c]No data of the knowledge test about additional information are available for one participant of the condition AP

194) = 9.89, $p = 0.002$, $\eta^2_p = 0.049$, as well as for effort, $F(1, 194) = 10.89$, $p = 0.001$, $\eta^2_p = 0.053$. Students receiving additional information stated that they found the content to be more complex, more difficult and to have invested more mental effort than students receiving no additional information.

Learning outcomes concerning Kepler's second law

As described above, according to our hypotheses, a focal contrast A was constructed that represented the two hypothesized main effects and interaction simultaneously. A multiple regression analysis was conducted for each of the three dependent variables concerning knowledge about Kepler's second law. Thereby, the focal contrast and the residual contrasts (as a set) were entered simultaneously. Results revealed that the focal contrast A was statistically significant for the dependent variable dynamic factual knowledge, $F(1, 195) = 13.67$, $p < 0.001$, $\eta^2_p = 0.066$, as well as for transfer performance, $F(1, 195) = 7.10$, $p = 0.008$, $\eta^2_p = 0.035$, while no significant effect for the dependent variable non-dynamic factual knowledge was observable, $F < 1$, $p = 0.72$. The set of residual contrasts were not significant for transfer performance $F < 1$, $p = 0.39$, $\eta^2_p = 0.004$ or for non-dynamic factual knowledge, $F < 1$, $p = 0.86$. However, the set of residual contrasts was significant for dynamic factual knowledge, $F(1, 195) = 4.04$, $p = 0.046$, $\eta^2_p = 0.019$. The significant focal contrast for dynamic factual knowledge can hence not be interpreted properly, since the corresponding residual contrast was also significant. Thus, for dynamic factual knowledge the hypothesis has to be rejected. However, since the residual contrasts were not significant for transfer, the significant focal contrast for transfer can be interpreted in that the data of the dependent variables are consistent with the hypothesized pattern of results: The benefit of an animation over a static picture was especially pronounced when additional information was given and that this benefit was observable only to a lesser extent when no additional information was given and that additional information hindered a deeper understanding of Kepler's second law.

Learning outcomes concerning additional information

For the knowledge test about additional information, a 2×2 between-subject ANOVA revealed no main effect for the independent variable visualization format, $F(1, 194) = 1.24$, $p = 0.27$, $\eta^2_p = 0.006$, and no interaction, $F(1, 194) = 1.20$, $p = 0.28$, $\eta^2_p = 0.006$. However, there was a main effect for the independent variable additional information, $F(1, 194) = 177.23$, $p < 0.001$, $\eta^2_p = 0.477$, with students receiving additional information clearly outperforming students who did not receive additional information.

Relationship between control variables, subjective measures and learning outcomes

Table 2 provides a correlational matrix including the control variables, subjective measures of cognitive load and interest as well as the different learning outcome measures.

Table 2 Intercorrelational matrix

Variables	1	2	3	4	5	6	7	8	9 [c]	10 [c]	11 [c]
1. Spatial abilities	–										
2. Interest	.35**[a]	–									
3. Self-rated prior knowledge	.31**[a]	.66**[c]	–								
4. Content complexity	– .13 [b]	– .23**[d]	– .26**[d]	–							
5. Difficulty	– .15*[b]	– .15*[d]	– .24**[d]	.76**[d]	–						
6. Concentration	– .05[b]	.07[d]	– .05[d–]	– .11[d]	– .19** [d]	–					
7. Effort	– .05[b]	– .05[d]	– .17*[d]	.20**[d]	.07[d]	.52**[d]	–				
8. Interestingness	.17*b	.37**[d]	.19**[d]	– .36**[d]	– .44**[d]	.34**[d]	.20**[d]	–			
9. Non-dynamic factual knowledge	.14**[a]	.19**[c]	.18*[c]	– .29**[d]	– .30**[d]	.22**[d]	.01[d]	.13[d]	–		
10. Dynamic factual knowledge	– .04 [a]	.05 [c]	.04 [c]	– .14* [d]	– .08 [d]	.09 [d]	.03 [d]	.03 [d]	.12 [c]	–	
11. Transfer	.24**[a]	.24**[c]	.25**[c]	– .35**[d]	– .34**[d]	.15*[d]	.00[d]	.20**[d]	.40**[c]	.30**[c]	–
12. Knowledge about additional information	.21**[b]	.20**[d]	.09[d]	.06[e]	.06[e]	.03[e]	.13[e]	.12	.17*[d]	– .01[d]	.24**[d]

[a]N = 188

[b]N = 187

[c]N = 199

[d]N = 198

[e]N = 197

*$p < .05$

**$p < .01$

Summary and discussion

In the current study we investigated whether the instructional advantage of a well-designed instructional animation compared to a static picture would become especially important when the original topic would be enriched with additional information—as it is often the case in school contexts.

