



Using Smartphones as Experimental Tools—a Follow-up: Cognitive Effects by Video Analysis and Reduction of Cognitive Load by Multiple Representations

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Abstract

Mobile devices (smartphones or tablets) as experimental tools (METs) offer inspiring possibilities for science education, but until now, there has been little research studying this approach. Previous research indicated that METs have positive effects on students' interest and curiosity. The present investigation focuses on potential cognitive effects of METs using video analyses on tablets to investigate pendulum movements and an instruction that has been used before to study effects of smartphones' acceleration sensors. In a quasi-experimental repeated-measurement design, a treatment group uses METs (TG, $N_{TG} = 23$) and a control group works with traditional experimental tools (CG, $N_{CG} = 28$) to study the effects on interest, curiosity, and learning achievement. Moreover, various control variables were taken into account. We suppose that pupils in the TG have a lower extraneous cognitive load and higher learning achievement than those in the CG working with traditional experimental tools. ANCOVAs showed significantly higher levels of learning achievement in the TG (medium effect size). No differences were found for interest, curiosity, or cognitive load. This might be due to a smaller material context provided by tablets, in comparison to smartphones, as more pupils possess and are familiar with smartphones than with tablets. Another reason for the unchanged interest might be the composition of the sample: While previous research showed that especially originally less-interested students profited most from using METs, the current sample contained only specialized courses, i.e., students with a high original interest, for whom the effect of METs on their interest is presumably smaller.

Keywords Technology-based activities · Secondary education · Physics education · Video analysis · Mobile devices as experimental tools

Introduction

Nowadays, most pupils cannot imagine life without mobile devices as smartphones or tablets. These devices create new possibilities for teaching and learning, especially in science education. They cannot only be used for communication or browsing the internet but also as mobile pocket-labs, as they come with a multitude of built-in sensors. The advantage of

using smartphones or tablets as experimental tools does not lie in the ability to take more accurate measurements than with traditional means, but in the ability to do a variety of experiments and combine experimental procedure with analyzing measuring data with only one device. With the internal sensors of mobile devices, it is possible to investigate phenomena in mechanics, acoustics, electromagnetism, optics, and even radioactivity. Interpretation of the sensor data is quickly and easily possible, as applications (apps) generate tables, graphs, or other forms of data representation automatically on the device's screen. Furthermore, the portability and versatility of smartphones and tablets allow for experiments inside as well as outside the classroom and also as homework (as almost every pupil possesses their own smartphone). Thus, experiment-oriented seamless learning can be generated. Numerous *experimental* concepts for the use of mobile devices as experimental tools (METs) in science education have appeared in the last years (for an overview, see Hochberg et al. 2018). The *Physics Teacher* journal has established a column

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about METs since 2012 (Kuhn and Vogt 2015). Despite the seeming “boom” of METs due to favorable theoretical and practical arguments, there have been few empirical studies regarding the learning effects of METs in science education in high school (see, e.g., Kuhn and Vogt 2015; Mazzella and Testa 2016; Becker et al. 2018a; Hochberg et al. 2018; for reviews, see, e.g., Bano et al. 2018; Oliveira et al. 2019).

In 2018, the *Journal of Science Education and Technology* published a study (Hochberg et al. 2018) which reported an empirical investigation of METs in science education regarding mechanical oscillations. The present study is a follow-up to that research addressing open questions mentioned in its limitations and outlook chapter. Briefly, Hochberg et al. (2018) used a quasi-experimental repeated-measurement design, consisting of an experimental group using a smartphones’ acceleration sensor to investigate pendulum movements (smartphone group, SG, $N_{SG} = 87$) and a control group working with traditional experimental tools (CG, $N_{CG} = 67$). Effects on interest, curiosity, and learning achievement were investigated with multiple-regression analyses and ANCOVA, taking into account various control variables. The study found significantly higher levels of interest in the SG (small to medium effect size). Pupils that were less interested at the beginning of the study profited most from implementing METs. Moreover, the SG showed higher levels of topic-specific curiosity (small effect size).

Inspired by the success of context-based science education (CBSE) interventions on the level of instructional episodes (see, e.g., Kuhn and Müller 2014; Bahtaji 2015), the previous study was focused only on the effects of potential “material contexts” of METs. A “material context” is defined as the “connection of the experimental medium itself, based on its material basis, to pupils’ everyday life” (Hochberg et al. 2018). This focus meant a concentration on affective rather than cognitive effects. As both groups were working with almost identical tasks, involving the same variables and forms of representations, cognitive activities were almost identical and no or only small differences could be expected from them. Indeed, no differences were found for learning achievement.

In the current follow-up study, we focus on potential cognitive effects of METs using video analyses instead of the acceleration sensor following the same instruction, namely to investigate pendulum movements. So, this study has two aims: first, we want to replicate the results of the prior study described in Hochberg et al. (2018), and second, we want to adapt the intervention by presenting multiple external representation (MER; see “[Learning with Multiple External Representations](#)”) using mobile video analysis in the treatment group (see Table 1).

Based on the research results of Becker et al. (2019) and Becker et al. (2018a), we suppose that pupils in the treatment group have higher cognitive activation by learning with multiple external representations and smaller extraneous cognitive

load by using video analysis methods which present an integrated learning format to the pupils. So we assume that treatment group has a higher learning achievement compared with the control group working with traditional experimental tools.

Current Research Status and Theoretical Background

As the current follow-up study is concentrating on the potential cognitive effects of using METs for video analyses in science education, the current research status and theoretical background are only related to these effects. A rationale for using METs in science education to foster interest and curiosity can be found in the previous paper (Hochberg et al. 2018).

