

Article

Effects of Pedagogical Agents on Learners' Knowledge Acquisition and Motivation in Digital Learning Environments

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Abstract: We assume that learners generate self-reference to a topic dealt with in class through motivational prompts of a pedagogical agent (PA). This assumption is based on self-determination theory and organismic integration theory. Consequently, learners are more motivated and achieve better learning results. We examined the influence of motivational prompts on learning success and motivation in a digital learning environment. Therefore, we implemented a PA within a web-based learning environment in order to scaffold learners' autonomous motivation. In an experimental pre-post design ($n = 60$), learning success and motivation were analyzed comparing learning environments with and without PA/prompting. Results suggest that learners with a PA reach a higher level of knowledge than learners without a PA. There was no significant influence of motivational prompts on motivation itself. The limitations and conclusions of this study are discussed.

Keywords: motivation; online learning; scaffolding; self-determination theory

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1. Introduction

Learning with interactive media requires self-directed learning as well as awareness of learning processes. Nevertheless, students frequently experience difficulties with systematically applying adequate and goal-oriented strategies during web-based learning. It is often difficult for learners to self-regulate their learning process, which does not only affect cognitive and metacognitive learning strategies, but also motivation and motivational strategies. This study is based on the assumption that learners need to develop their own expertise in using learning strategies. Consequently, motivational strategies (in addition to cognitive and metacognitive strategies) are of significant importance concerning highly motivated learning and achieving better learning outcomes during self-regulated learning.

2. Theoretical Framework

2.1. Self-Regulated Learning

Self-Regulated Learning (SRL) is considered a key element of academic achievement and lifelong learning [1–3]. From a socio-cognitive point of view, the concept of *self-regulation* describes the interaction and regulation of cognition, performance, and environmental factors while learning. Pintrich [4] describes SRL as an active and constructive process enabling learners to activate volitional control in order to monitor their learning behavior and to regulate their actions and thoughts towards a certain goal. In contrast to the cognitive orientation of metacognitive frameworks, self-regulation emphasizes the behavioral and emotional aspects of learning [5]. Therefore, Zimmerman's model [6] takes cognitive and metacognitive as well as emotional and motivational components of SRL into account. This theory sees SRL as a proactive action phase with learners controlling (meta-) cognitive, motivational, and behavioral processes.

(Self) Regulation provides the basis for most purposeful actions; hence, either hierarchical or process-oriented models are proposed in order to describe SRL. In her framework, Boekaerts [7] suggests that the basis of SRL consists of three components: regulation of the learning processes, regulation of the self, and monitoring of learning behavior. Based on this assumption, Pintrich's hierarchical model [4] suggests that these fundamental processes can be further divided into four types of self-regulated activities (forethought planning, monitoring, control, and reaction). On the one hand, the hierarchical structure of these processes describes learning processes in strongly guided learning activities; on the other hand, the order of these phases may shift during individual learning in multimedia environments [8]. In contrast to the rather static hierarchical model, Zimmerman [9] describes self-regulation as a process consisting of three cyclical phases: the preparation phase, the action phase, and the self-reflection phase. Therefore, self-oriented feedback loops (behavioral self-regulation, environmental self-regulation, covert self-regulation) are used, enabling learners to improve their learning. Reflecting on their own learning activities allows for monitoring efficiency and adapting learning behavior. Consequently, Azevedo [10] assumes that novice learners' limited knowledge gain during SRL may be due to inadequate self-regulation skills. Therefore, receiving feedback is a major factor in improving learning performance.

2.2. Motivation

Motivating learners and keeping them motivated during learning is an important challenge. However, especially in unguided multimedia environments, where learners need to take responsibility for their own learning process, motivation is central for successful learning. In general, the concept of *learning motivation* describes the intention of an individual of acquiring new information and specific skills and reaching certain learning goals. Thus, learners' motivation can either be influenced by intrinsic or extrinsic factors [11–14]. While intrinsically motivated learning processes are driven by internal rewards, extrinsically motivated learning relies on external motives, such as praise from parents, good grades, or avoiding punishment [13,15,16]. Although both motivational concepts can improve SRL, intrinsic motivation is assumed to be a stronger predictor for long-lasting and high engagement in learning activities [17,18].

