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Sven Scheu
*Karlsruhe Institute of Technology (KIT)*, sven.scheu@kit.edu

Ivo Benke
*Karlsruhe Institute of Technology (KIT)*, ivo.benke@kit.edu

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# DIGITAL ASSISTANTS FOR SELF-REGULATED LEARNING: TOWARDS A STATE-OF-THE-ART OVERVIEW

*Research in Progress*

Sven Scheu, Karlsruhe Institute of Technology, Karlsruhe, Germany, sven.scheu@kit.edu

Ivo Benke, Karlsruhe Institute of Technology, Karlsruhe, Germany, ivo.benke@kit.edu

## Abstract

*We observe a continuous shift from face-to-face to hybrid or online education. Today, learners are exposed to a high level of autonomy and, at the same time, have less contact with peers and teachers. In this environment, the ability to self-regulate one's learning is becoming more relevant to achieve positive learning results and academic success. However, the application of self-regulated learning is not trivial. A potential solution for this challenge comes in the form of digital assistants like chatbots or pedagogical agents that provide structure for the learners. Existing research on digital assistants for self-regulated learning (SRL) is scattered across several fields. In this research-in-progress paper, we present preliminary results of a systematic literature review study providing a state-of-the-art overview of digital assistants supporting SRL. Our results show that future research in this domain should focus on affect, behavior, and context regulation and that more longitudinal studies are required.*

*Keywords: Digital Assistants, Systematic Literature Review, Self-regulated learning.*

## 1 Introduction

Academic success is an important personal step and a critical driver for economic growth (OECD, 2019). Dropping out of tertiary education puts strain on the individual and society as a whole, but is a common occurrence (OECD, 2019). The causes are diverse, but motivation, satisfaction as well as personal learning strategy and organization are important factors (Behr *et al.*, 2020). The COVID-19 pandemic has put additional stress on students as many educational systems were mostly unprepared for such a situation (OECD, 2021). One concrete effect of this, namely fewer students being able to finish their studies, is already becoming apparent as some regions and institutions start reporting lower numbers of graduates in recent semesters (destatis, 2021; HESA, 2021; MIT Registrar, 2022).

One solution for students to counteract this challenge is self-regulating their learning. When learners engage in self-regulated learning (SRL), they "orient on the task at hand, plan and implement their actions, monitor and evaluate their choice of strategies, and remedy ineffective strategies" (Boekaerts, 2006, p. 348). SRL has a positive effect on learning results and academic success (Mega, Ronconi and De Beni, 2014). However, not all students are equally capable of employing and developing SRL capabilities natively, and many students lack education on how to apply them (Zimmerman and Pons, 1986; Zimmerman, 2000; Kornell and Bjork, 2007). Common insufficiency in SRL capabilities include overestimating the effectiveness of the chosen learning strategy (Kornell and Bjork, 2008) or the stability of their memory over time (Kornell and Bjork, 2009). In some cases, this even results in learners adopting harmful strategies. A well-known example is the tendency of students to learn a large amount of material in a short time in preparation for exams very close to the exam date. Students do so because massed learning is an effective strategy for short term retention and they might not see the benefits of spaced learning regarding long term retention (Rawson and Kintsch, 2005; Bjork, Dunlosky and Kornell, 2013).

Assisting learners in developing SRL capabilities with the help of digital assistants is a promising approach (Azevedo, 2008). Digital assistants in an educational context are software agents that interact with the learner through natural language (Maedche *et al.*, 2019). They are able to provide structure for learners, that helps learners to acquire knowledge by adapting the difficulty of the learning content appropriate to the learner's skill level (Graesser *et al.*, 1999; Reiser, 2002; Azevedo, 2005). Innovations in technology and recent research on advanced digital assistants have opened new research avenues for SRL support and development for learners. There are multiple examples for digital assistants that support students' learning processes in recent studies (e.g., Adamopoulou and Moussiades, (2020); Pérez, Daradoumis and Puig (2020)). However, to the best of our knowledge, there is no integrated overview of previous research of digital assistants in SRL. To address this shortcoming, we aim to answer the following research question:

*"What is the state-of-the-art in research on digital assistants supporting self-regulated learning?"*