Empirical findings

For our main dependent variable, namely the knowledge tests about Kepler's second law, there were specified hypotheses. Therefore, we analyzed the data according to a predefined contrast. This contrast corresponded to the two hypothesized main effects as well as the interaction between visualization format and additional information. The hypothesized pattern of results was not true for the two factual knowledge tests, but for the transfer test. The missing effect for factual knowledge, in particular for dynamic factual knowledge, was unexpected. One possible explanation for the absence of the interaction for the dynamic factual knowledge tasks may be that the information about dynamic features (change in planet's velocity) was very prominent for students who received the animation, who could see the changes in the animation, while this information was not prominent for students' learning with static pictures. It may be the case that when asked to write down everything they can remember about Kepler's second law (within three minutes), students receiving the animation list the prominent information about dynamic features, while students receiving static pictures might simply hardly list this information—irrespective whether additional information is given or not. However, not listing this information does not necessarily reflect whether this information was understood. The hypothesized pattern of results was actually met for the transfer test. This means that particularly for the task that required a deeper understanding of the core topic, the beneficial effect of the animation over the static picture was more pronounced when additional information was presented, and less pronounced when no additional information was given, while additional information overall hampered learning. Or to put the interaction the other way around: Additional information was less detrimental for gaining a deeper understanding of the core topic when an animation was given than when a static picture was presented. Given that the hypothesized interaction was met for the most crucial knowledge test, namely transfer, these results stress the importance of using well-designed instructional animations for helping students to achieve a deeper understanding of the dynamic interrelations—especially when additional information also needs to be learned.

With regard to the knowledge about the additional information, the visualization format did not affect performance on this knowledge test. However, students receiving additional information clearly outperformed students not receiving additional information on this test. Even though this result can be considered as a kind of manipulation check that this information was actually learned, it should however not be degraded solely as a manipulation check, since such additional information can be a learning goal in itself, especially in school contexts.

Concerning the subjective measures of interest and cognitive load, it had no influence on any of the measures whether students learned with an animation or a static picture. Receiving additional information had also no influence on the reported concentration or on how interesting students perceived the learning environment. However, students receiving additional information found the content to be more complex, more difficult and stated to have invested more effort than students receiving no additional information. The higher reported mental effort for students receiving additional information may be interpreted as an effort to counteract the higher perceived content complexity and difficulty. Given the high correlation between the items complexity and difficulty ($r=0.76$) in this study, it is fair to say that those items have measured a very similar aspect, but did rather not distinguish between ICL and ECL (cf. Cierniak et al. 2009). Since they both are negatively correlated with the learning outcome measure, these items may be cautiously interpreted as an indicator of ECL. However, besides the main effect of additional information, it should be noted that the subjective measures did overall not directly mirror the results of the learning outcome measures.

Theoretical contribution

In line with the coherence principle in multimedia learning (Mayer 2009), students who received additional information performed poorer in a transfer test. Overall, when considering the coherence principle, there is a large amount of research about seductive details (for reviews see e.g., Eitel and Kühl 2019; Mayer 2009; Rey 2012), but surprisingly little research with respect to the influence of additional information (Mayer 2009; Mayer and Jackson 2005; Verkoeijen and Tabbers 2009). Our study was not directly building on this previous work, since we used different instructional material, and also changed the amount and nature of the additional information and conducted the study in the classroom. On the one hand, given the little research about this topic, it may be useful to conduct studies that directly build up on previous work by solely changing one aspect. On the other hand, the current study broadens previous research about the influence of additional information in several ways. First, by using new instructional material (about how planets orbit the sun), we extended, in this respect, the existing research. Thereby, we not only focused on quantitative details, but also provided further additional information that addressed concepts that are related to the core topic, but that are not directly relevant for its understanding. Second, in our study we used instructional material that is in the curriculum of (German) schools. Our participants were students and the study took part in the school environment. In this sense, our study was overall more ecologically valid than previous work, which used students from university in a laboratory setting of the respective universities (Mayer and Jackson 2005; Verkoeijen and Tabbers 2009). These two aspects of new instructional material as well as examining them in a school context may contribute to the generalizability of the coherence principle with respect to the role of additional information.