2.2.1. Self-Determination Theory of Motivation

In addition to intrinsically and extrinsically motivated behavior, the *Self-Determination Theory of Motivation* [19] describes different sources and types of motivation that form an individual's personality. This macro-theory focuses on the interaction of goal- and self-determined actions [20]. That is, a person's decision to complete an action is influenced by environmental aspects. In order to describe the interaction of motivation, personality, and environment, five mini theories were established. In accordance with the thematic orientation of this study, the fundamental aspects of two sub-categories, the Organismic Integration Theory (OIT) and the Basic Psychological Needs Theory (BPNT), are discussed [21].

In order to highlight learners' interaction with their environment, OIT discusses the shift of externally controlled motives to autonomous motivations. This theory assumes that an individual's motivation is determined by the degree of external determination and self-determination involved in an action. The degree of self-determination is decisive for learners' motivation, i.e., a higher level of autonomy leads to a higher level of motivation. However, controlled motivation may also, up to a certain degree, be self-determined. Due to different socializing processes, foreign behavioral structures can be adopted by an individual and be integrated into their personality structure. Consequently, learning environments that support autonomy are of central importance, since the degree of self-determination influences learners' motivation [22].

While OIT highlights the development of motivation and self-regulation through the influence of environmental aspects, BPNT describes the effects of social environments on

autonomous motivation. BPNT states that there are three basic needs (autonomy, competence, relatedness), which need to be satisfied in order to enable development, integrity and well-being. Therefore, autonomous motivation can only be improved if these basic requirements are met [23–26]. However, not satisfying these needs may result in frustration, academic failure, or low integrity [21].

Learning environments that support learners' self-regulation need to be established in order to meet learners' basic needs and to enhance autonomous motivation. Multimedia tasks support students' autonomous motivation via navigating autonomously through scholarly contents, interacting, and collaborating with others. In addition, feeling competent also plays a central role in learning. That is, knowledge gain can only be achieved if task complexity is congruent with learners' cognitive capacity. Sometimes technical support is necessary, because multimedia learning environments usually impose a high extraneous cognitive load. Using scaffolds enables the lowering of the learning-irrelevant load and the improving of learners' SRL in unguided learning-processes [27,28].

2.2.2. Academic Self-Concept

In addition to task complexity and motivational support, students' feeling of competence can also be influenced by their academic self-concept. Therefore, the academic self-concept is an evaluation of the self, formed through a persons' perceptions of doing well or poorly in general school contexts or in specific domains as, for instance, in geography [29,30]. It is assumed that the self-perception of a learner can be mediated by cognitive factors, such as learners' academic achievement, as well as by motivational aspects [31]. These reciprocal relationships between students' academic self-concept, academic achievement, and motivation have been widely investigated by former studies [29,32] and can be explained by Self-Determination Theory [19]. As already stated, students' academic motivation can be either autonomous or controlled in nature. However, these two types of motivation may not have the same effect on their performance [33]. Research on nursing students', for example, showed that autonomous motivation leads to improved academic achievement. Consequently, academic-self-concept perceptions were rated higher by students with autonomous motivation than within the group of students whose learning motivation was controlled by external factors [32].

In sum, combining Self-Determination Theory and individuals' academic self-concept, it can be concluded that learning environments supporting students' general and domain specific academic-self-concept can have a positive effect on motivation. Feeling competent when performing a task may increase learners' experience and their autonomous motivation, which will help them achieve better grades and again foster self-perception, academic achievement, and motivation.

2.3. Scaffolding and Prompting

Difficulties during learning in digital learning environments stem from missing self-regulation capacities. Supporting methods helping learners in structuring their learning process are so-called *scaffolds* [34–36]. These can support using cognitive and metacognitive methods, allowing students to monitor and regulate their learning process [37]. Students need to apply learning strategies activating pre-knowledge and to reflect their learning behavior in order to promote successful learning in unguided learning environments [5,38].