Current Research Status

Current work points out that little is known about integrating multimedia learning in inquiry-based learning processes with physical experiments in real classroom settings (Oliveira et al. 2019). Through a meta-analysis of 80 primary studies published between 2000 and 2016, Hillmayr et al. (2017) demonstrated that the overall use of digital media in teaching has a moderately strong impact on students’ learning performance, across all subjects studied (biology, chemistry, physics, and mathematics) as well as across all grade levels. In a meta-analysis for the teaching of mobile digital media (laptops, tablets, smartphones, etc.), Sung et al. (2016) found a positive medium effect ($g = 0.52$) on students’ learning performance; for the teaching use of only tablets, the effect was $g = 0.62$. The research findings prove the potential of digital media to effectively support the teaching process. However, the authors of the meta-studies agree that a blanket statement on how digital media can be meaningfully used in the classroom is also not possible due to the variety of teaching and learning scenarios as well as the media and learning programs used. Rather, each newly developed digitally supported learning process must be tested for the fit of medium and learning program, as well as for learning effectiveness. Using mobile devices as smartphones and tablets as experimental tools in physics was first investigated by Kuhn and Vogt (2015) in the field of acoustics in lower secondary education. A positive learning effect on achievement and motivation could be proven. Mazzella and Testa (2016) used smartphones to increase students’ conceptual understanding of acceleration. In higher secondary instruction, they showed that students who followed smartphone activities regarding the motion on an inclined plane and pendulum oscillations were more able to design an experiment to measure acceleration and to correctly describe acceleration in a free fall motion than their peers following traditional instruction.

Table 1 Similarities and differences between the original and the replication study in table form

	Original study (Hochberg et al. 2018)	This replication study
Topic	Mechanical oscillations	
Study design	Quasi-experimental repeated-measurement, treatment-control group comparison	
Intervention	Three experiments on the periodicity of a spring pendulum, a simple pendulum, and a coupled pendulum	
Control group	Conducting the experiments by using a ruler and a stopwatch to measure the oscillations' period	
Treatment group	Conducting the experiments by recording the acceleration of the pendulum movement with a smartphone implemented in the experimental setup	Conducting the experiments by recording a video of the pendulum movement and performing a video motion analysis with the tablet positioned outside the experimental setup
Dependent variables	Learning achievement, curiosity (state), interest, self-concept, relation to reality	Learning achievement, curiosity (state), interest
Control variables	Gender, age, physics grade, possession of media, frequency of using media, personal assessment of tutor, curiosity (trait), cognitive load, spatial ability, experience with experiments, representational competence in kinematics	Gender, age, physics grade, possession of media, frequency of using media, self-concept, personal assessment of tutor, curiosity (trait), cognitive load
Study sample	154	52
Technology	Smartphone	Tablet
Sensor used for data collection	Internal acceleration sensor	Internal camera
Analyzing method of the data collected by the students	Device is included in the experimental procedure and collects acceleration data during the experimental process.	Device records the experimental procedure from outside the experiment, non-contact measurement of time, and location of moving object
Data visualization	Acceleration-time-diagram which is analyzed by the students after the experiment	Tables, strobe pictures, and diagrams (distance-time, velocity-time, acceleration-time)
Significant results	Interest (ANCOVA: $F(1, 149) = 6.11, p = 0.015, d = 0.40$); curiosity (multiple-regression analysis: $b^* = 0.21, t(150) = 3.19, p = 0.002, d = 0.25$)	Learning achievement (ANCOVA: $F(1, 47) = 5.22, p = 0.027, d = 0.66$)

Against this background, it can be stated that modern technologies offer a variety of possible applications to support the experiment-based learning process, especially in the subject area of mechanics, which represents an essential field of classical physics and is therefore treated very intensely in physics teaching, as well as in physics studies. One possibility for technology support is provided by video motion analysis, a method for non-contact measurement of time and location of moving objects, which means that the position of a moving object with respect to a two-dimensional coordinate system is stored in each frame of a recorded video, from which velocity and the acceleration of the object can be calculated. The learning effectiveness of video analysis has been empirically studied in education research since the 1990s. Thus, a positive learning effect could be empirically proven with regard to different forms of representation (for diagrams: Beichner 1998; for strobe pictures: Boyd and Rubin 1996; for tables: Pappas et al. 2002; for vectors: Kanim and Subero 2010) as well as conceptual understanding in the field of mechanics (Hockicko et al. 2014; Wee et al. 2015). Regarding affective effects of video analysis, qualitative studies indicated possible advantageous effects on motivation, interest, and curiosity (for example, Zollman and Escalada 1996; Rodrigues et al. 2010;

Wee et al. 2012). It should be noted that, to date, when using video analysis in teaching-learning scenarios, the recording (usually with conventional digital camera) and the analysis of the movement (usually on the PC) are separated and take place one after the other. The transfer to the PC can also be associated with technical hurdles such as a necessary conversion of the video format. The resulting disruption of the learning process can reduce the learning-promoting effect of the video motion analysis by the temporal separation of corresponding sources of information (temporal contiguity principle; Mayer and Moreno 2003) and thus complicate an effective learning implementation in regular lessons. Tablets today have technically advanced cameras that can record videos in outstanding quality. Specially developed video analysis applications open up the possibility of combining the single video motion analysis process steps on only one mobile device, from the recording of the moving object in an experiment to the analysis of the movement to the visualization of the relevant physical quantities by providing multiple representations such as tables, strobe pictures, and diagrams (see Fig. 1), between which the learner can switch as needed and view them in combination. Thus, learners can use this digital learning tool to record movements of arbitrary bodies and

