The effect of metacognitive training and prompting on learning success in simulation-based physics learning

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Abstract
Computer-based simulations are of particular interest to physics learning because they allow learners to actively manipulate graphical visualizations of complex phenomena. However, learning with simulations requires supportive elements to scaffold learners’ activities. Thus, our motivation was to investigate whether direct or indirect metacognitive scaffolding (i.e., training and prompting, respectively) or a combination of both during simulation-based learning leads to better learning outcomes compared to simulation-based learning alone. Employing a 2 × 2 factorial design (N = 99 Austrian secondary school students), we explored the role of metacognitive training prior to the use of simulations and the role of metacognitive prompting during the learning phase. Four different conditions were compared in relation to knowledge about the principle of energy conservation. A pre- and posttest assessing knowledge acquisition, metacognitive behavior, cognitive load, and mental effort was applied. At first glance, the results indicate no main effects for training and prompting, and no interaction effect. A closer look at the actual use of prompting after the empirical data were obtained, however, reveals a significant impact of the metacognitive strategies employed on performance in the posttest, with higher scores in the condition where appropriate prompting was used. This result emphasizes the importance of guidance during simulation-based learning.

KEYWORDS
interactive, learning environments, metacognition, physics learning, simulation-based Learning

1 | INTRODUCTION

Learners in science education often have to deal with complex concepts or processes that are frequently considered difficult to grasp. Digital technologies can help to facilitate knowledge acquisition and understanding in this context.
However, such computer-based learning environments usually include constructivist elements and often require learners to accept a high level of individual responsibility regarding their own learning process. Thus, learners must also regulate their own learning process. The present paper focuses on the application of different supportive elements to foster learners' self-regulation during learning with digital technology. More precisely, we investigate the application of metacognitive training and prompting during computer simulations, as they represent a powerful tool for learners to gain deeper insights into the principle of energy conservation—a central concept in physics.

Simulation-based learning is an educational method that is widely used by educators in different fields. Learners can actively explore domain-specific principles by changing input variables within graphically visualized models (de Jong, 1991). As a consequence, it is assumed that simulation-based learning allows learners to develop adequate mental models of complex systems (de Jong & van Joolingen, 1998; Sarabando, Cravino, & Soares, 2014), along with proper higher order thinking and research skills (Chang, Chen, Lin, & Sung, 2008; Monaghan & Clement, 1999). One advantage of simulations can be seen in the opportunity to present simplified external visualizations of phenomena that cannot be easily observed. Compared to other educational media such as textbooks or animations, opportunities for learners to interactively manipulate different scientific variables and observe the results in graphical representations like graphs or tables are crucial for knowledge acquisition. According to Jimoyiannis and Komis (2001), simulations should enable learners (1) to develop a deeper understanding of phenomena and domain-specific laws, (2) to isolate and manipulate certain parameters, (3) to employ different representations that visualize the process, (4) to express mental models and representations, and (5) to investigate processes or systems that would otherwise not be observable or manipulable. Thus, according to de Jong and van Joolingen (1998), learning with computer simulations is closely related to scientific discovery learning and also to inquiry learning (see Van Joolingen, de Jong, & Dimitrakopoulou, 2007). It can help learners to formulate scientific questions, generate hypotheses, collect data, and redefine theories. Furthermore, the use of simulations has positive motivational aspects (Rutten, van Joolingen, & van der Veen, 2012).

Nevertheless, several studies have found that simulation-based learning as a form of discovery learning needs supportive elements to scaffold learners' activities to enhance learning (de Jong & van Joolingen, 1998; Patwardhan & Murthy, 2015; Rutten et al., 2012; Sarabando et al., 2014; Yaman, Nerdel, & Bayrhuber, 2008). Consequently, the present paper focuses on investigating different forms of scaffolding the learning process during simulation-based learning. (Meta-)cognitive processes play a central role in this respect (Borgenheimer & Weber, 2010; de Jong & van Joolingen, 1998; Zhang, Chen, Sun, & Reid, 2004). Hence, one goal of the present study is to investigate how the use and support of metacognitive and cognitive strategies foster knowledge acquisition during simulation-based learning.

In the following sections, we start out by introducing the domain of simulation-based learning, subsequently placing particular emphasis on simulations dedicated to physics-related content. Afterward, we explain metacognition and describe several metacognitive scaffolds for learning. To bring those issues together, we take a closer look on simulation-based learning with a special focus on the opportunities it provides to support the learning process.

2 | SIMULATION-BASED LEARNING

Computer-based simulations for education purposes have become a relevant part of teaching, especially in natural sciences such as chemistry, biology, or physics (Blake & Scanlon, 2007; Rutten et al., 2012). Generally, simulations are devoted to the graphical visualization of complex processes or systems. De Jong and van Joolingen (1998), for example, define a computer simulation as “(...) a program that contains a model of a system (natural or artificial; e.g., equipment) or a process” (p. 180). Merchant, Goetz, Cifuentes, Keeney-Kennicutt, and Davis (2014) similarly see simulations as “(...) interactive digital learning environments that imitate a real-world process or situation” (p. 30). The educational intention of simulations is to “(...) encourage[s] students to explore and interact with the system by including elements in the world, changing parameters and observing the result of this manipulation” (Esquembre, 2002, p. 15).

The intentional advantages of computer simulations are manifold and are expected in various fields. Simulations are supposed to enable the learner to understand and predict complex processes or to investigate and observe
certain effects by manipulating diverse variables within the simulated environment. To make use of those advantages, the instructional usage of computer simulations for learning purposes should comprise the following four characteristics: (1) presence of a formalized model that can be manipulated, (2) presence of learning goals, (3) elicitation of specific learning processes, and (4) presence of learner activity (de Jong, 1991).

The opportunity to visualize complex processes is one reason for using interactive simulations in science education. Furthermore, in some domains, the use of simulations is advisable due to time or cost restraints or to prevent exposure to hazards (de Jong, 1991). In other situations, simulations might also be used for ethical reasons, for example, when animals are dissected in classrooms virtually instead of in real-life experiments (Akpan & Andre, 2000).

In science education, the acquisition of conceptual understanding and fluency in experimental processes (e.g., selecting variables to be observed, repeating measurements, or drawing conclusions) is a central goal related to the use of simulations. Research results of Schreiber, Theyßen, and Schecker (2014) indicate that tests with simulated experiments can potentially replace tests with hands-on experiments as setting them and performing measurements require less competencies. In physics education, for example, computer simulations offer the possibility to directly observe phenomena and constructs like kinetic energy, and to isolate effects such as friction, or to virtually turn them on or off at will (Marshall & Young, 2006). Thus, learning processes in the domain of physics are frequently supported by means of simulations (Trundle & Bell, 2010). The following section provides a summary of research findings and conclusions related to simulation-based physics learning.