With respect to providing metacognitive support, research highlights the positive effects of scaffolds on learning outcomes. Engelmann et al. [3] and Chen [39] show the significant positive effects of prompting on academic performance. However, little research has been done regarding the effects of scaffolds on affective and motivational states during learning with multimedia. One way to keep students motivated during learning processes is through integrating prompts [39].

2.3.1. Function and Efficiency of Prompts

As a type of scaffold, prompts are assumed to support metacognitive processes and to activate pre-knowledge [40–43]. According to Zumbach et al. [37] and Azevedo et al. [44], prompts can have different functions during learning with multimedia. In addition to activating cognitive and metacognitive strategies, prompts can also encourage motivational as well as regulative processes and support the development of self-regulation strategies. These positive aspects are mentioned in various publications such as a review provided by Devolder et al. [45] or a meta-analysis by Zheng [46]. However, there is little research regarding the motivational aspects of prompts. In this context, the study of Dauttiller and Dresel [47], who showed that metacognitive prompts can encourage learners' motivation, supports the assumption that prompts can have positive effects on affective states.

In sum, using prompts seems to have a positive effect on academic achievement and learners' motivation. Moreover, in his meta-analysis, Zheng [46] concluded that prompts' encouraging effects could be intensified by adaptive scaffolds. Pedagogical agents (PA) are a tool that allows for addressing learners' needs during learning.

2.3.2. Effects of Prompts on Cognitive Load

Although from a motivational point of view it can be assumed that the use of prompts can activate supporting strategies and therefore improve students' academic performance, scaffolds may also impact cognitive load perceptions during learning. One theory that explains how human memory processes and stores information is *Cognitive Load Theory* [48]. Overall, this theory relies on three major components: long-term memory, working memory, and organizational structures of knowledge, called schemas. While it is assumed that a nearly infinite number of organized knowledge structures can be held in long-term memory, the processing capacity of working memory is highly limited. In order to learn effectively, it is assumed that working memory's processing capacity needs to be freed up from irrelevant information and directed towards fruitful learning content. In order to describe these different forms of information processing, Cognitive Load Theory distinguishes three types of load, namely Intrinsic Cognitive Load (ICL), Germane Cognitive Load (GCL), and Extraneous Cognitive Load (ECL) [48,49]. ICL refers to the complexity of learning materials, defined by the number of interacting elements of a task and learners' pre-knowledge. As this type of load is partly inherent in the learning content, it cannot be modified unless the information presented in the learning task is revised. GCL refers to activated schemata from Long-Term Memory (LTM). Current approaches to CLT assume that ICL and GCL refer to the same source of cognitive load, which is the activation of LTM content. In contrast, ECL can be imposed by poorly designed learning materials, and describes a type of load irrelevant for learning [50–52]. Thus, it is assumed that in order not to exceed learners' cognitive capacity, ECL should be reduced to a minimum. However, as the use of scaffolds forms part of the instructional design of a learning task, the relationship between prompts, in the form of PAs, and cognitive load will be discussed in the following section.

Although scaffolds have been shown to successfully guide learners through the learning task, cognitive load theorists argue that the implication of prompts may lead to an increase of ECL and therefore interfere with learning. Analyzing the effects of PAs on former ECL studies showed ambiguous results. While Schroeder et al. [53] as well as Yung and Paas [54] could not find a significant difference on cognitive load measures between students working with or without PA support, Dincer and Dogany indicated that the integration of PAs can result in a favorable relationship between cognitive load and learning outcomes [50]. However, these divergent results may be due to the fact that the majority of studies analyzing the effects of PAs only use general cognitive load measures. As ICL and ECL are very different in nature, it can be argued that measuring these types of loads

individually may shed light on the impact of scaffolds on students' perceived cognitive load.

2.4. Pedagogical Agents

As PAs are a type of scaffold, their main function is to guide the learning process and to motivate and support learning in multimedia environments [55–57]. Apart from their appearance (real persons, avatars, comic characters), several characteristics—such as gender, (non-) verbal communication, motion, and voice—can influence their efficiency [58,59]. Furthermore, PAs' complexity can range from simple static characters to complex, animated, three-dimensional agents.