In this research-in-progress paper, we conducted a systematic literature review (SLR) based on the approach by Kitchenham and Charters (2007) and Webster and Watson (2002). In our rigorous literature screening process, we received 584 papers from which we identified 45 relevant publications investigating different types of digital assistants supporting SRL. We analyzed these publications based on the theory of SRL (Zimmerman and Pons, 1986; Pintrich, 2000). Preliminary findings show that current research mainly focuses on SRL support interventions of cognition regulation, with other areas not being well explored. In the future, we will analyze the sample in detail. With our work, we contribute to the field of SRL by providing a research overview of digital assistants supporting SRL.

## 2 Conceptual Background

### 2.1 Self-regulated learning

SRL describes learners as active participants in their learning that are able to shape and manipulate their learning processes (Boekaerts, 1999; Efklides, 2011; Schunk and Greene, 2018). Successful self-regulated learners employ strategies to improve their success in learning (Zimmerman and Pons, 1986) and utilize metacognition to continuously refine their learning approach (Schunk and Greene, 2018). In SRL, learners actively run through a cyclical process of the forethought, performance, and reflection phases (cf. Figure 1) (Zimmerman, 2000). In the forethought phase, learners engage in actions to prepare for the learning task by planning the task execution and objectives, as well as motivating themselves. During the performance phase, they monitor their progress and compare that to their plan and goals, as well as employ strategies based on their progress to keep up motivation. In the reflection phase, learners assess the learning outcomes and engage in self-reactions like emotional response and attributions about what caused these outcomes.

A simple example for the SRL process is the setting of a learning goal, the application of a basic learning strategy like note-taking and monitoring the learning progress, and, finally, the reflection of how much the note-taking strategy contributed to the learning success in contrast to previously employed learning strategies.
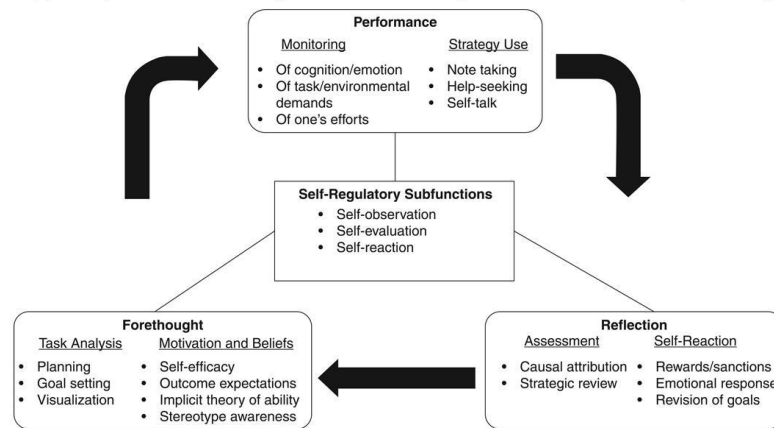
*Figure 1.*    *SRL process and its subfunctions (Usher and Schunk, 2018) based on (Zimmerman, 2000).*

In the SRL process, multiple human dimensions play an essential role besides the application of pure cognitive resources. Learners may also engage in regulation of their motivation and affect, their behavior, as well as their learning context. The SRL framework by Pintrich (2000) maps these dimensions (cognition, motivation and affect, behavior, and context) on the SRL cycle phases. Table 1 presents an exemplary list of actions learners can take in the phases of the SRL cycle (Pintrich, 2000). This framework serves as the foundation for the analysis in this paper.