2.1 Simulations in physics learning

Jimoyiannis and Komis (2001) point out that “Physics is one of the first areas where the possibilities that computers may offer for the employment of new teaching methods have been and are still explored” (pp. 184–185). As a result, the use of computers in physics education has a long tradition (Esquembre, 2002). In particular, simulations are “…applications of special interest in physics teaching because they can support powerful modeling environments involving physics concepts and processes” (Jimoyiannis & Komis, 2001, p. 183). As a consequence, “…simulation environments offer the possibility that students will be able to test hypotheses more deliberately and systematically, and also reach more robust conclusions, particularly for complicated phenomena in which many different effects come into play” (Marshall & Young, 2006). Computer simulations in the domain of physics have also become available for a broad audience online (e.g., Physlets; University of Colorado Boulder, 2015).

Zacharia and Olympiou (2011) showed that virtual manipulation is as valuable as physical manipulation for learning about heat and temperature concepts. Jimoyiannis and Komis (2001) demonstrate that traditional classes combined with computer simulations about the concept of velocity and acceleration in projectile motions have led to higher learning outcomes compared to traditional classes only. Their results also indicate that simulations can help students to confront their cognitive constraints and change their misconceptions to develop a better understanding of physical concepts. Sarabando et al. (2014) compared the learning progress of students about the concepts of mass and weight in three different scenarios: computer simulation only, hands-on experiment only, and a combination of both. They found that learning outcomes were stronger in the computer simulation conditions (on their own or combined with hands-on experiments) than in the hands-on activities only. Trundle and Bell (2010) worked with preservice teachers and found advantages for simulation-based observations of sequencing moon phases compared to real-life nature observations. No difference was found for conceptual change in the conceptions of moon shapes or the ability to draw scientific moon shapes. Zacharia and de Jong (2014) showed that undergraduate students’ conceptual understanding of electric circuits was comparable for virtual manipulatives and physical manipulatives (real instruments) in simple circuits. For complex circuits, students who used virtual manipulatives developed more appropriate models of the concept than students who used physical manipulatives. Finally, students who used virtual manipulatives first developed an appropriate model afterwards in the physical manipulatives phase.

Other studies are less promising. Winn et al. (2006) compared field experiments and simulated experiments on oceanographic concepts. The overall learning outcomes of undergraduate students showed no difference between the
two conditions. Marshall and Young (2006) even found simulations to be less effective when compared with traditional instruction and hands-on experiments.

While some studies did not find any advantages for simulation-based learning at all, or at least in particular knowledge domains (Marshall & Young, 2006; Winn et al., 2006), other results showed that computer simulations led to comparable or even greater learning outcomes compared to traditional methods (Akpan & Andre, 2000; Chang et al., 2008; Jimoyiannis & Komis, 2001; Sarabando et al., 2014; Trundle & Bell, 2010; Zacharia & Olympiou, 2011). Simulations visualizing invisible phenomena appear to be particularly beneficial (Rutten et al., 2012). In their meta-analysis, Rutten and colleagues (2012) found more positive results for conditions with simulations than for traditional methods, with effect sizes of up to 1.5 for learning outcomes, and above 2.0 for motivation and attitude. However, it seems implausible that simulations are generally effective in terms of knowledge acquisition, in particular without taking several influencing factors into account (Yaman et al., 2008).

Overall, the previously mentioned research indicates that use of simulations can also be beneficial for learning and understanding complex concepts in physics learning. However, learners might encounter several problems during learning with simulations. One such problem is the demand for a high level of control over one’s own learning process. This may pose a particular challenge for learners whose ability to regulate their own learning process is insufficient (de Jong & van Joolingen, 1998). Thus, the use of simulations per se does not result in better learning outcomes. As simulation-based learning represents a form of discovery learning, it benefits to a great extent from the availability of supportive elements. Supporting learners during simulation-based learning seems to be crucial for constant learning success, also in the domain of physics. In a study by Chang et al. (2008), high school physics students learned about optics either in a traditional lab or in a simulated lab. The authors found that simulation-based learning led to better learning outcomes than traditional laboratory learning when learning was supported, for example, by prompts related to experimental strategies. De Jong (1991) points out that simulation-based learning puts high cognitive demands on learners, which may result in inefficient learning processes. He stresses the need for learner support along with the simulation to avoid random strategy usage by the learners. Instructional support can be given by the computer system itself (see additional features assisting learners in a study by Patwardhan & Murthy, 2015, for example) or by teachers or tutors (Sarabando et al., 2014).

Overall, instructional support can enhance knowledge acquisition when using computer simulations for learning (de Jong & van Joolingen, 1998). Computer-based simulation learning implies particularly demanding requirements from learners’ metacognitive and cognitive abilities (Borgenheimer & Weber, 2010). Consequently, one method to support learning processes is the scaffolding of metacognitive and cognitive processes to avoid adverse learning behaviors. Those processes and strategies will be briefly introduced in Section 3.

3 | METACOGNITIONS AND METACOGNITIVE SCAFFOLDING

When learning with computer simulations, students need the ability of self-directed learning as well as awareness of their own learning processes (Eckhardt, Uhrahne, Conrad, & Harms, 2013). De Jong and van Joolingen (1998) found that students frequently experience difficulties with systematically applying adequate and goal-oriented strategies during simulation-based learning. Studies in related domains such as hypermedia learning also demonstrate that it is often difficult for learners to self-regulate their learning process (Lawless & Brown, 1997). Bannert (2007) found in her studies that students are frequently unsuccessful when learning with hypermedia. This is due to a lack of students’ spontaneous use of metacognitive activities during learning (Bannert, 2007; Bannert, Hildebrand, & Mengelkamp, 2009). Although students already possess knowledge about metacognitive learning strategies, they often fail to reliably apply these strategies in the appropriate situations (Artelt, 1999; Bannert et al., 2009). Borgenheimer and Weber (2010) further suggest that students might be unable to cope with the multitude of interactions offered by simulations.

This study is based on the assumption that students need to develop their expertise in using learning strategies, especially in using metacognitive strategies, to achieve better learning outcomes when learning with simulations. Thus,
to enhance learning, students need guidance or clear instructions on how to use these metacognitive strategies during the learning process. Because our study is primarily concerned with learning with simulations and metacognitive support, we briefly outline the concept of learning strategies while focusing in particular on metacognition and metacognitive strategies.

Learning strategies can be classified within three main categories: (1) cognitive strategies, (2) metacognitive strategies, and (3) resource management (Bannert, 2007). Cognitive strategies imply revision strategies (students try to integrate new information into their long-term memory by actively repeating it over and over; Wild, 2005), elaboration strategies (learning activities that integrate new information with existing information, for example, by establishing relations between new and old information or self-declaration), and organizational strategies (which comprise learning strategies for structuring complex information, for example, by creating charts or plots). Metacognitive strategies refer to learners’ ability to control cognitive processes and will be discussed later in this paper. Resource management is not truly a learning strategy, but rather a strategy that supports the learning processes. Kuhl (1987) sees resource management as a strategy for self-motivation, attention control, and time management.