Especially while navigating through multimedia learning environments, PAs can encourage activating pre-knowledge and using learning strategies. Following Dincer and Doğanay [52], three different types of agents—categorized according to their functions—can be identified. Whereas *assistant agents* provide hints and pose questions in order to facilitate learning, *guide agents* inform learners about software usage. The most effective type of agents are *smart agents*. These can adapt to learners' needs, thus providing optimum support by using artificial intelligence. However, due to smart agents' complexity, assistant agents are most frequently used in learning software [57,60].

Despite different types and functions of PAs, studies report divergent results regarding their influence on learning processes. As the effects of PAs on aspects of learning vary, studies need to be categorized according to their research goals. Therefore, analyses towards the effects of PAs on learning outcomes, self-regulation, and motivation can be found to include PAs. In their meta-analysis, Schroeder et al. [51] reported small positive effects of PAs on learning. Indeed, Deibl and Zumbach [55] did not find positive effects of PAs on learning outcomes. However, results revealed that the presence of PAs did not distract from learning. Regarding learners' perception of their own learning process, Van de Meij et al. [61] concluded that cinematic PAs can have positive effects on self-efficacy beliefs and knowledge gain.

As stated above, the majority of research in this field shows medium positive effects of PAs on different aspects of learning. However, in order to achieve more detailed results concerning the impact of these tools, Heidig and Clarebout [62] argue that studies with a more narrow focus are needed. Accordingly, the effects of design elements and PAs' characteristics on learning outcomes and motivation require closer examination. In order to increase PAs' positive effects, Johnson and Lester [56] suggest following certain design guidelines. For instance, using audio is more effective than using written text. Moreover, communicative instead of formal exchange as well as gestures enhance PAs' effectiveness.

The aforementioned design guidelines support *Social Agency Theory* [63], which assumes that PAs' voice and appearance can activate learners' social interaction schemata [60,64,65]. According to Atkinson et al. [66] this social relationship can lead to higher mental effort when solving a task, thus having desirable effects on learning. In order to investigate the influence of agent gestures in multimedia learning environments, Davis [67] conducted a meta-analysis consisting of 20 experiments ($N = 3841$). Findings reveal that PAs' gestures can have beneficial effects on learning and learners' perception in digital learning environments. In addition, PAs' appearance can influence their effectiveness. Here, Veletsianos [68] showed that learners tend to be prejudiced against PAs depending on their appearance and their academic domain. They showed that students' unwillingness to draw conclusions can be based on PAs' inadequate visual appearance; thus, domain fit is of central importance.

In sum, proper design plays an important role concerning PAs' effectiveness. In order to reach ideal performance, audiovisual types of PAs should be used. PAs can guide learners by providing instructions and explanations in spoken form. Furthermore, active engagement in the learning process and reflection of already learned information can be triggered via using audiovisual PAs [55]. Finally, in order to efficiently support self-

regulated learning processes, Deibl and Zumbach [55] argue that benefits and costs regarding design need to be taken into account.

2.5. Open Research Questions

Our study aims at applying findings from research on PAs and motivation in multimedia environments. More precisely, the question is: How do PAs that scaffold elaboration and motivation by prompts contribute to motivation and learning outcomes? Based on Self-Determination Theory [20] we assume that PAs lead to higher motivation (Hypothesis 1; see Figure 1) and improved learning outcomes (Hypothesis 2) when comparing results of students' learning with and without PA-support. Both hypotheses are in line with prior research in this field [69,70]. Furthermore, positive correlations between learning motivation and knowledge acquisition was hypothesized (Hypothesis 3). Therefore, the relationship between motivation, cognitive load, and academic self-concept as a connecting variable between cognitive and motivational parameters and knowledge acquisition was analyzed.