| Phases | Areas for regulation | | | |
| --- | --- | --- | --- | --- |
| | **Cognition** | **Motivation/affect** | **Behavior** | **Context** |
| Forethought, planning, and activation | • Target goal setting<br>• Prior content knowledge activation<br>• Metacognitive activation | • Goal orientation adoption<br>• Efficacy judgments<br>• Ease of learning judgments (EOLs); perceptions of task difficulty<br>• Task value activation<br>• Interest activation | • [Time and effort planning]<br>• [Planning for self-observation of behavior] | • [Perceptions of task]<br>• [Perceptions of context] |
| Monitoring | • Metacognitive awareness and monitoring of cognition (FOKs, JOLs) | • Awareness and monitoring of motivation and affect | • Awareness and monitoring of effort, time use, need for help<br>• Self-observation of behavior | • Monitoring changing task and context conditions |
| Control | • Selection and adaptation of cognitive strategies for learning, thinking | • Selection and adaptation of strategies for managing motivation and affect | • Increase/decrease effort<br>• Persist, give up | • Change or renegotiate task<br>• Change or leave context |
| Reaction and reflection | • Cognitive judgments<br>• Attributions | • Affective reactions<br>• Attributions | • Choice behavior | • Evaluation of task<br>• Evaluation of context |

*Table 1.*    *Classification framework for areas and phases of SRL (Pintrich 2000).*

## 2.2 Digital Assistants for self-regulated learning

Digital assistants have become almost ubiquitous, finding their way into our lives, for example, in the form of text-based (e.g., Chatbots in Facebook Messenger) or voice-based assistants (e.g., Amazon Alexa) (Maedche *et al.*, 2019). They are conversational agents that incorporate artificial intelligence (AI), natural language processing, and knowledge based on the specific needs of their context (Maedche *et al.*, 2019). In the interaction with humans, they are seen as social actors that invoke social responses in human users similar to those that interactions with humans would (Nass and Moon, 2000). These social responses include an increase of perceived social presence by the user, a higher level of trust, or an improved user satisfaction (Feine *et al.*, 2019). This makes them prime candidates as learning companions that can provide direct support on the learning task as well as meta-level support like motivational or strategic interventions (Kim and Baylor, 2006). One important class of digital assistants in learning are pedagogical agents that engage with the learner in a human like manner and often have human like features such as a human avatar, voice and name (Graesser *et al.*, 1999; Reiser, 2002; Azevedo and Hadwin, 2005). They can also be embedded into tutoring systems that provide human-like individual instructions, so-called intelligent tutoring systems (Smelser and Baltes, 2001).

In SRL research, digital assistants take the role of a peer that engages in shared regulation (so called coregulation) or a mentor that transfers its knowledge to the learner (Azevedo and Hadwin, 2005; Hadwin and Oshige, 2011). By doing so they support learners in the acquisition of SRL capabilities or the application of SRL. For example, a digital assistant can suggest the use of appropriate learning strategies, prompt users to engage in metacognitive action like reflecting on their learning progress or give concrete feedback on the application of SRL by the learner.

## 3 Research Method

To execute this review, we followed the method described by Kitchenham and Charters (2007) and Webster and Watson (2002). Based on these, we organized the review process into three main phases. In the *planning phase,* we identified existing literature reviews on digital assistants for self-regulated learning and articulated the research question introduced. All reviews we identified, targeted specific domains of learning (e.g., computer-based learning environments (Devolder, van Braak and Tondeur, 2012), e-Learning (Garcia, Falkner and Vivian, 2018; Araka *et al.*, 2020), and MOOCs (Lee, Watson and Watson, 2019; Wong *et al.*, 2019)). We also created a review protocol that guided the subsequent review execution. In the *conducting phase*, we, first, performed an exploratory literature search to identify primary studies. On this basis, we articulated our initial search string and collected data from four major publication databases. Finally, after data extraction, monitoring and synthesis, we produced this paper as a critical deliverable of the *reporting phase*.

To develop our search string, we conducted an exploratory search for pedagogical agents and conversational agents for self-regulation on Google Scholar. Based on the studies by Kerly, Ellis and Bull (2008) and Jones and Castellano (2018), we identified a need to widen our search terms regarding the type of artifact. After refining the search string, we ended up with the search string depicted in Table 2.

| Domain | Self-regulated learning | | Digital Assistants |
|---|---|---|---|
| Search string fragment | "self-regulated learning" OR "self regulated learning" | AND | "pedagogical agent" OR chatbot OR "conversational agent" OR "personal assistant" OR "voice assistant" OR "embodied agent" |

*Table 2.        Search string.*

To maintain a relevant sample, we limited our search to peer-reviewed journal and conference articles in English. Further, we only included papers that implemented an SRL intervention. For a similar reason, we excluded publications targeting teams or groups as, in these cases, the assistant's role is secondary to the social interaction between the human actors. To get an accurate representation of the state-of-the-art, we decided to only include studies in our review that evaluated the experimental artifact (i.e., the digital assistants). We, finally, focused our search in the fields of computer science, education science,

and information systems. Therefore, we selected the databases Scopus, the ACM Digital Library, IEEE Explore, ERIC, ScienceDirect, Web of Science, and AIS eLibrary as our databases according to this choice.