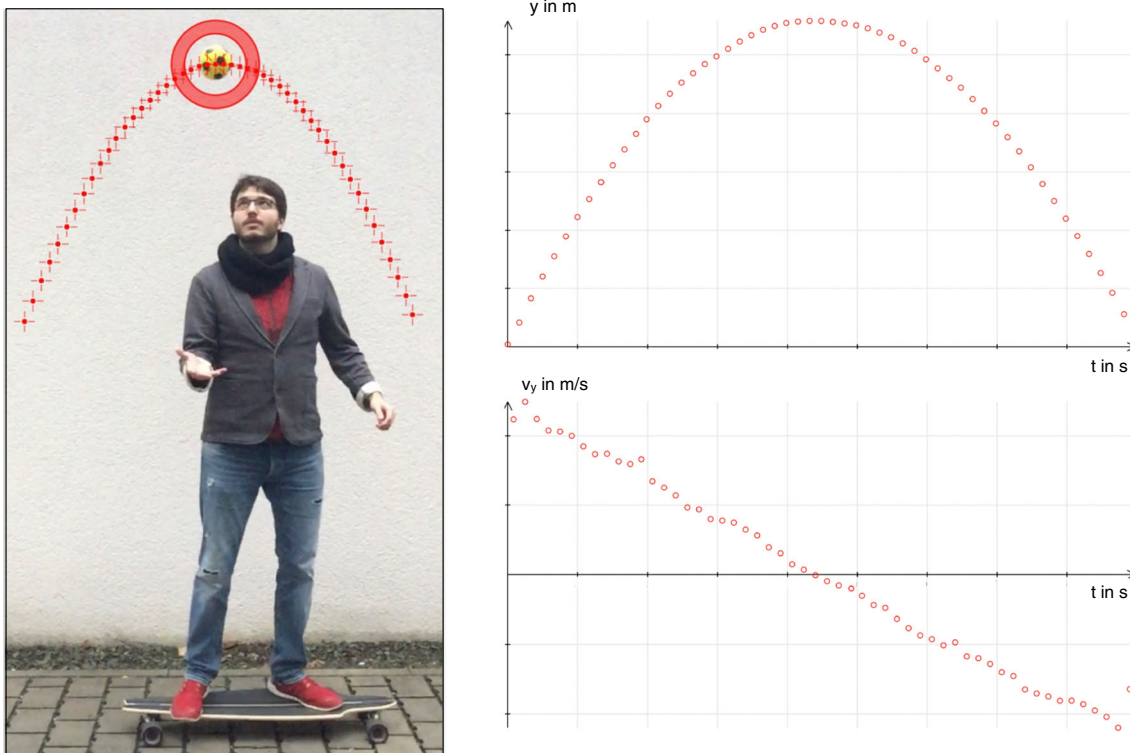


Fig. 1 Screenshots from video motion analysis application: video with tracking of object (left), $y(t)$ -(position-time)-graph (upper right), $v_y(t)$ -(velocity-time)-graph (lower right)

investigate their physical relationships and laws independently almost in real time by interpreting multiple forms of representation. In this way, the advantages of using mobile devices in teaching-learning scenarios are combined with the possibilities of physical video motion analysis as a measurement method. This opens up new creative possibilities for learning processes (Becker et al. 2016, 2018b, 2018c; Thees et al. 2018; Klein et al. 2013), which can help to foster the learning with multiple representations.

In this regard, Klein et al. (2018) designed a learning scenario for task-oriented learning with (mobile) video analysis using tablets for introductory physics courses in universities and could diagnose positive effects on conceptual understanding and representational competence. In a quasi-experimental study with a pre-post-test design involving high school physics courses, Becker et al. (2019) and Becker et al. (2018a) could show for two essential topics of mechanics, uniform and accelerated motion, that using mobile video analysis in regular teaching leads to better conceptual understanding than traditional lessons, especially for the more complex topic of accelerated motion. Furthermore, Becker et al. (2019a) conceived an application for task-oriented learning with mobile video analysis using tablet computers and were able to determine positive effects on intervention-induced extraneous cognitive load and conceptual understanding for high school physics courses.

Theoretical Background

Learning with Multiple External Representations

For scientific learning, multiple external representations (MERs) play a beneficial role, which is well documented for the natural sciences, in general (Tytler et al. 2013), and for physics, in particular (Treagust et al. 2017). It is of especially great importance for conceptual understanding (Verschaffel et al. 2010) and is discussed as a necessary condition for in-depth understanding (DiSessa 2004). Ainsworth (2006, 2008) created a conceptual framework that provides an overview of the prerequisites for the effective use of MERs in teaching-learning situations and the unique benefits for learning complex or new scientific content. According to her, in the design, functions, and tasks (DeFT) taxonomy, learning with MERs means two or more external representations (e.g., diagrams, formulas, and data tables) are used simultaneously. Specifically, there are three key functions that MERs can fulfill (even simultaneously) to support the learning process. According to the first function, MERs can complement one another either by providing complementary information or by allowing for complementary approaches to process information. The presentation of MERs with complementary information content may be advantageous if the presentation of all relevant information in a single form of representation would

lead to cognitive overload of the learner. However, even if different representations contain the same information, they can support the learning process by allowing learners to select the most appropriate form of representation to accomplish the given learning task in the particular learning situation. The second function is that simultaneously presented representations can constrain one another's interpretation in two ways: the more familiar representation can constrain the interpretation of the less-familiar one, or the inherent properties of one representation can trigger the usage of the other representation, which is considered helpful for the learning process. According to the third function, the construction of a deeper understanding is fostered if learners integrate information from different forms of representation to gain insights that could not have been obtained with just one form of representation. Although MERs demonstrably have the potential to support learning processes, their use in learning situations is also associated with learner demands that can overwhelm learners and even negatively affect the learning process (De Jong et al. 1998). Indeed, many studies point toward student difficulties with MERs (e.g., Ainsworth 2006; Nieminen et al. 2010). Consequently, the difficulty of the learning environment must be considered and managed carefully. In this context, technology support can facilitate the learning-promoting effect of MERs (e.g., Horz et al. 2009) by helping to reduce learning irrelevant parts of the so-called cognitive load when learning with MERs.

Cognitive Load Theory

The basic assumption of the Cognitive Load Theory (CLT) (Sweller 1988; van Merriënboer and Sweller 2005) is the limited capacity of working memory in terms of the amount of information that can be processed simultaneously, but also in terms of the time at which information is available for processing. In the relevant literature (Leppink and van den Heuvel 2015; Sweller et al. 1998; Sweller et al. 2019), the cognitive load is composed of three types: intrinsic cognitive load (ICL), extraneous cognitive load (ECL), and germane cognitive load (GCL). ICL refers to the complexity of information that the learner has to process during the learning process and is therefore determined by the learning task and the foreknowledge of the learner regarding the learning content. ECL refers to learning irrelevant cognitive processes, which occupy the working memory but do not lead to a relevant learning gain and can be influenced by the design of the learning procedure, such as how the information is presented to the learner. GCL refers to the amount of cognitive resources needed while processing the information in a learning process. Principles can be derived from CLT to enable instructors to design (short) instructional units that are conducive to learning (Sweller et al. 2019). One fundamental principle is to keep the learning-irrelevant ECL as low as possible during the learning

process (Leppink 2017; Leppink and van den Heuvel 2015; Sweller et al. 1998). Sweller et al. (1998) reported seven effects that can influence the cognitive load. One of them is the split-attention effect (Mayer and Pilegard 2014; Sweller and Chandler 1994; Sweller et al. 2019). This (negative) effect implies that the spatial or temporal separation of related information sources requires mental integration processes, thus increasing ECL and therefore inhibiting the learning process by occupying mental resources that are no longer available for learning-related processing.