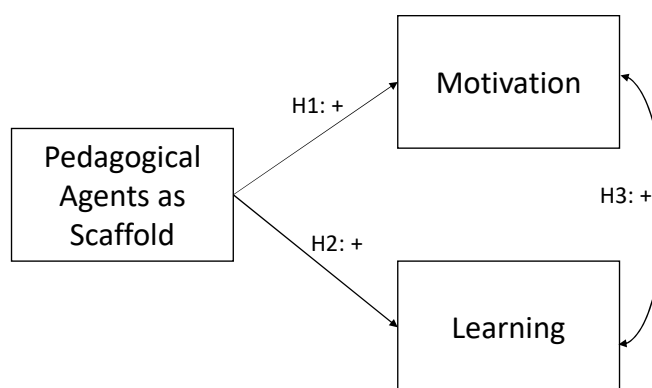


Figure 1. Hypotheses of the study.

3. Material and Method

This study aimed to investigate the effects of PAs scaffolding cognitive and motivational processes by means of prompting on motivation and learning outcomes in multimedia learning environments. Therefore, we analyzed PAs' impact on learning motivation, perceived cognitive load, and knowledge acquisition.

3.1. Sample

A total of 60 middle school students between the ages of 12 to 16 (mean age: $M = 13.61$; $SD = 1.15$) participated in this study; 27 of them were female and 22 were male. No rewards were given, and each participant was randomly assigned to one of the two experimental conditions (a learning session with a PA and a learning session without a PA). Parents and the school administration gave informed consent, since the study was conducted during regular school time. Participation was voluntary and all data were obtained anonymously.

3.2. Design

In this study, there was one independent variable, namely, the provision of prompts in the form of a PA in the experimental group. Apart from support via a PA, the two learning sessions of the experimental and the control group were the same. Participants' intrinsic and extraneous cognitive load were dependent variables, whereas students' general and geographical academic self-concept were included as control variables. Control variables were assessed by questionnaires after completion of the learning task.

3.3. Material

Learning Environment

In this study, a digital learning environment for a geography lesson on glaciers was developed (see Figure 1). This multimedia environment provided information about glacier formation, landscape, and the development of glaciers in light of global warming. Pre-knowledge on and motivation for this topic are low [71], and the learning content is perceived as difficult [72]. Thus, this thematic area provides an ideal possibility for supportive interventions. In order to scaffold learners' motivation and support elaboration and reflection during the learning process, a PA was designed and applied (see Figure 2).

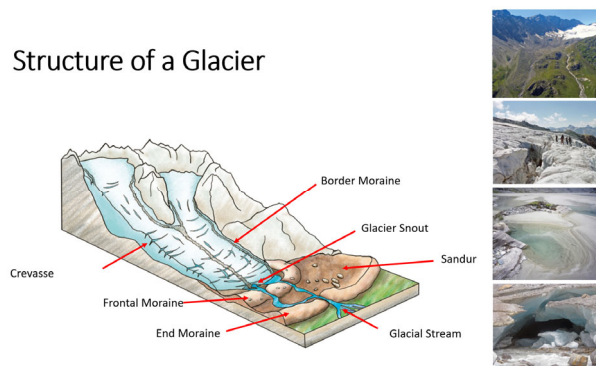


Figure 2. Sample Screen from the learning environment.

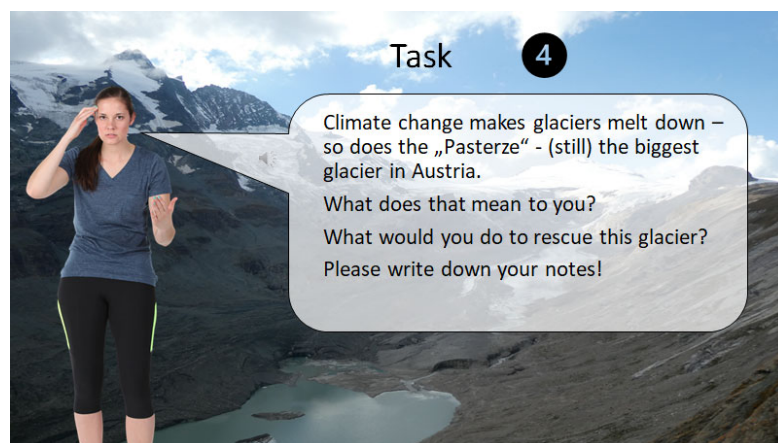


Figure 3. Task provided by the Pedagogical Agent.