Our initial search yielded 584 results which reduced to 532 studies after applying deduplication based on title, outlet, and publication year. We then applied the defined inclusion and exclusion criteria by scanning the titles for false positive results and read the abstract of the remaining papers. We excluded 386 studies based on screening of title and abstract. After removing duplicates, we ended up with 146 papers. We filtered the remaining papers by reading them to assess that they match our inclusion criteria. This resulted in 41 publications. Subsequently, we performed a backward and forward search. We repeated all steps starting from filtering by inclusion and exclusion iteratively until we ended up with a final set of 45 sources. Details of the search process are shown in Figure 2, which we based on the PRISMA flow diagram template (Page *et al.*, 2021).
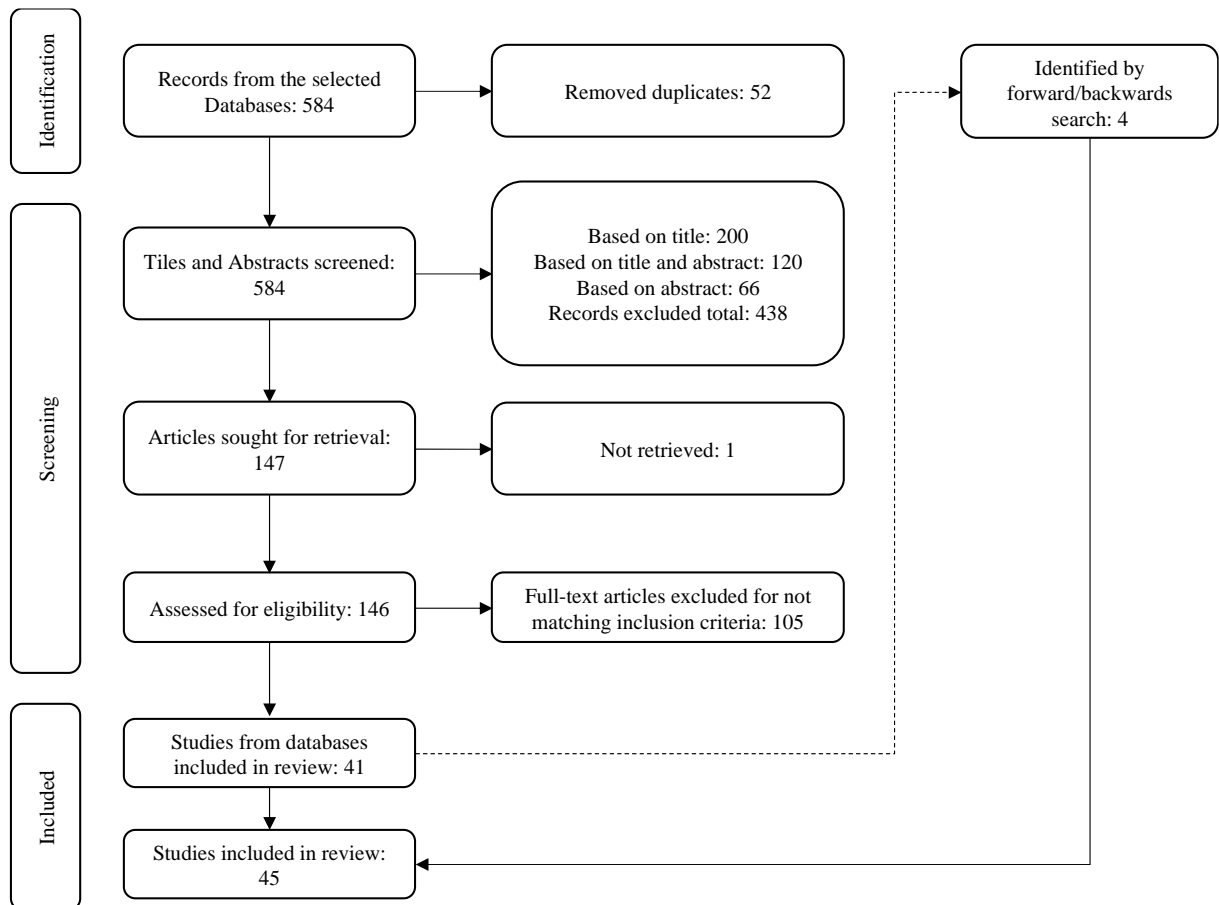