Cognitive Theory of Multimedia Learning

The Cognitive Theory of Multimedia Learning (CTML; Mayer 1999, 2003, 2005) builds on the principle of CLT of limited working memory. In addition, the CTML postulates two separate channels of limited-capacity working memory in which visual-pictorial and verbalized information is processed. Learning environments should be designed so that both learning channels (visual and auditory) are addressed during the learning process. The CTML is based on the principle of active knowledge construction, which assumes that an active engagement with the subject of learning is required to form a coherent, mental representation. Furthermore, one feature of an effective multimedia instruction should be to “reduce extraneous processing, manage essential processing, and fostering generative processing” (Mayer 2009, p.57). The principle of contiguity (Mayer 2009; Mayer and Moreno 2003) aimed at reducing extraneous processing by avoiding split-attention effects (Mayer 2009; Mayer and Moreno 2003). With the principle of contiguity, the CTML provides an explanatory approach for avoiding/specifying the split-attention effect (Moreno and Mayer 1999). On the one hand, corresponding information should not be presented spatially separated from each other (spatial contiguity principle). Spatial proximity helps to avoid visual search processes that contribute to an increase in extraneous cognitive load. On the other hand, a temporal separation should also be avoided (temporal contiguity principle). This is justified by the additional cognitive load that arises when mental representations have to be maintained over a longer period of time (Mayer and Moreno 2003; Clark and Mayer 2011). In addition, the segmentation or interactivity principle is assumed in the context of dynamic visualizations (Mayer and Chandler 2001; Mayer and Pilegard 2014), which postulates a learning-conducive effect when learners themselves can determine the sequence or tempo of the information presentation. This self-control of the learning process avoids cognitive overload.

Research Questions

As reported in the current research status, a promising method to support the learning process in the subject area of

mechanics is video analysis. This is especially true for tablet-supported video analysis, as the latest research findings prove that the use of this digital learning tool can effectively reduce ECL in experiment-based learning processes (Becker et al. 2019a). This learning-enhancing effect can be theoretically substantiated on the basis of the previously described fundamental learning theories. In particular, elementary functions of the video analysis application that can contribute to a learning-conducive use of MERs in learning environments will be explained.

Fulfillment of the Key Functions of the DeFT Framework The video analysis application automatically provides learners with multiple forms of representation that include complementary information regarding the investigated motion, the real and stroboscopic image, and the associated motion diagrams (the first key function). The learners in this study are much more familiar with the diagram representation form than with the stroboscopic image representation form because of the experienced teaching (in accordance with their curriculum). The interpretation of the less-familiar stroboscopic image representation form could thus be triggered by the automatic display together with the familiar motion diagram representation form (the second key function). In addition, the automatic multicoding of the movement process makes it easier for the learner to integrate the information from the different MERs into a coherent mental model of the movement process, which would not be possible if only one form of representation were presented (the third key function).

Fulfillment of the Principle of Contiguity By simultaneously displaying corresponding sources of information (real motion sequence and the stroboscopic image, as well as the time-position and time-velocity diagram), the use of the video analysis application fulfills the spatial contiguity principle. In addition, the learner is allowed to switch between the individual forms of representation quasi-simultaneously, which is understood here as the absence of a noticeable time delay, by means of a swipe movement. This also fulfills the temporal contiguity principle.

Fulfillment of the Interactivity Principle During the video analysis, the students themselves can control the transition between the individual segments (forms of representation) of the data evaluation (real motion sequence, motion diagrams, and the stroboscopic image). For example, to improve the understanding of the motion diagrams, the students can again call up the stroboscopic image or vice versa. The use of the video analysis application fulfills the interactivity principle by allowing this self-control of the learning process. The interactivity of the application also promotes the active engagement of the learners with the subject of learning itself. For example, the origin and spatial orientation of the coordinate system can

be manipulated by the learner at any point in the learning process, and the effects of this variation on the motion diagrams can be observed quasi-simultaneously.

In summary, we assume that the presentation features of the video analysis application regarding MERs meet the design principles for multimedia learning environments and thereby reduce ECL (especially via the avoidance of the split-attention effect) in multi-representational learning environments; in turn, this fosters the effective use of MERs in the study's learning scenarios. From this theoretically founded learning-enhancing effect on the learning process and the rationale for using METs in science education to foster interest and curiosity that can be found in the previous paper (Hochberg et al. 2018), we derive the following research questions:

RQ1: Does using METs for video motion analysis lead to higher learning achievement than using conventional experimental tools?

RQ2: Can the advantages of METs for interest and curiosity found in the previous study be reproduced by using METs for video motion analysis?

The Intervention

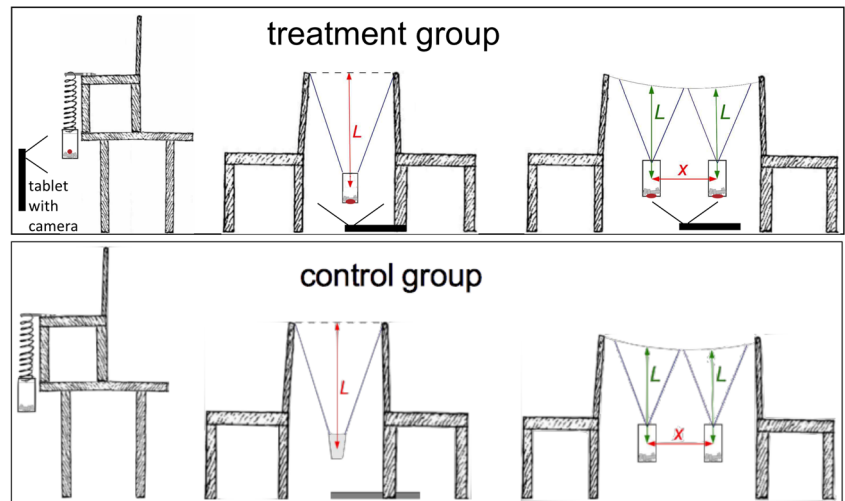
The intervention was comprised of experiments and associated instruction material, largely based on those of the previous study (Hochberg et al. 2018). For the treatment group (TG), experiments and materials were adapted to video motion analysis (see [Online Resource](#) “Instruction Material”). For the control group (CG), exactly the same experiments and materials as in Hochberg et al. (2018) were used.