A clear definition of metacognition is difficult to find. As pointed out by Flavell (1981, p. 37), it is a “fuzzy concept” that is defined differently depending on the research domain. Weinert (1987) regards metacognition as “(...) second-order cognitions: thoughts about thoughts, knowledge about knowledge, or reflections about actions” (p. 8). Hacker (1998) provides a concise definition of metacognition as thinking about thinking. Garner (1987) describes the differentiation between cognition and metacognition, stating that we need cognitive skills to perform a task, while metacognition is necessary to understand how the task was performed. Metacognitive thoughts are deliberate, tactical, intentional, goal-directed, and future-oriented mental behaviors that can be used to accomplish cognitive tasks (Flavell, 1981). Hacker (1998) differentiates these metacognitive thoughts into three ways of thinking: (1) what one knows (metacognitive knowledge), (2) what one is currently doing (metacognitive skill), and (3) what one’s current cognitive or affective state is (metacognitive experience).

Metacognitive strategies help students to control their learning process. They imply planning, monitoring, and controlling the learning processes (Bannert, 2007). Research assumes that regulation of cognition refers to a better use of attentional resources, a better use of existing strategies, and a greater awareness of comprehension breakdowns (Schraw, 1998). Students are, however, often unable to regulate their learning activities (Azevedo, 2009; Bannert & Mengelkamp, 2013), thus requiring guidance or instruction, especially in learning situations involving simulations. Bannert et al. (2009) argue that metacognitive support to increase students’ learning competence is more effective than systematic instruction.

One possibility to support metacognitive strategies through systematic instruction is to foster learners’ learning strategies. This can be done directly via training or indirectly via scripting, scaffolding, or prompting (Bannert, 2009; Friedrich & Mandl, 1997). Ideally, both training and prompting measures take place to support effective self-regulated learning (Friedrich & Mandl, 1997).

Training is aimed at conveying metacognitive strategies, their possible applications, and their effects (Bannert, 2004). Direct training helps learners to foster the process of developing effective learning strategies (Mandl & Friedrich, 1992). Bannert et al. (2009, p. 830) point out that “for students lacking metacognitive competence (so-called mediation deficit, e.g., Hasselhorn, 1995), direct training is necessary to extensively teach the metacognitive knowledge skills.” Effective training takes into account three general principles for effective metacognitive instruction, all of which are based on empirical research (Bannert & Mengelkamp, 2013, p. 173): (1) metacognitive instruction needs to be integrated into domain-specific instruction, (2) it is necessary to make learners aware of the application and benefits of all metacognitive strategies taught to consequently make them use these strategies spontaneously, and (3) students need enough training time so that they can implement and automatize the metacognitive activities learned (see also Bannert et al., 2009; Mandl & Friedrich, 1992). Results from training studies are generally very encouraging as they show positive outcomes after the training program (in particular regarding metacognitive knowledge and control: e.g., Lucangeli, Galderisi, & Cornoldi, 1995; text comprehension: Carretti, Caldarola, Tencati, & Cornoldi, 2014; Yuill & Oakhill, 1991; planning ability: Fritz & Hussy, 2001). However, students often already possess metacognitive skills but are unable to transfer them to new situations (e.g., Bannert et al., 2009; Hasselhorn, 1995; Weinert, 1987).
An adequate method to encourage students to use metacognitive strategies in this respect seems to be indirectly via prompts.

Bannert (2004) defines prompts as “(…) instructional measures integrated in the learning context which ask students to carry out specific metacognitive activities” (p. 2). Using instructional prompts, the intention is not to teach new information, but rather to “(…) support the recall and execution of students’ knowledge and skills” (Bannert, 2009, p. 140). Thus, students get precise instructions they should consider during the learning phase to draw their attention to certain aspects of the learning process (Bannert, 2009). This is crucial, because students often already possess metacognitive skills but fail to use them spontaneously (Artelt, 1999; Bannert et al., 2009). “Metacognitive prompts therefore seem to be an adequate measure which stimulates students to apply their skills during learning” (Bannert, 2007). Chi, Bassok, Lewis, Reimann, and Glaser (1989) found in their study that, when using prompts during the learning phase, students with prompting used self-declarations more often and achieved better learning outcomes than students without prompting. Bannert and Mengelkamp (2013) as well as Sonnenberg, Mengelkamp, Loudwin, and Bannert (2015) found that instructional support via prompts helps students to activate several learning strategies. Nevertheless, we have to note here that this “metacognitive prompting” might be likewise a misleading term. The prompting itself can fulfill two functions here: to genuinely activate metacognitive thinking processes (e.g., monitoring one’s own attentional processes) and to act as a metacognitive process itself that activates subsequent cognitive processes. Thus, metacognitive prompting or scaffolding enables metacognitive and cognitive processes.

3.1 Metacognitive scaffolding in simulation-based learning

As mentioned above, simulation-based learning, which is considered a form of inquiry learning, generally benefits from instructional support (de Jong & van Joolingen, 1998; Rutten et al., 2012; Patwardhan & Murthy, 2015; Sarabando et al., 2014; Yaman et al., 2008). A recent taxonomy by Zacharia and colleagues (2015) identified different types of support for computer-based inquiry learning environments, for example, giving students specific directions on what to do (prompts). Talking specifically about simulations, Chang and colleagues (2008) found five strategies to support simulation-based learning: (1) providing background knowledge, (2) helping learners to develop hypotheses, (3) helping learners to conduct experiments, (4) helping learners to interpret data, and (5) helping learners to regulate the learning process. Similar categories describing difficulties during scientific discovery learning can be found in the study of de Jong and van Joolingen (1998). Zhang et al. (2004) proposed a triple scheme with three spheres of learning support for learners using simulations: “(…) (a) interpretative support that helps learners with knowledge access as well as the generation of meaningful and integrative understandings; (b) experimental support that scaffolds learners in systematic and valid experimental activities; and (c) reflective support that increases learners’ self-awareness of the discovery processes and prompts their reflective abstraction and integration” (p. 269).

With regard to physics learning, Chang et al. (2008) examined the impact of supportive scaffolds during simulation-based learning on learning success. The authors found that the integration of experiment and hypothesis prompting during simulation-based learning about optics is more effective in terms of learning success than step guidance. This applies in particular to learners with stronger abstract reasoning skills. Nevertheless, the authors found only small to medium effects. They further emphasize the challenge of supporting learners without restricting their autonomy, which can be responsible for weaker learning outcomes. Zacharia and colleagues (2015) stress the superior value of metacognitive support in computer-supported inquiry learning about electric circuits compared to scaffolding content choices. Kim and Pedersen (2011) found that metacognitive scaffolds (e.g., self-questions) during learning with simulations dedicated to a biological topic led to better performance in students’ hypothesis development in comparison to their performance without support. Piksööt and Sarapuu (2015) demonstrated that students’ knowledge transfer can be enhanced by implementing question prompts during learning with web-based models of molecular genetics. Eckhardt, Urhahne, Conrad, and Harms (2013) compared two different instructional interventions in the domain of biology (water ecosystem). Students either received support during the data interpretation phase or during self-regulation of their learning process. The results indicate that students who received either instructional support for data analyses or for self-regulation achieved greater learning outcomes and experienced a lower
cognitive load than students who received both kinds of support. A study by Borgenheimer and Weber (2010) investigated the effect of prompts addressing specific activities of learners during simulation-based learning about electric circuits compared to prompts that foster the processing of new information. They conclude that a combination of action-oriented and process-oriented prompts was most beneficial for learning. With regard to the optimal timing of metacognitive support in simulation-based physics learning, Thillmann, Künsting, Wirth, and Leutner (2009) showed, for example, that prompting during the learning phase is more beneficial compared to prompting before the learning phase.