Practical implications

From a practical point of view, particularly for topics where an understanding of dynamic interrelations is crucial, it seems reasonable and important to use focused and well-designed instructional animations compared to static pictures. This seems to be especially the case when additional information is given and needs to be learned—as may for instance is the case in school contexts. Other than implicitly suggested in the coherence principle, we do not consider this additional information (such as quantitative details) as some type of extraneous material that can simply be dropped, since in contexts like school, the additional information may be a learning goal in itself. Rather, at this still early stage of research, we suggest to compensate the impeding effect of additional information by means of providing well-designed instructional material. However, further research is needed on how the additional information itself may be best presented.

Limitations and future directions

In the current study, the core topic was very short and narrowly defined, while the additional information was approximately twice as long as the core topic. This comparatively high amount of additional information might have contributed to the observed pattern of results, since it may be argued that if we would have enriched the core topic with less additional information, this would have had a lesser impact on the results. In addition, the additional information was presented before the core topic about Kepler's second law (and learned quite well). It may be reasoned that before the core topic was presented, students already experienced a certain amount of cognitive load.[1]

This in turn may have somewhat provoked the enhanced positive effect of learning the core topic with the animation, since under these conditions it may be particularly hard for learners with static pictures to be able or willing to try counteracting the informational disadvantage of the static picture. Moreover, especially for learners in the additional information conditions, receiving an animation after six pages of text with static pictures might have been a welcome change that may have additionally motivated learners to engage with the topic of this page. Even though this notion is not reflected in the results of the interest item, it nevertheless cannot be completely ruled out. This issue may be investigated more systematically in future studies.

It is an open question whether the enhanced beneficial effect of the animation compared to the static picture would also remain when the core topic would be presented at the beginning of the learning environment (or would be interspersed). Also, it is unclear if in this case, the additional information would be learned better or worse, compared to when the additional information would be presented first. Verkoeijen and Tabbers (2009) showed that additional information is harmful for the understanding of the core topic when additional information is interspersed, but not when the additional information is presented after the core topic. Thus, the latter order may be a promising candidate for how core topic and additional information may be ordered, since it may also prevent from a potential overload scenario, at least for the core topic. However, much more research is needed around this issue with various instructional materials that for instance differ in length, complexity and that are investigated in different educational setting.

We assessed cognitive load for rather exploratory purposes. The observed results were in some aspects in line with CLT, but did overall not mirror the pattern of results for learning outcomes. We used single items that were also used in previous studies (Cierniak et al. 2009; Paas 1992). Besides the two items that may be interpreted as an indicator of ECL, the other items were rather poor indicators of cognitive load. Even though single items are frequently assessed (cf. Sweller et al. 2011), using single items is also criticized and we

[1] This reasoning may be at first glance supported by the subjective ratings of content complexity, difficulty and effort. However, this type of evidence should be treated very cautiously, since we did not measure cognitive load directly after the presentation of additional information, but only once after the learning phase. Moreover, the conditions with additional information took more time. Due to this confound, it may be the case that these results do not reflect higher cognitive load, but, for instance, the invested additional time (cf. Van Gog et al. 2012).

may receive more reliable results when using multiple items questionnaires (e.g., Klepsch et al. 2017).

Next to these abovementioned limitations, it should generally be noted that we conducted only one experiment, which may limit the robustness of our findings. Hence, it is necessary to conduct further studies to be able to estimate how stable and generalizable our observed effect actually is (cf. Pashler and Wagenmakers 2012).

A major goal of the current study was to systematically broaden multimedia research of animations and static pictures that is often characterized by narrowly defined topics - by extending such topics through providing additional information (which somewhat mirrors the reality in school contexts). Thereby, we decided to enlarge the instructional material, but still be able to conduct the experiment with a multimedia learning environment within a school lesson. Through this trade-off, our used instructional material may, on the one hand, be considered as ecologically more valid than using a narrowly defined topic. Nevertheless, from the perspective of a school curriculum, it still was a short multimedia learning environment. Moreover, the manipulation of the animation factor compared to static picture solely referred to one page of the computerized instructional material. Hence, future research may use longer multimedia lessons that mirror the practical work of teachers in schools to an even better degree and may also use animations more extensively.

Conclusion

As the results of this study showed, learning with a well-designed instructional animation helps students gain a deeper understanding of the core topic that such an animation illustrates. This advantage is especially pronounced when additional information is presented, as is frequently the case in school contexts. Thereby, such additional information is often a learning goal in itself. Hence, in such cases the question should not be whether or not additional information, like quantitative details, should be added to a core topic. Rather the question for future directions should incorporate how the additional information should be added so that the core topic as well as the additional information is best understood. Thereby, we advocate that especially in such cases of a high amount of additional information, the learning environments should be designed in ways that foster learning, as was done in the present study by using a well-designed instructional animation.

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