As in Hochberg et al. (2018), during the intervention, each pupil conducted three experiments on the periodicity of a spring pendulum, a simple pendulum, and a coupled pendulum (see Fig. 2; for more details about the embedment of the intervention into the regular classes, see Hochberg et al. 2018). The experimental setups of both groups were almost identical; different were only the measurement tools: While the CG used a ruler and a stopwatch to measure the oscillations' period, the TG recorded a video of the pendulum movement and performed a video motion analysis with the tablet using the apps Viana and Graphical Analysis.¹ These apps showed measurement data as position markers within the video and as acceleration-time, velocity-time, and position-time graphs.

Pupils were provided with all necessary materials for conducting the experiments. All pupils in the TG were given

¹ The newest version of Viana can be found under the following link: <https://itunes.apple.com/de/app/viana-videoanalyse/id1031084428?mt=8> (FU Berlin 2017); a detailed description of the application is available from Becker et al. (2018a); the newest version of Graphical Analysis can be found under the following link: <https://itunes.apple.com/us/app/vernier-graphical-analysis/id522996341?ls=1&mt=8> (Vernier 2018).

Fig. 2 Experimental setups of TG (above) and CG (below): spring pendulum (left), simple pendulum (middle), coupled pendula (right)



the same devices, regardless of whether they owned a tablet. Where possible, everyday material was used to realize the experimental setups.

The instruction material was designed to be almost identical for both groups; e.g., both groups were provided with worksheets showing idealized graphs of the oscillation. The CG compared the given, idealized graphs on the worksheets with their observation of the experiment and measured the oscillations’ period with a stopwatch. The TG produced several measurement graphs of different oscillations on the tablet and used them to investigate the period of the oscillation. They compared different graphs on the tablet with each other and with the given idealized graphs on the worksheets.

Methods

Study Design

The study design also was mostly adopted from Hochberg et al. (2018). Again, we conducted a quasi-experimental treatment group–control group study (see Fig. 3), which took place during pupils’ regular physics lessons: Before the intervention, all pupils were tested for 45 min. In the following four lessons (spread over 1 or 2 weeks), the intervention took place

as described above. In the next lesson, a post-test of 45 min was conducted. In addition, the treatment group got an introduction of 45 min, in which pupils were taught how to conduct a video motion analysis on the tablet with an example video regarding a projectile motion. The control group did not get any special introduction. The treatment groups’ introduction took place before the pre-test so that any learning differences caused by the introduction can be controlled by using the pre-test as control variable.

Sample

The sample of this pilot study consists of 52 pupils in specialized physics courses of grade 12 from 5 secondary schools in Rhineland-Palatinate, Germany (age range 16–19 years). In agreement with the participating teachers, 3 courses were assigned to the treatment group ($N(TG) = 23$) and 2 to the control group ($N(CG) = 28$). In both groups, the majority of pupils were male (TG, 26% girls; CG, 7% girls). Each group was taught by the same tutor.

Test Instruments

All test items were adopted exactly from Hochberg et al. (2018).

Affective Variables

All items except learning achievement and curiosity as a trait were assessed using 6-point Likert-type scales (for examples, see Table 2). For the items concerning curiosity as a trait (CT), according to the original instrument, a 4-point Likert-type scale was used. For conducting statistical analyses, the mean score of every item was transformed into a percentage, where 0% meant no affirmation of the statement and 100% meant a

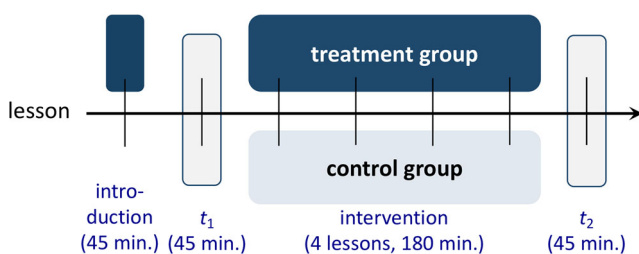


Fig. 3 Process of study. t_1 : pre-test, t_2 : post-test

Table 2 Affective variables (sample items translated from German, more items in post-tests due to more time for testing, repeated items formulated equally in pre- and post-test)

Subscale	Number of items	Example
Interest (IN)	Pre-test: 9 Post-test: 10	“In my leisure time, I engage in topics that are related to physics in excess of my homework.”
Self-concept (SC)	8	“My achievement in physics is, in my opinion, good.”
Personal assessment of tutor (AT)	5	“Our teacher/tutor is/was motivating me.”
Curiosity as a trait (CT)	7	“Reviewing previous ideas is fun to me.”
Curiosity as a state related to content of experiments (CSE)	6	“The experiments piqued my curiosity regarding the topic of oscillations.”

full affirmation of the statement. For negated items, the scale was inverted, so that 100% always stood for the highest evidence of the underlying variable. To put it clearly, all ratings were linearly transformed to a [0, 100%] scale where 0% represents the lower bound of the Likert-type scale, meaning the lowest affirmation to the individual statement, and 100% represents the upper bound of the Likert-type scale, meaning the highest affirmation to the individual statement.

Learning Achievement

As in the previous study, the free text and drawing items were categorized, rated, and accordingly scored as 0, 0.25, 0.5, 0.75, or 1 point (for item examples, see Table 3). The total score was calculated as the sum of points divided by number of items; hence, it was always a percentage between 0 and 100%. There were in sum 23 items in the pre-test and 29 items in the post-test. This was due to the fact that pupils were already acquainted with the questionnaires in the post-test and able to answer more items in the same time and that they had more knowledge and could be asked additional questions especially about coupled pendula.

Cognitive Load and Further Control Items

As in Hochberg et al. (2018), the intervention-induced general cognitive load (GCL) was measured with 10 items (CLE) adapted from Kuhn (2010), Paas et al. (1994), and Chandler and Sweller (1991) and with the 5 items of the NASA TLX instrument (Hart 2007, 2019; Hart and Staveland 1988), which is one of the most used, multi-dimensional rating scale for workload (Hart 2006). As in the other instruments, 6-point Likert-type scales were used (bipolar scales in case of the NASA TLX instrument), the scales of negated items were inverted, and the mean scores transformed into percentages, so that 100% correlated the highest evidence of cognitive load

(for item examples, see Table 4). Further control variables that were measured can be found in Table 4.