The digital learning environment consisted of either 21 pages with support from a PA or 16 pages without support in the control group. At the starting page, a non-linear overview of the subject was given. During the session, learners were able to work with the learning material at their own pace and to repeat already learned information. The experimental group was supported by a PA. This PA's purpose was scaffolding learners' autonomous motivation by providing motivational prompts that had to be addressed by written statements (see Figure 2). As the goal of these prompts was to motivate learners, they were designed to reflect upon their own motivation and increase the subjective importance and relevance of the topic. Thus, the PA asked students to reflect on previously learned knowledge and to complete motivational self-reflection tasks in written form (see Figure 3). As such, the scaffolding was not genuinely motivational, but also showed elements of prompting cognitive processes. Overall, the PA presents four prompting tasks within the learning environments, each following a topical unit.

3.4. Instruments

Motivation as an independent variable was measured during pre- and post-test via SMR-L (Scales of Motivation and Regulation during Learning), as provided by Thomas and Müller [73]. Based on Self-Determination Theory [22], especially OIT, this research instrument consists of four sub-scales assessing learners' intrinsic, identified, introjected, and external regulation of motivation. The present study combines these four sub-scales in order to assess learners' autonomous and controlled motivation. For instance, six items combining intrinsic and identified regulation are used, such as: "I learn something about glaciers because I think it is important to reflect on this subject." Also, seven items combining external and introjected regulation of motivation are used, such as: "I learn something about glaciers because I would be ashamed knowing nothing about his subject." All questionnaires used a 5-point Likert scale. In the pre- and post-test, both sub-scales reached high Cronbach's alpha values (autonomous pre-test: $\alpha = 0.87$; autonomous post-test: $\alpha = 0.92$; controlled pre-test: $\alpha = 0.78$; controlled post-test: $\alpha = 0.81$).

Participants' cognitive load was assessed by the *Naïve Rating Questionnaire* provided by Klepsch et al. [74]. This self-reporting questionnaire with 5-point Likert scales has three sub-scales measuring intrinsic (ICL; $\alpha = 0.70$), extraneous (ECL; $\alpha = 0.63$), and germane cognitive load (GCL; $\alpha = 0.49$). Each type of cognitive load is assessed by three items (ICL, e.g., "For this task many things needed to be kept in mind simultaneously."; ECL, e.g., "During this task it was exhausting to find the important information."; GCL, e.g., "For me it was important to understand the learning content."). The sub-scale of GCL had to be excluded from further analyses due to insufficient reliability.

Participants' academic self-concept as a connecting and control variable between cognitive and motivational parameters was assessed via the SESSKO questionnaire developed by Dickhäuser et al. [75]. Here, the general and geographical self-concept were measured on a 5-point Likert scale. While learners' general academic self-concept was assessed by five items ($\alpha = 0.82$, e.g., "I am very intelligent."), four items were applied in order to measure students' geographical self-concept ($\alpha = 0.91$, e.g., "I am good at geography.").

3.5. Procedure

The study was conducted during regular school time. At the beginning, learners were informed about the nature of the study and its content. Afterwards, participants were randomly assigned to one of the two experimental conditions (a learning session with or without support by a PA). The first part of the study started with a questionnaire on participants' socio-demographic data (age, gender, school type, and number of school years), followed by a pre-test consisting of multiple choice tasks and open questions. After assessing students' prior knowledge, data concerning their motivation was collected. In the second part of the study, learners worked with the learning environment about glaciers. Depending on the experimental group, students were either in the condition with or without support by a PA. After the learning session, perceived knowledge, cognitive load, and motivation were assessed.

4. Results

In general, descriptive data (see Table 1) indicated a larger increase in knowledge test performance and autonomous motivation in the experimental group compared to the control group. In line with this result, cognitive load measurements in the experimental group show lower levels of intrinsic and extraneous cognitive load than in the control group.

Table 1. Mean values and standard deviations of dependent and control variables.