In summary, we can assume that scaffolding learning, in particular with regard to metacognitive processes, during simulation-based learning is valuable in terms of learning success. Especially in physics learning, a domain where simulation-based learning is widely adopted, it would be useful to gain further insights into the processes related to students’ learning about physics concepts and opportunities for fostering and supporting learning.

4 | APPLYING METACOGNITIVE SUPPORT IN PHYSICS EDUCATION: RESEARCH QUESTIONS AND HYPOTHESES

Physics education opens a broad range of content and its didactics. One central field that is fundamental in physics is the concept of interaction (Grimellinio-Tomasini, Pecori-Balandi, Pacca, & Villani, 1993). Following these authors, within the area of mechanics there are two major different approaches to interaction, namely conservation laws and Newton’s third law. Here, we focus on the first one, energy conservation. While Grimellinio-Tomasini et al. (1993) focus on collisions, we address a more basic issue of energy conservation with just a single body moving on a track. Although observing a single body is less complex than an interaction between bodies, a common and basic misconception here (and in other areas of energy conservation) is that energy is something that is created out of nothing. Another misconception refers to the belief that energy is something that can vanish. Students’ difficulties to understand energy conservation increases when collision (elastic and inelastic) is introduced (Villani & Pacca, 1990). Grimellinio-Tomasini et al. (1993) suggest, as an instructional consequence, that teachers should guide students to look on energy conservation in terms of cause and effect and to observe development over time. We assume here that the use of simulation software should be beneficial to support both of these views and help learners to create appropriate mental models beginning on a more basic level without collision by simply focusing on transformation of energy of a single body that moves on a track. Nevertheless, working with simulations in these areas need active information processing rather than a mere experimenting and observing without deeper elaboration. Here, metacognition is essential in starting, maintaining, and evaluating such active ways of information processing. Koch (2001) suggests training of metacognition to increase comprehension of physics texts. She was able to show that training to self-assess one’s own reading comprehension improves comprehension significantly compared to no such training. Nevertheless, training in metacognition is not always successful and can also result in learners’ resistance, especially when learners do not see the need for such instructional interventions (Jing, 2006). Training of metacognitions can be improved by providing incentives and feedback for learners (Miller & Geraci, 2011). Also, prompting of metacognitions can be more or less beneficial as Thillmann et al. (2009) showed. They used prompts either before learning, at an optimal stage during working with a simulated physics laboratory, or at a rather suboptimal stage during working the simulation. Results revealed that prompting during the learning phase is beneficial compared to prompting before the learning phase. There were no differences between optimized time of prompting and rather suboptimal time of prompting.

Taken together, research is ambiguous on the question how to support students’ learning by fostering metacognition. On the one hand, some research shows benefits of metacognitive training in physics teaching and learning (e.g., Koch, 2001), whereas some not (e.g., Jing, 2006). In addition, prompting of metacognition during working with simulations seems to be an effective instructional device when timed accurately (Thillmann et al., 2009). An open research question here is how metacognitive training might foster learning with simulations within the domain of energy conservation laws.
As shown above, students are faced with difficulties in understanding the concept of energy and its transitions between different types of energy. Thus, we assume that (1) using a simulation approach that enables active learning and (2) providing metacognitive support for learning with this simulation should foster knowledge acquisition and understanding within this domain.

Consequently, we assume that (Hypothesis 1) metacognitive training prior to learning with a simulation on energy conservation law will support learners in active information processing and monitoring of their learning progress and, thus, will lead to better learning outcomes than without such training.

We further assume (Hypothesis 2) that prompting of metacognitions will also support learners’ active information processing and lead to better learning outcomes.

Finally, we assume that there might be an interaction effect between training and prompting of metacognitions (Hypothesis 3). It is likely that learners with basic knowledge in the nature and use of metacognitive strategies might benefit more from prompting, because they already know what to do when asked to apply a metacognitive strategy. Thus, they will not experience the prompting as a kind of dual task (i.e., a task additional to learning with the simulation). This again should reduce their cognitive load, and highest learning outcomes among all compared experimental conditions should be expected within this group.

As prior knowledge of learning strategies might mediate the effect of the above-described scaffolding, we also take into account learners’ common use of learning strategies (Wild & Schiefele, 1994). Additionally, we were interested in motivational aspects that might influence the learning process, in particular the learners’ interest (Rheinberg, Vollmeyer, & Burns, 2001) and their perceived general and physics-related self-efficacy (Schöne, Dickhäuser, Spinath, & Steinsmeier-Pelster, 2002).

5 | METHOD

5.1 | Sample and experimental design

The participants were 99 students from two Austrian secondary schools with an average age of 13.23 years (SD = 0.77). Sixty students were female and 39 students were male. The study was conducted using a 2 × 2-factorial pre-/posttest experimental research design. We used a pretest to assess students’ prior knowledge. The posttest analyzed the effectiveness of simulation-based learning combined with direct (training) and indirect (prompting) metacognitive scaffolds, or a combination of both during simulation-based learning compared to simulation-based learning alone. Participants were randomly assigned to one of four conditions: simulation-based learning alone (SB, n = 26), simulation-based learning with metacognitive training (MT, n = 24), simulation-based learning with prompting (P, n = 25), and simulation-based learning with metacognitive training and prompting (MTP, n = 24).

5.2 | Material

All learners in this study learned about energy conservation via the interactive simulation-based program Energy Skate Park (University of Colorado Boulder, 2015; see Figure 1). The computer simulation offers opportunities to observe and control a virtual skateboarder on a ramp. Learners can explore the characteristics of energy by moving the skater on the half-pipe and letting him roll down. The interface allows users to select and manipulate several variables such as the skateboarder’s weight or the friction of the road. The simulation further demonstrates the relationship between kinetic, thermal, potential, and total energy as the skater moves. It is also possible to create one’s own tracks and half-pipes and to observe the changes in energy. The simulation also allows users to visualize the changes in the different forms of energy related to weight, friction, position, and speed in a bar or pie chart. The overall goal of the simulation is to illustrate that the total amount of energy remains constant but transforms from one form into another.
The instructional intervention comprised the following four groups:

1. The simulation-based only group (SB) learned about the principle of energy conservation via the simulation and received no additional support related to metacognitive strategies.

2. The metacognitive training group (MT) received paper-based metacognitive training on learning strategies prior to learning with the computer simulation. Within the training unit, learners were introduced to general metacognitive learning strategies, for example, planning and evaluating the learning process, summarizing, and self-questioning. Several cognitive strategies were presented as part of metacognitive scaffolding to increase learners’ awareness of when and how to use them during learning (e.g., making connections between topics, clarifying terms). As a result, learners gained a comprehensive overview of the learning process and related supportive strategies. Three times in total, learners were given paper-based information, including suggestions regarding different metacognitive strategies. To foster understanding and application of these strategies, learners had to rephrase them in their own words. The first training unit, for example, focused on the planning of learning processes and aimed at helping the students to obtain an overview of learning materials. The wording of the training unit was as follows (analogous translation from German): “Sometimes we are puzzled by too much information that is presented all at once. In such cases, it is often not easy to deal with large amounts of new knowledge. One strategy to cope with this issue would be to lean back and obtain a preliminary overview of the learning material. This will give you a general impression of the nature and amount of information presented. During this process, you could ask questions like “What is the central issue of the learning unit? Which terms are relevant for me? Do I already know some of them?” Subsequently, students were asked to rephrase the strategy in their own words (about four sentences). One student, for example, wrote: “First, you should find out the most relevant content. Then you should search for key terms. Further, you should try to connect the content to previously learned topics. This helps to get an overview over the learning material.”