Data Analyses


Analyses of Test Instruments

As all test instruments were exactly adopted from Hochberg et al. (2018), and the sample was considerably smaller than the original sample, item and scale characteristics were not reassessed. Subscales were adopted from the original instruments and reliability analyses performed for a comparison with the original reliability.

Analyses of Cognitive and Affective Effects

As a first step, predispositions in TG and CG were compared by *t* tests, or Mann-Whitney *U* tests, if the normal distribution assumption was not met. For all significantly different predispositions, correlations with the dependant variables were calculated to check for a sampling bias. As we collected a wide range of possible covariates for our analyses and our sample is too small to meet the assumptions for structural equation modeling or multiple regression analysis, *t* tests and analyses of covariance (ANCOVA) were used to analyze cognitive and affective effects. For these analyses, the following assumptions were tested: independence and normal distribution of residuals and homogeneity of residuals' variances, and additionally, for analyses of covariance homogeneity of regression slopes, adequate correlation between the covariate and the dependant variable ($r > 0.3$), sufficient reliability of the covariate, and measurement of the covariate prior to the intervention. Of all covariates that met the assumptions, we only included those in the ANCOVA that explained a significant amount of additional variance (tested with a stepwise regression analysis).

Table 3 Example items for the test instrument used to measure learning achievement (translated from German)

item format	example for items
multiple choice item	<p data-bbox="496 254 1406 342">In the picture, you see a wooden toy, which can swing up and down on a metal spring after displacement.</p>  <p data-bbox="496 709 1406 798">What is the influence of the mass of the wooden figure on the period of the oscillation of the toy?</p> <ul style="list-style-type: none"> <li data-bbox="496 831 1023 858"><input type="checkbox"/> The greater the mass, the longer the period. <li data-bbox="496 892 1023 919"><input type="checkbox"/> The smaller the mass, the longer the period. <li data-bbox="496 953 1225 980"><input type="checkbox"/> The mass of the wooden figure has no influence on the period.
multiple true false items	<p data-bbox="496 1016 986 1043">The period of a simple pendulum is longer, ...</p> <ul style="list-style-type: none"> <li data-bbox="544 1077 1342 1104">a) ... if its mass is greater. <input type="checkbox"/> true <input type="checkbox"/> false <li data-bbox="544 1138 1342 1165">b) ... if the length of its string is longer. <input type="checkbox"/> true <input type="checkbox"/> false
assertion reason task	<p data-bbox="496 1199 1278 1226">In reality, a pendulum that was set in motion once is oscillating forever.</p> <ul style="list-style-type: none"> <li data-bbox="496 1260 603 1287"><input type="checkbox"/> right <li data-bbox="496 1320 619 1348"><input type="checkbox"/> wrong <p data-bbox="496 1381 715 1409">Justify your answer!</p>
drawing diagrams	<p data-bbox="496 1442 1406 1530">Draw in the field below the diagram of an oscillation with a continuously decreasing amplitude and a constant period!</p>

Results

Analyses of Test Instruments

The reliability (Cronbach’s α) of all scales used in the analyses below and the respective original scales from Hochberg et al. (2018) can be found in Table 5. The

reliability exceeded $\alpha = 0.7$ for all subscales and did not differ largely from the original values except for the general cognitive load. To keep the data comparable with the previous study, the scale for cognitive load was not altered despite the low reliability. Of all scales and subscales, means and standard errors for both groups can be found in Table 6.

Table 4 Cognitive load and further control items (sample items translated from German)

Subscale	Number of items	Example
Cognitive load related to the experiments (CLE)	10	“I had to make an effort to solve the tasks of the experiments.”
NASA TLX instrument (TLX)	5	“How successful were you in conducting the experiments in your own opinion? Perfect success – failure”
Gender (G)	1	“gender: male / female”
Age (A)	1	“age”
Physics grade (PG)	1	“last school report grade in physics” (0 to 15 points)
Possession of media	2	“I own a smartphone / tablet”
Frequency of using media	2	“I use my smartphone / tablet very often / often / rather often / rather rarely / rarely / very rarely.”

Analyses of Cognitive and Affective Effects

Learning Achievement (RQ1)

The assumptions for calculating ANCOVA (see “[Data Analyses](#)” above) were met. The ANCOVA showed a significant mid-sized effect between groups: $F(1, 47) = 5.22$, $p = 0.027$, $d = 0.66$ (group means and standard errors; see Fig. 4 and Table 7).

Interest and Curiosity (RQ2)

The assumptions for calculating ANCOVA (see “[Data Analyses](#)” above) were met. The ANCOVA did not show an effect between groups, neither for interest ($F(1, 49) < 0.01$, $p = 0.960$) nor for curiosity ($F(1, 49) = 0.02$, $p = 0.889$) (for group means and standard errors, see Table 8).

Control Variables

Regarding personal assessment of tutor in the post-test, self-concept in the post-test, and cognitive load, no significant effects between treatment groups were found (see Table 9).

Table 5 Test instruments: number of items (N_i) and reliability (Cronbach’s α) of the current and the original scales, N_i of post-test scales higher because of more testing time

Scale	Pre-/post-test	N_i	α_{current}	α_{original}
Interest (IN)	Pre-test	9	0.82	0.92
	Post-test	10	0.88	0.96
Self-concept (SC)	Pre-test	8	0.80	0.90
	Post-test	8	0.87	0.92
Assessment of teacher (AT)	Pre-test	5	0.78	0.88
Assessment of tutor (AT)	Post-test	5	0.84	0.77
Curiosity as a trait (CT)	Pre-test	7	0.70	0.83
Curiosity as a state related to content of experiments (CSE)	Post-test	6	0.82	0.91
Learning achievement (LA)	Pre-test	23	0.71	0.71
	Post-test	29	0.82	0.85
General cognitive load (GCL)	Post-test	15	0.46	0.89

Discussion

Learning Achievement (RQ1)