	Without PA (<i>n</i> = 30)		With PA (<i>n</i> = 30)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Knowledge Pre-Test	1.41	1.40	1.84	1.86
Knowledge Post-Test	7.17	4.07	8.81	4.28
Autonomous Motivation (pre)	2.38	0.96	2.58	0.91
Autonomous Motivation (post)	2.33	1.00	2.65	1.04
Controlled Motivation (pre)	2.21	0.74	2.36	0.85
Controlled Motivation (post)	2.07	0.72	2.15	0.83
Intrinsic Cognitive Load	3.39	0.89	2.94	0.77
Extrinsic Cognitive Load	3.08	0.75	2.69	0.75
Academic Self-Concept (General)	3.30	0.67	3.12	0.85
Academic Self-Concept (Geography)	2.90	0.69	2.81	1.25

Note: All scales are on a 5-point Likert scale with 1 as minimum and 5 as maximum, except for knowledge tests (minimum = 0; maximum = 24).

In order to test group differences regarding cognitive outcomes, a MANCOVA was computed using academic self-concept-scales and results from knowledge pre-tests as covariates, and performance in knowledge post-test and cognitive load measures as dependent variables. Results revealed no significant impact of any of the covariates (Knowledge pre-test: $F(3, 53) = 0.42$; $p = 0.74$; $\eta_p^2 = 0.02$; Academic Self-Concept General: $F(3, 53) = 0.81$; $p = 0.49$; $\eta_p^2 = 0.04$; Academic Self-Concept Geography: $F(3, 53) = 2.51$; $p = 0.07$; $\eta_p^2 = 0.12$).

Between-group comparison revealed a significant overall effect ($F(3, 53) = 2.83$; $p = 0.047$; $\eta_p^2 = 0.14$). Single comparisons were significant for Intrinsic Cognitive Load $F(1, 55) = 4.25$; $p = 0.044$; $\eta_p^2 = 0.07$), Extraneous Cognitive Load ($F(1, 55) = 4.52$; $p = 0.038$; $\eta_p^2 = 0.08$), and performance in knowledge post-test $F(1, 55) = 2.93$; $p = 0.046$; $\eta_p^2 = 0.06$; one-sided). Descriptive data showed that learners within the PA-condition obtained higher scores in the knowledge test (Hypothesis 1; see Figure 4) and reported lower cognitive loads in general.

A second MANCOVA concerning motivational variables was computed, again using both measures of self-concept, autonomous motivation and controlled motivation in the pre-test as covariates, and autonomous motivation and controlled motivation in the post-test as dependent variables. Outcomes indicate no significant impact of Academic Self-Concept General: $F(2, 53) = 0.03$; $p = 0.97$; $\eta_p^2 = 0.001$; Academic Self-Concept Geography: $F(2, 53) = 1.10$; $p = 0.34$; $\eta_p^2 = 0.04$). In contrast, autonomous motivation and controlled motivation in the pre-test significantly impact their corresponding post-test scores (Autonomous Motivation: $F(1, 54) = 149.89$; $p < 0.001$; $\eta_p^2 = 0.74$; Controlled Motivation: $F(1, 54) = 17.97$; $p < 0.001$; $\eta_p^2 = 0.63$). An overall comparison between both conditions did not turn out to be significant $F(2, 53) = 0.75$; $p = 0.48$; $\eta_p^2 = 0.03$). Descriptive data show that there is a slight increase in autonomous motivation from pre- to post-test within the PA-condition. In contrast, conditions without the PA showed a slight decrease in autonomous motivation from pre- to post-test. Nevertheless, these differences are not statistically significant (Hypothesis 2). A correlation analysis reveals that there is a significant correlation between outcomes in knowledge post-test and Autonomous Motivation post-test ($r(60) = 0.28$; $p = 0.03$; Hypothesis 3).