Subsequent training units included further strategies and aspects directly related to the process and content of the simulation presented. An example of this is: “Please, write down a list with aspects you have not heard of before (like dynamics),” or “Try to explain several concepts in your own words (e.g., acceleration = the rate of change of velocity of an object with respect to time), or “Draw connections from the learning content presented (e.g., Have you ever dealt with the concept of motion? If yes, think about basic rules of motion. Is there a similar situation for skateboarding?).”
3. In the prompting group (P), the instructors interrupted learners four times for 2–3 minutes each during simulation-based learning. During those intervals, learners were asked to use several suggested metacognitive learning strategies to scaffold the learning process. The scaffolds consisted of process-oriented prompts that motivated students to engage with the previously presented learning contents (see Borgenheimer & Weber, 2010). Learners received paper-based materials enabling them to indicate which metacognitive or cognitive strategy they intended to use in this very moment (e.g., drafting an overview, taking notes of open questions, summarizing observations, and making connections). Afterward, they were asked to apply the strategies and state their own ideas about the learning content. The text of the scaffolds says (analogous translation from German): “During learning, using several learning strategies can help you to memorize new learning content. Please use at least one of the following strategies and write down your thoughts below. Please indicate which strategy/strategies you intend to use for the content presented during the simulation: (1) Lean back and obtain an overview of the learning environment. What does the learning material look like? (2) Think about content you understood and content you did not understand. (3) Rephrase in your own words central aspects from the domain of physics that you have previously heard of. (4) Try to make connections between several aspects of the learning content. (5) Link central aspects and thematic priorities of the new learning content and highlight their relationships. Please write down at least 4 sentences.” The idea behind this intervention was to foster learners’ application of learning strategies and to support an effective engagement with the simulation. One example of an answer from a student who used “drafting an overview” as strategy was “First I obtain an overview and watch the skateboarder going up and down the ramp. I am looking at all the possibilities for playing this game. I am taking a closer look at the design of the game and its background image (e.g., landscape).” Another student used the “summarizing observations” strategy and his/her answer was: “I understand now that the highest kinetic energy is at the lowest point of the ramp where thermal energy is the lowest. There is no potential energy at the lowest point of the ramp.”

4. The training and prompting group (MTP) received both metacognitive training prior to simulation-based learning and prompting during learning.

5.3 | Measures and instruments

First sociodemographic data (age, gender) and students’ recent grades in physics, mathematics, and German (which was the primary language of instruction in this study) were assessed. In the pretest phase, a test on knowledge about energy conservation, students’ use of learning strategies, their interest in learning content, and their academic self-concept were assessed. In the posttest phase, the knowledge test was reapplied along with measures of cognitive load, mental effort, and actual usage of prompting (for participants in the prompting condition). Please see Table 1, for example, items of each scale, number of items, and values of internal consistency.

5.3.1 | Knowledge about energy conservation

To assess knowledge acquisition and understanding of energy conservation, a knowledge pre- and posttest was developed. The test consisted of 12 multiple choice questions, three transfer questions, and one essay task (see Appendix). Before answering the questions, learners were given to read a short introduction: “Peter is an enthusiastic skateboarder. He rolls down the pictured ramp (half pipe). The ramp has a rather rough concrete surface. Peter just rolls down the ramp without pushing.” Afterward, several terms for different kinds of energy were explained along with a picture of the corresponding situations. Subsequently, questions on the described situation were posed, for example, “What will happen to the total energy when Peter rolls down the ramp?”. Four different answering options for each question were provided (plus one “I don’t know” option). Learners had to indicate the right answers to the multiple choice items and the transfer questions. Additionally, confidence about the answer given could be indicated on a 5-point rating scale (1 = totally confident that the answer is right; 5 = not confident at all that the answer is right). For the essay task, learners had to write down their understanding of kinetic, potential, and thermal energy, as well as the relation between the three. There was also an option for specifying physical formulas. Each multiple choice item and
the transfer questions were scored with one point. The essay task was scored with 4.50 points. Here, students were asked about the relationship between kinetic energy, potential energy, and thermal energy in relation to total energy. Those who knew related formulas were asked to write them down. For each explanation of total energy and/or formula (e.g., the total amount of energy in the system is calculated by adding up all forms of energy; the total amount of energy always stays the same: $E_{\text{tot}} = E_{\text{kin}} + E_{\text{pot}} + E_{\text{therm}}$), the answer was awarded with a score of one point. Half a point was given for additional explanations/formulas of $E_{\text{kin}}$, $E_{\text{pot}}$, and $E_{\text{therm}}$. Overall, participants could reach up to 20.50 points.

### 5.3.2 Common use of learning strategies

The LIST questionnaire for measuring students’ learning strategies (Wild & Schiefele, 1994) was applied to assess students’ common use of learning strategies. To keep the time of the test as short as necessary, only five subscales were included in the present study: four scales in connection with cognitive strategies (organization, elaboration, critical reviewing, and repeating) and one scale in connection with metacognitive strategies. Cognitive strategies cover methods related to processing and memorizing information directly. Metacognitive strategies focus on activities related to controlling the learning process. On a 5-point rating scale (1 = rarely; 5 = very often), participants indicated how often they used a particular strategy.

### 5.3.3 Interest

Participants’ interest in the topic and the related simulation-based activity was assessed via the Questionnaire on Current Motivation (QCM; Rheinberg et al., 2001). The QCM uses 18 items to measure anxiety, probability of success, interest, and challenge. In the present study, only the interest subscale comprising five items was applied.
5.3.4 | Academic self-concept

A questionnaire to measure participants’ academic self-concept was used (Academic Self-Concept Scales; SESSKO; Schöne et al., 2002). Three subscales assessed students’ general academic self-concept, mathematical self-concept, and self-concept in physics.

5.3.5 | Cognitive load and mental effort

Considering that training and prompting demand a certain amount of the learners’ cognitive resources, measuring cognitive load and mental effort was indicated. Thus, in the posttest phase, two instruments were applied to measure participants’ subjective cognitive load during the learning phase. First, an adapted version of the NASA-TLX (Task Load Index; Hart & Staveland, 1988) was used. The NASA-TLX consists of five self-report items (i.e., task requirements, effort in understanding the content, expectation of success, effort in navigation, and stress). Participants could indicate their answers on a 5-point rating scale (1 = completely disagree; 5 = completely agree). As a second instrument, the Mental Effort Rating Scale (Paas, van Merriënboer, & Adam, 1994) was employed to assess the mental effort participants invested in processing the learning material via a single item. Again, a 5-point rating scale was used (1 = make no effort at all; 5 = make a real effort).