Results of the analysis of the cognitive effects prove that the intervention led for both control and treatment group to a learning gain. By comparing both groups, the assumed higher learning achievement of the use of METs for video analysis could be statistically confirmed with a significant mid-sized effect. This reproduces and extends the research findings from Becker et al. (2019), Becker et al. (2018a), Hockicko et al. (2014), and Wee et al. (2015), which have already been able to prove empirically a positive effect of the video motion analysis on the understanding of physical concepts for other topics of mechanics. We assume that the positive effect is on the one hand based on the automatic recording and visualization of measurement data. In this way, repetitive activities, which do not lead to an increase in the understanding of the physical concept, can be avoided for the learner. According to the CLT, this results in a reduction of learning-irrelevant cognitive load, which enables the learners to use the becoming free cognitive resources for an active preoccupation with the learning subject. According to CTML, this is essential for forming of a coherent mental representation and thus for the active

Table 6 Test instruments/variables: mean and standard error (SE) in TG/CG in pre- and post-test

(Sub) scale/variable	Pre-test				Post-test			
	TG		CG		TG		CG	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Gender	0.7	0.09	0.9	0.05	–	–	–	–
Age	17.4	0.12	16.7	0.14	–	–	–	–
Physics grade	9.3	0.71	8.7	0.70	–	–	–	–
Possession of smartphone	95.5	4.55	100.0	0.00	–	–	–	–
Possession of tablet	59.1	10.73	46.4	9.60	–	–	–	–
Frequency of using smartphone	94.3	2.02	87.1	3.60	–	–	–	–
Frequency of using tablet	66.2	9.17	56.9	7.79	–	–	–	–
Interest (IN)	67.0	3.97	66.1	2.31	67.7	3.85	66.9	2.51
Self-concept (SC)	67.9	3.69	71.9	2.14	69.6	4.24	74.7	2.02
Personal assessment of tutor (AT)	80.5	3.14	90.2	1.77	74.8	3.87	71.9	3.26
Curiosity as a trait (CT)	76.2	2.90	73.6	2.45	–	–	–	–
Curiosity as a state related to content of experiments (CSE)	–	–	–	–	58.1	3.55	58.4	3.15
Learning achievement	52.6	2.39	59.6	3.03	74.1	3.55	69.4	2.71
General cognitive load (GCL)	–	–	–	–	34.4	1.37	37.2	1.18

construction of knowledge structures. On the other hand, we assume that the simultaneous presentation of multiple representations by the video analysis application has a positive effect on the representational competence of the learners. Being based on the CTML, this can be explained by avoiding the split-attention effect which reduces the learning-irrelevant cognitive load furthermore. As one of the main aims of this study is to replicate effects of the original study and to optimize its shortcoming concerning the lack of increasing learning achievement by a change in the intervention (see “Introduction”), we used the same materials and methods as the original study (Hochberg et al. 2018). This included a cognitive load scale which does not allow differing between the three dimensions of cognitive load (Ayres 2006). It was hence not possible to investigate the reduction of the learning-irrelevant extraneous load through the use of mobile video analysis within the scope of this work. We did not measure a

significant difference regarding cognitive load between the treatment and the control group. This is not surprising, as based on results of corresponding work (Becker et al. 2019a) we have evidence to assume that the effects of ECL and GCL have neutralized each other within the treatment and the control group (Wouters et al. 2009). In other words, learning with traditional experiments in the control group may have imposed rather high extraneous cognitive load and low germane cognitive load, whereas learning with video analysis in the treatment group may have imposed rather low extraneous cognitive load and high germane cognitive load, leading in sum to approximately the same amount of general cognitive load.

Interest and Curiosity (RQ2)

Positive effects of METs regarding interest and curiosity, which were found in the previous study, could not be found. There are different reasons which might explain this finding: First, in the current study, there was a change of the mobile device. Out of practical reasons (bigger screen), pupils were working with tablets instead of smartphones. In the previous study, Hochberg et al. supposed that the effect on pupils’ interest was generated by the “material context” of the smartphones that were used as experimental tools. It is possible that this material context, i.e., the “connection of the experimental medium itself, based on its material basis, to pupils’ everyday life” (Hochberg et al. 2018), is weaker for tablets than for smartphones, because they are less present in pupils’ lives. In the current study, 98% of the pupils

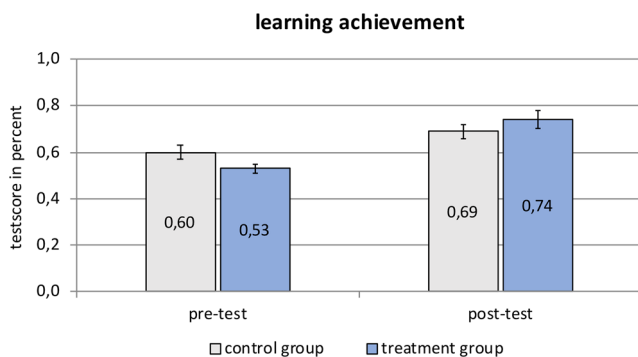


Fig. 4 Group means and standard errors of learning achievement (LA)

Table 7 Sample sizes (N), group means (M), standard errors (SE), adjusted means (M^*), adjusted standard errors (SE^*) of post-test of learning achievement (LA), covariates with means (M), and F -test with significance p and effect size d

Group	N	M	SE	M^*	SE^*	Covariates	ANCOVA
TG	23	0.74	0.04	0.76	0.02	Pre-test learning achievement (LA), $M = 0.57$ Physics grade (PG), $M = 8.94$	$F(1, 47) = 5.22$, $p = 0.027$, $d = 0.66$
CG	28	0.69	0.03	0.69	0.02		

reported possessing their own smartphone and using it very frequently ($M = 90.2\%$), only 52% reported the possession of a tablet and they were using it less frequently ($M = 61.5\%$). The lower everyday occurrence of tablets might also affect the effect on curiosity: In the previous study, the rationale behind the effect on curiosity was that pupils were provided with a new way of accessing information by performing experiments with their own everyday devices, that was said to raise their confidence in being able to find a satisfactory resolution, thereby increasing their curiosity. Not possessing an own tablet might lower that confidence. All experiments performed in the current intervention could also be done with smartphones, but this was not explicitly taught to pupils. Another possible reason for the absence of an effect on pupils' interest is a difference of the samples in the current and the previous study. In the previous study, pupils with less original interest ($IN_{pre} \leq 0.40$) profited most from the intervention. In the current study, only specialized courses were part of the sample, i.e., pupils, that specifically chose physics to be one of their main courses. As expected, the original interest is higher in this sample ($IN_{pre}: M = 0.66$, only one case with $IN_{pre} \leq 0.40$). It is possible that, in an originally less interested sample, effects on interest might be found even though pupils were working with tablets instead of smartphones. Another reason why no effect on interest or curiosity was found might be the size of the current sample: In the previous study in a sample of $N = 154$, a small to midsize effect on curiosity was found ($d = 0.40$). To find an effect of this size with a test power of 0.80, a similar sample size would be needed. For curiosity, the effect was small ($d = 0.25$) and could only be detected with a multiple regression analysis. To find an effect of this size with a test power of 0.80 with an ANCOVA, a sample size of $N = 505$ would be needed.