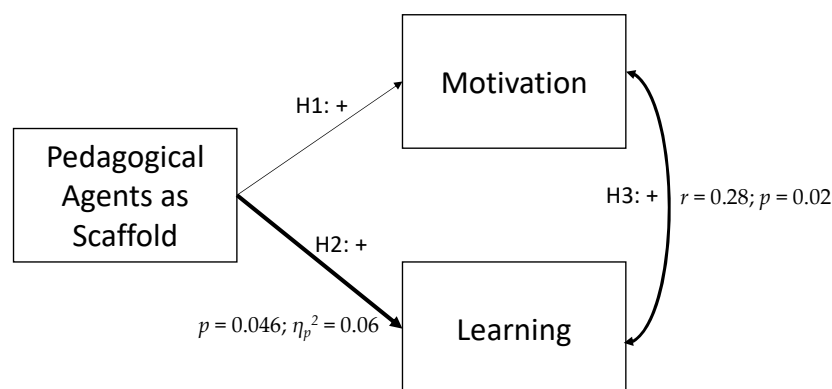


Figure 4. Core findings of this study.

5. Discussion

The importance of cognitive and motivational scaffolding on learning is well documented (e.g., [76,77]). However, this study is one of very few analyses directly testing the effects of metamotivational scaffolding on performance in interactive learning environments. Overall, results showed only significant effects of metamotivational prompts provided by the Pedagogical Agent on knowledge acquisition and cognitive load. Regarding motivation, descriptive data also shows small benefits of the PA in increasing autonomous motivation, but this effect did not turn out to be statistically significant. Although there is research indicating that motivational support increases learners' motivation (e.g., [76]) in e-learning environments [78], we found hardly any measurable effects. The lack of measurable effects might be attributed to limited intervention time. It is possible that more intervention time—leading to continuous metamotivational scaffolding—might be beneficial [79].

Nevertheless, results revealed significant differences concerning knowledge acquisition in favor of the PA-condition. Not only did the PA trigger motivational processes supporting autonomous motivation, it also supported learners in reflecting on and elaborating the content scaffolded. This, in turn, resulted in lower self-reported scales concerning intrinsic and extraneous cognitive load. Usually, providing additional tasks such as those operationalized by the PA would result in higher extraneous cognitive load by creating a dual-task situation. However, in this learning scenario, scaffolding by the PA and its prompted tasks, which were perceived as a core part of the learning environment that contributed to learning by elaborating and reflecting the content, led to increased learning performance. Furthermore, the lower score of intrinsic cognitive load showed that learners in the PA-condition did not regard the learning material to be as complex as learners in the condition without a PA did. Interestingly, predictors linking cognitive and motivational values, such as prior knowledge and academic self-concept, did also not turn out to be significant co-variables and, as such, predictors for motivation and learning performance.

We expected higher prior knowledge and self-concept to contribute to increased motivation and learning performance. However, that was not the case in this study that directly focused on fostering autonomous motivation and learning performance. Instead, we found a slight impact on motivation and a significant effect on learning. Consequently, the PA did support cognitive processes, but it did not enhance scaffolding motivational processes that interact with cognitive processes. Therefore, longer interventions and adaptive scaffolding might be more effective.

6. Conclusion and Further Directions

Expanding former research on PAs, this study indicates that the quality of metamotivational scaffolding matters most. Furthermore, it has been demonstrated that

metamotivational support can support learners with regard to knowledge acquisition. Although there is a link between autonomous motivation and knowledge acquisition, this study failed to find a direct effect of scaffolding on motivation.

However, given that this study was a first attempt to investigate the effects of PAs on students' motivational behavior, some limitations can be noted. Besides limited intervention time, the comparison of present results with former [47,80] studies show that the effects of PAs on metamotivational processes correlate with learners' academic experience. This assumption is made based on divergences found between the present study and the ones of Tuckman [80] or Daumiller and Dresel [47], who investigated the effects of PAs on university students' learning processes. Therefore, further research investigating whether university students are able to use such prompts more effectively than high school students is needed. As processing motivational prompts requires additional mental effort from learners, research activities also need to show understanding and awareness of the dosage of metamotivational prompts. Another promising strategy is the use of adaptive motivational scaffolding, which should be subject to further empirical research [81].

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Informed Consent Statement: Informed consent was obtained from all people involved in the study.

Data Availability Statement: The data presented in this study are available on request from Joerg Zumbach (joerg.zumbach@plus.ac.at).

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