5.4 | Procedure

After an initial introduction, students received general instructions related to the test and the procedure. Students were randomly assigned to the different conditions and were asked to sit down in front of a computer. To avoid any interference, the students in the prompting condition were tested in a computer room separate from the groups without prompting. Then, the pretest took place, followed by the questions on learning strategies and academic self-concept. Afterward, students with metacognitive training received the paper-based training materials. Meanwhile, students without training were asked to read a short text (fairytale) to ensure similar test durations. Subsequently, the simulation-based learning phase took place (each student had to interact with the simulation for about 20 minutes). Students in the prompting condition were interrupted four times for about 2 minutes each to apply several learning strategies. Students without prompting received another text (again a short fairytale) to read at the end to ensure similar test durations. Finally, the questions on cognitive load and mental effort were applied, as well as the knowledge posttest. Students in the prompting condition subsequently received the questions on their usage of learning strategies during the prompting phase. Overall, the experiment took about 90 minutes.

6 | RESULTS

An analysis of the descriptive data collected reveals that metacognitive training led to slightly increased performance in the knowledge posttest (see Table 2). The descriptive data also revealed that scaffolding via prompting tended to lead to increased performance in the knowledge posttest. Nevertheless, an ANCOVA (analysis of covariance) using participants’ performance in the knowledge pretest as the covariate neither showed any main effect for training ($F(1, 93) = 0.28, p = .60, \eta^2 = .00$) nor for prompting ($F(1, 93) = 0.01, p = .93, \eta^2 < .00$). The interaction was not statistically significant ($F(1, 93) = 1.24, p = .27, \eta^2 = .01$). Prior knowledge had a significant impact on participants’ performance in the knowledge posttest ($F(1, 93) = 38.72, p < .001, \eta^2 = .29$).

A closer look at how learners had used prompting in the corresponding condition revealed that there was a huge discrepancy among participants: while some had used prompting extensively and intensively, others did not use any prompting scaffold at all throughout the whole experiment or did not use them properly (e.g., by giving nonsense answers). Thus, we decided to slightly change our Hypothesis 2 and to re-code the independent variable of “prompting” by not using pure availability but rather the way in which it was actually used. As a result, our rephrased Hypothesis 2...
TABLE 2  Means (standard deviations) of dependent variables with original variable “prompting”

<table>
<thead>
<tr>
<th>Without Training</th>
<th>With Training</th>
<th>Without Prompting</th>
<th>With Prompting</th>
<th>Without Prompting</th>
<th>With Prompting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge pretest</td>
<td>6.12 (2.90)</td>
<td>6.44 (2.76)</td>
<td>7.73 (3.04)</td>
<td>5.65 (3.37)</td>
<td></td>
</tr>
<tr>
<td>Knowledge posttest</td>
<td>7.65 (2.95)</td>
<td>7.41 (3.93)</td>
<td>8.36 (3.51)</td>
<td>7.74 (3.93)</td>
<td></td>
</tr>
<tr>
<td>Self-confidence pretest</td>
<td>3.46 (0.56)</td>
<td>3.39 (0.94)</td>
<td>3.66 (0.73)</td>
<td>3.32 (0.90)</td>
<td></td>
</tr>
<tr>
<td>Self-confidence posttest</td>
<td>3.72 (0.63)</td>
<td>4.00 (0.82)</td>
<td>4.18 (0.66)</td>
<td>3.86 (1.07)</td>
<td></td>
</tr>
<tr>
<td>Cognitive load</td>
<td>2.62 (0.81)</td>
<td>2.83 (0.93)</td>
<td>2.92 (0.71)</td>
<td>2.63 (1.02)</td>
<td></td>
</tr>
<tr>
<td>Mental effort</td>
<td>2.38 (0.80)</td>
<td>2.83 (0.94)</td>
<td>2.77 (1.07)</td>
<td>2.78 (1.41)</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3  Revised prompting: examples for each coding category

<table>
<thead>
<tr>
<th>Category</th>
<th>Example strategy: drafting an overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>I read all the information. I will catch up on all the things I do not understand by the next physics lesson.</td>
</tr>
<tr>
<td>1</td>
<td>First, I gain an overview and watch the skateboarder going up and down the ramp. I am looking at all the possibilities how to play this game. I am taking a closer look at the design of the game and its background image (e.g., landscape).</td>
</tr>
<tr>
<td>2</td>
<td>First, I lean back and rethink the learning material. Thermal energy only exists if there is friction. Highest kinetic energy is shown at the lowest point of the ramp (0 m). Potential energy always exists, except at the lowest point of the ramp (0 m).</td>
</tr>
</tbody>
</table>

reads as follows: the actual use of prompting of metacognitions (prompting application) will support learners’ active information processing and monitoring of their learning progress and lead to better learning outcomes.

Therefore, we differentiated between participants using prompting in an appropriate manner and those who did not use this instructional device appropriately. Two examiners independently rated the students’ answers. Overall, 209 answers from 49 students in the prompting condition were recoded as 0 = insufficient, 1 = sufficient, 2 = very comprehensive. Students’ answers that did not fit within the concept of using metacognitive strategies and/or were related to the physics simulation were rated with 0 points. We awarded 1 point where students applied the strategy on a very general level to the physics content. Two points were given if their answers were more specific, indicating a thorough use of the strategy (e.g., using the right terminology, making connections to prior knowledge, see Table 3 for examples). Good interrater reliability was found. The average measure ICC was 0.89 with a 95% confidence interval from 0.86 to 0.92 (F(203,203) = 9.19, p < .001), indicating little variation between the scores given by the examiners.

Finally, we computed an overall mean value of the four times prompting was provided for each person. Students with less than 4 points were identified as students who did not actually apply the prompts, and students with 4 or more points were categorized as students who actually applied the prompts in an appropriate manner. Overall, 20 participants remained in the condition where prompts were actually applied.

A MANCOVA (multivariate analysis of covariance) was computed using the independent variables of “training” and the recoded “prompting application.” Dependent measures were the performance in the knowledge posttest, learners’ self-confidence related to their knowledge in the posttest, cognitive load, and mental effort. Performance in the knowledge pretest and participants’ self-confidence were used as covariates. Again, there was no significant main effect for training (F(4, 85) = 0.12, p = .970, η² = .01) and no significant interaction (F(4, 85) = 0.30, p = .880, η² = .01). With the recoded independent variable of prompting application, there was a significant main effect (F(4, 85) = 3.91, p = .006, η² = .16). For descriptive values, please see Table 4.

A closer look on the single dependent variables revealed that prompting application had a significant impact on performance in the knowledge posttest, with higher scores in the condition where prompting was actually used in an appropriate manner (F(1, 88) = 5.24, p = .025, η² = .06; see Figure 2).
In addition, prompting application led to higher values related to participants’ self-confidence here ($F(1, 88) = 11.34, p = .001, \eta^2 = .11$; see Figure 3). There were no significant effects on cognitive load ($F(1, 88) = 2.03, p = .160, \eta^2 = .02$) or mental effort ($F(1, 88) = 0.55, p = .500, \eta^2 = .01$).