Conclusions, Limitations, and Outlook

We first aimed at replicating a study about using METs in an attempt to generate relevant material context in the sense of a relation to pupils' everyday life and like this increase their interest and curiosity (Hochberg et al. 2018). Second, we focused on potential cognitive effects of METs using video analyses instead of the acceleration sensor to investigate pendulum movements in the current study. As before, the devices were used within standard, well-tried experimental setups involving pendulum movements in regular physics classes of the upper secondary level; the video analyses provided pupils with multiple representations of their data which we assume reduced their extraneous cognitive load. Besides the already known practical and experimental advantages of METs and mobile video analysis, we can conclude the following statements from our findings: (a) The use of METs significantly raised pupils' learning achievement compared with the control group. Even after a relatively short intervention (3 h), we found mid-sized effects. (b) There were no effects found regarding interest or curiosity as in the previous study. The reason for this might be that tablets, which were used in this study for practical reasons, are less familiar to pupils than smartphones as fewer pupils possess them. This might lead to a reduction of the material context in comparison to smartphones and hence in a smaller potential of tablets to increase interest or curiosity. Another reason why students' interest has not been increased by METs might be the composition of the sample: Hochberg et al. (2018) showed that especially originally less interested students profited most from using METs in their physics classes. The current sample contained only specialized courses, i.e., students with a high original interest, for whom the effect of METs on their interest is presumably smaller.

Table 8 Sample sizes (N), group means (M), standard errors (SE), adjusted means (M^*), adjusted standard errors (SE^*), covariates with means (M), and F -tests with significance p

Variable		N	M	SE	M^*	SE^*	Covariates	ANCOVA
Interest (IN)	TG	23	0.68	0.04	0.67	0.01	Pre-test interest (IN), $M = 0.66$	$F(1, 49) < 0.01$, $p = 0.960$
	CG	29	0.67	0.03	0.67	0.01		
Curiosity rel. to cont. of exp. (CSE)	TG	23	0.58	0.04	0.58	0.03	Pre-test interest (IN), $M = 0.66$	$F(1, 49) = 0.02$, $p = 0.889$
	CG	29	0.58	0.03	0.59	0.03		

Table 9 Sample sizes (*N*), group means (*M*), standard errors (*SE*), adjusted means (*M**), adjusted standard errors (*SE**), covariates with means (*M*), and *F*-test with significance *p*

Variable		<i>N</i>	<i>M</i>	<i>SE</i>	<i>M*</i>	<i>SE*</i>	Covariates	ANCOVA																											
Pers. assessment of tutor (at)	TG	23	0.75	0.04	0.78	0.01	Pers. assessment of teacher (at), <i>m</i> = 0.86	<i>F</i> (1, 49) = 3.27, <i>p</i> = 0.077																											
	CG	29	0.72	0.03	0.69	0.01			Self-concept (SC)	TG	23	0.70	0.05	0.73	0.02	Pers. assessment of teacher (AT), <i>M</i> = 0.86 Pre-test self-concept (SC), <i>M</i> = 0.70	<i>F</i> (1, 48) = 0.03, <i>p</i> = 0.865	CG	29	0.75	0.02	0.72	0.01	General cognitive load (GCL)	TG	23	0.34	0.07	–	–	No correlating variables	<i>F</i> (1, 50) = 2.52, <i>p</i> = 0.119	CG	29	0.37
Self-concept (SC)	TG	23	0.70	0.05	0.73	0.02	Pers. assessment of teacher (AT), <i>M</i> = 0.86 Pre-test self-concept (SC), <i>M</i> = 0.70	<i>F</i> (1, 48) = 0.03, <i>p</i> = 0.865																											
	CG	29	0.75	0.02	0.72	0.01			General cognitive load (GCL)	TG	23	0.34	0.07	–	–	No correlating variables	<i>F</i> (1, 50) = 2.52, <i>p</i> = 0.119	CG	29	0.37	0.06	–	–												
General cognitive load (GCL)	TG	23	0.34	0.07	–	–	No correlating variables	<i>F</i> (1, 50) = 2.52, <i>p</i> = 0.119																											
	CG	29	0.37	0.06	–	–																													

The current study provided evidence for the research question, if a higher learning efficacy can be achieved by using video analysis with tablets in comparison with traditional physics classes. These findings are limited to the specific learning situation concerning pendulum movements in a specific sample (specialized courses of the German “Gymnasium”). Furthermore, the test instrument used to measure cognitive load did not allow a differentiation of the three different categories of cognitive load. This was caused by the aim of replicating effects of the original study and so using the same measures as before. Like this, the expected reduction of extraneous cognitive load by relieving learners of tasks which are irrelevant for learning by using video analysis could not be measured. The dependence of the efficiency of using video analysis from the amount of intrinsic cognitive load could neither be investigated. This methodological deficit will be resolved in follow-up studies by using an instrument after Leppink et al. (2013), with which Becker et al. (2019a) were already able to prove the reduction of ECL for the use of mobile video analysis in another physical context. Nevertheless, this study shows the vast potential of using tablets as experimental tools. Further research might concern different topics of mechanics or other areas of physics and different target groups. As Hochberg et al. (2018) showed that METs have the potential to promote especially the interest of originally less interested students, it may be advantageous to study mobile video analysis with tablets in samples of lower academic levels. Furthermore, the full potential of METs has not been used to full capacity in this study: The fact that they are mobile. Knowing that there are advantageous effects of using METs for mobile video analysis in the classroom of regular physics classes, subsequent studies may investigate the effects of analyzing movements in everyday life in their authentic context on interest, curiosity, and learning achievement.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest. All procedures performed in studies involving human participants were in accordance

with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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