The covariates also showed significance in this model (self-confidence pretest: $F(4, 85) = 8.12, p < .001, \eta^2 = .28$; performance in the knowledge pretest: $F(4, 85) = 8.71, p < .001, \eta^2 = .29$). A univariate analysis revealed that the higher participants’ self-confidence was in the knowledge pretest, the higher their self-confidence in the knowledge posttest ($F(1, 88) = 31.01, p < .001, \eta^2 = .26; r = .61, p < .001$). There was no significant impact of self-confidence as a covariate on the other dependent variables. Performance in the knowledge pretest had an impact on participants’ performance in the knowledge posttest as well as self-confidence in the posttest assessment. The better the performance in the pretest, the better the performance in the posttest ($F(1, 88) = 28.47, p < .001, \eta^2 = .24; r = .54, p < .001$) and the higher participants’ self-confidence ($F(1, 88) = 10.10, p = .002, \eta^2 = .10; r = .55, p < .001$). Other dependent variables were not significantly influenced by this covariate.

In a subsequent analysis, we additionally analyzed the influence of different learner characteristics related to metacognition on knowledge acquisition. We therefore conducted a stepwise regression analysis using performance in the knowledge posttest as a dependent variable and participants’ common use of cognitive and metacognitive strategies (organization, elaboration, critical reviewing, repeating, and metacognitive strategies; assessed by means of the LIST questionnaire; see above), prior knowledge, subject matter interest, ability self-concept (general and physics related), prompting application, and cognitive load as predictors. The resulting model was statistically significant ($R^2$...
FIGURE 3  Group differences in self-confidence in the pre- and posttest

= 0.41; F(2, 40) = 13.95, p < .001) but revealed only two significant predictors: prior knowledge (β = .45; t = 3.60, p = .001) and prompting application (β = .36; t = 2.86, p = .007). All other assumed predictors proved not to be significant. Thus, the model suggests that the higher prior knowledge and the more intensive metacognitive prompts are used, the more likely a better performance in the knowledge posttest.

DISCUSSION

In this experiment, we analyzed in great detail the application and influence of different scaffolds supporting metacognitive processes during simulation-based learning. We employed training and/or prompting of various metacognitive strategies to strengthen learners’ self-regulative abilities. In the present study, the application of these strategies was aimed at fostering learning and understanding of the law of energy conservation in the domain of physics. The learning material used was a simulation that enabled learners to investigate the relationship between potential energy, kinetic energy, and friction, and to understand that energy is not “lost” but rather undergoes a transition to different states (e.g., from potential energy to kinetic energy and vice versa or to heat energy). Based on extensive empirical research, the key aim of this study was to examine different strategies on how to foster knowledge acquisition during learning with simulations. While some research on the use of simulations in the physics classroom revealed a number of benefits of these instructional devices (e.g., Zacharia & de Jong, 2014), other research suggests that additional instructional support is necessary to support learners and to ensure that they benefit from the use of simulations (e.g., Chang et al., 2008; Marshall & Young, 2006; Winn et al., 2006). While almost all of these supporting mechanisms remain on a cognitive level, the approach of this research in fostering metacognitive processes during learning with and from simulations is rather rare and, thus, innovative.

With regard to prior research, we assumed that both interventions (i.e., training and prompting) we chose here should contribute to fostering metacognitive activities. These metacognitive activities should, in turn, support rather active information processing and thus lead to better learning outcomes. Our first hypothesis was that metacognitive skills training should have an impact on knowledge acquisition. Nevertheless, our findings showed that metacognitive training had no significant impact on the results in the knowledge posttest. This is rather surprising, as the training unit was closely related to the learning content of the simulation, asked students to actively process the strategies, and highlighted why it is beneficial for students to use metacognitive strategies during learning. However, this lack of effect can be explained as follows: First, the training was introduced into certain basic metacognitive strategies in compressed form. This may have led to a rather superficial processing of the training contents and to rather inert
knowledge, meaning that students were unable to transfer these strategies from the training to the learning phase. Findings with regard to the effectiveness of such trainings are likewise ambiguous. While some trainings conducted over a far longer time period have shown to be effective (e.g., Koch, 2001), other studies found no or even a negative impact of such approaches (Jing, 2006). With regard to our findings, students most likely failed to either deeply process the information provided during metacognitive training and were either unable or unwilling to apply this knowledge to their learning supported by the simulation. Further, training over an extended period of time might have been beneficial (Bannert & Mengelkamp, 2013). This may also be the reason for the lack of an interaction effect between the two independent variables of training and prompting (Hypothesis 3). There was no interaction between the ineffective training applied in this study and metacognitive prompting.

With regard to the use of prompting in this study (Hypothesis 2), we found that prompting of metacognitive strategies per se did not automatically lead to better learning outcomes. A closer analysis of the ways in which and the frequency with which students used prompting revealed that only those students benefitted from this treatment who (1) made the most out of the prompts (e.g., by taking elaborate notes) and (2) used them regularly. Students who fulfilled both conditions demonstrated a better understanding of the basic ideas of the simulation and of the law of energy conservation. The application of the prompted metacognitive strategies might also be an indicator that these students processed information rather actively, supported and maintained by metacognitive promptings. This is also in line with prior research, showing that prompting as part of learning by means of a physics simulation can contribute to fostering knowledge acquisition (e.g., Borgenheimer & Weber, 2010; Chang et al., 2008; Thillmann et al., 2009). Interestingly, again no interaction effect was found between the application of training and prompting. Thus, Hypothesis 3 is unsupported also with regard to the actual use of prompting. Prior knowledge about learning strategies did not interact with the application of prompting, nor did it lead to a more adequate use of promptings, for example. Additionally, the difference compared to most other studies, which have used metacognitive prompting, is that we not only provided this instructional device but analyzed how learners actually used it and linked these usage patterns to learning outcomes. This was also part of the regression analysis we applied. It revealed that none of the possible predictors such as metacognitive abilities (i.e., students’ common use of cognitive strategies such as organization, elaboration, critical reviewing, and repeating), metacognitive strategies, subject matter interest, ability self-concept (general and physics related), and cognitive load were able to predict learning outcomes. Only prompting application and students’ prior knowledge provided a significant model explaining the 41% of variance. At a first glance, this might not be surprising, as prior knowledge has been shown to be one of the strongest predictors of learning success (cf. Hattie, 2009). What did come as a surprise, however, was that prompting and the application of this instructional device was a stronger predictor than ability self-concept or the common use of learning strategies. This result emphasizes the role of guidance during the learning process instead of relying on attitude-based learner characteristics. Instructional materials, that is, the simulation of a skateboarder to illustrate the basics of energy conservation law in the present study, should be designed as diligently and as supportively as possible. There is still potential for such tools to support learners. However, as demonstrated in our study, the effectiveness of that support depends on learners’ acceptance of the tools offered as prompting only proved to be beneficial to those students who had used it as intended. In our experiment, learners were given the opportunity to take an active, self-regulated, and reflected approach to the learning process. The computer simulation provided possibilities for learners to explore the characteristics of energy. Learners could select and manipulate several variables such as weight or friction to learn about the relationship between kinetic, thermal, potential, and total energy as the skater moves. Furthermore, learners could observe the changes in energy. Different visualizations were presented to allow learners to understand that the amount of energy remains constant but transforms from one form into another. Learners who used the promptings efficiently did not simply choose random strategies and “play” with the skateboarder in the simulation. Prompting appears to have encouraged them to obtain an overview of the different possibilities of the simulation (e.g., different visualizations of the various kinds of energy) and to engage with the relationships between different parameters and the transformation of energy from one type to another. As shown in Table 3, some learners demonstrated better application of the prompts and linked the strategies to the current learning content. Apparently, this enabled them to understand the principles beyond by accepting the intended prompts and using them actively.
However, we have to mention several limitations of our study. First, the present study was conducted using content from the domain of physics. Although we assume that our findings are also applicable to related domains, future research should look at other topics for which the use of simulations is indicated (e.g., chemistry or biology) to arrive at more generalizable assumptions. Second, the study was limited to participants from secondary schools. It would be beneficial to repeat the study with a different sample, for example, younger or older students with different prior knowledge and abilities. Additionally, we investigated short-term effects via knowledge tests applied directly after the intervention. It would be of further interest to investigate possible long-term effects of scaffolding. Further limitations are associated with the fact that the main result has been obtained after slightly modifying Hypothesis 2, following the reexamination of the obtained data. An additional investigation carried out on the basis of the modified Hypothesis 2 before obtaining the empirical data might be of advantage for the validation of the results. Further research might also explore the ways in which students actually use prompting in greater detail, resulting in deeper insights into aspects that make prompting appropriate and effective. Not just the mere possibility of using scaffolds, but learners’ effective use of supportive elements is crucial when providing scaffolds. As a practical result of the research presented here, we conclude that applications requiring learners to stop during the learning process and actually make use of the supportive elements provided before continuing might be one way to do so. In our case, the prompts actually asked students to apply several strategies. However, it appears as though it was too easy for them to skip this step. A particular challenge in this respect, however, is to keep the balance between guiding the learning process and maintaining a self-regulated learning experience.

8 | CONCLUSION

In conclusion, we would like to point out that the results from the present study provide us with supportive evidence that scaffolding of metacognitive strategies can be helpful to learners during simulation-based physics learning. Our analyses indicate that metacognitive prompting in particular has a positive effect on learning with simulations, provided that learners use prompts in an appropriate manner. Consequently, we recommend that researchers and instructors not only provide scaffolds for simulation-based learning, but that they additionally ensure that learners use the support offered to them in an appropriate and therefore effective manner.

REFERENCES


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**APPENDIX**

Knowledge Test

Dear student,

We are pleased that you participate in our survey!

Participation is voluntary and anonymous.

Do you have any questions? If so, please ask now. If not, we’ll start now.

First, we would like to ask you for some general information.

You are □ a girl  □ a boy

How old are you? _______ Years

What grade did you get last year in  German _____,  Mathematics _____,  Physics _____?
Please read the following information carefully:

Peter is a passionate skater. He drives down the halfpipe that is presented in the picture below. The ramp has a rough surface. Peter rolls down the ramp on the skateboard without pushing.

Please note:

Potential energy = energy caused by change in height
Kinetic energy = energy caused by motion
Thermal energy = energy caused by friction (warmth)

Please indicate the right answers in the following. (There is only one right answer). You can also indicate if you do not know the answer and how certain you are about your answer.

1. The higher Peter stands on the ramp,
   - the lower the potential energy.
   - the higher the potential energy.
   - the higher the thermal energy.
   - the lower the thermal energy.
   - I don’t know

2. Compared to the bottom of the ramp, on top of the ramp Peter has
   - a maximum of potential energy.
   - a maximum of thermal energy.
   - a maximum of kinetic energy.
   - a minimum of potential energy.
   - I don’t know.

3. On the top of the ramp, the kinetic energy of Peter
   - equals zero.
   - is the same as the thermal energy.
   - is at its peak.
   - equals potential energy.
   - I don’t know.
4. On the way down the ramp
- potential energy becomes larger.
- kinetic energy becomes larger.
- thermal energy decreases.
- all three energies become larger.
- I don’t know.

5. What happens to the total energy while Peter rolls down the ramp?
- It becomes larger.
- It stays the same.
- It declines.
- It equals zero.
- I don’t know.

6. The higher Peter’s weight,
- the smaller the potential energy, but the higher the kinetic energy.
- the higher the potential energy, but the lower the kinetic energy.
- the lower the total energy.
- the higher the total energy.
- I don’t know.

7. The smoother the surface of the ramp, the lower the friction, and consequently
- Peter is faster.
- Peter is slower.
- there is no influence.
- total energy is higher.
- I don’t know.

8. On the way down, the total energy consists of
- solely potential energy.
- solely kinetic energy.
- solely thermal energy.
- potential, kinetic and thermal energy.
- I don’t know.

9. On the other side of the ramp, Peter reaches a lower height than he started at. Why?
- Due to declining total energy.
- Due to friction.
- Due to the wear of the tyres.
- None of the previous three answers is right.
- I don’t know.
10. When kinetic energy is at its highest level, Peter is
  o at the lowest point of the ramp.
  o at the highest point of the ramp.
  o halfway up.
  o It does not matter where Peter is because kinetic energy stays the same.
  o I don’t know.

11. Assume, Peter’s ride is frictionless, because the ramp is new and has an extremely smooth surface. In this case total energy:
  o stays the same.
  o declines.
  o grows.
  o equals zero.
  o I don’t know.

12. During a ride on a surface without friction, thermal energy
  o grows.
  o declines.
  o stays the same.
  o is always zero.
  o I don’t know.

13. Below you see a wrecking ball, about to crush the house. Please indicate with a cross, the point/points on the ball’s path where it has the highest kinetic energy.
  o I don’t know.
14. A hunter shoots a lead bullet with his gun straight up in the air. What is the velocity of the bullet, on its way down as it passes the level of the rifle?

- Same as when leaving the rifle.
- Slower than when leaving the rifle, because air resistance reduces kinetic energy.
- Higher than when leaving the rifle.
- Significantly higher than when leaving the rifle, because gravitational force is so strong.

- I don’t know.

Please indicate: How certain are you about your answer?

\[ \square \square \square \square \square \square \]

Very certain  rather certain neutral  rather uncertain  not certain at all

15. A sledge starts from a hill. Please indicate the point/points where the sledge has potential AND kinetic energy. (A, B, C, D and/or E).

- I don’t know.

Please indicate: How certain are you about your answer?

\[ \square \square \square \square \square \square \]

Very certain  rather certain neutral  rather uncertain  not certain at all

Please answer in your own words.

16. What is the relationship between kinetic energy, potential energy, and thermal energy in relation to total energy. In case you know formulas, please write them down.

- I don’t know.

Please indicate: How certain are you about your answer?

\[ \square \square \square \square \square \square \]

Very certain  rather certain neutral  rather uncertain  not certain at all

Thank you for your participation!