*Figure 2.*      *SLR process.*

After the search process execution, we coded the articles to answer our research question. We identified the primary artifact used as well as the type of device the agent was deployed on and their input modality. We also gathered information on the type of study conducted, the number of participants, what kind of participants, as well as the study duration. Finally, we coded the intervention of the digital assistants according to the framework by Pintrich (2000).

# 4 Results

In the following, we describe the preliminary results of our study. We found a total of 45 relevant articles with 23 having been published in conference proceedings and 22 in journals. Most studies in our sample were published after the year 2012 with an increase of studies in recent years (cf. Figure 3). This development is not surprising since there has been a lot of progress in recent years when it comes to the maturity of digital assistants based on technological advances in artificial intelligence.
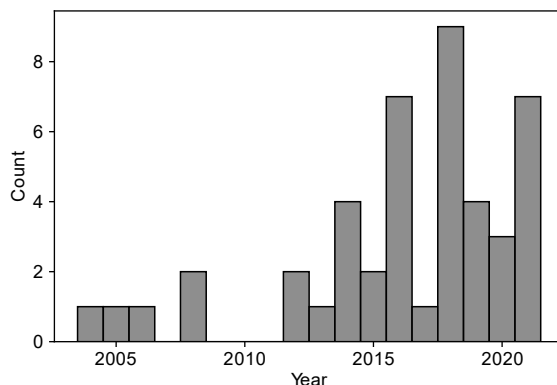


*Figure 3.        Publication distribution by year.*

When looking at the context of the publications, a majority of the studies (34) were conducted in a higher education environment. Only a small set of papers focused on primary education (6). Regarding study duration, the studies were overwhelmingly conducted as cross-sectional experimental studies while only seven studies were conducted as longitudinal studies. Of these longitudinal studies that spanned a semester or more, none provided sufficient information on how much interaction the learners had with the agent (Karaoğlan Yılmaz, Olpak and Yılmaz, 2018; Cabales, 2019; Tian *et al.*, 2021). Overall, that leaves us with the conclusion that long term regular use of these agents is a largely unexplored area of research.

The digital assistants investigated were mainly pedagogical agents (32) often embedded into intelligent tutoring systems and chatbots (20). An explanation for this result is that a large share of publications in our sample have been conducted with the intelligent tutoring system MetaTutor (15) with its pedagogical agents. They provide guidance, conduct pretests, encourage learners to engage in prior knowledge activation and goal setting, help with self-monitoring, and encourage strategy use (e.g. Trevors, Duffy and Azevedo (2014); Duffy and Azevedo (2015); Harley *et al.* (2018)). In total, 15 publications by different authors investigated MetaTutor, with a focus on varying subsets of the available pedagogical agents in MetaTutor. The interaction with these pedagogical agents was almost exclusively via textual and visual interface elements (i.e., buttons that relied on prompts). We only found two examples for voiced-based interaction with the digital assistant MetaTutor (van der Meij, van der Meij and Harmsen, 2015; Kuttal *et al.*, 2021). One artifact that was used in two studies, taught SRL with the help of example-based learning instead of prompting (Poitras, Lajoie and Hong, 2012; Poitras and Lajoie, 2014). We also encountered only one robot-based assistant which was mainly used to replace a screen-based avatar (Jones and Castellano, 2018).

Table 3 presents the classification of our studies on the SRL support provided by digital assistants we identified. First, we noticed a strong focus on cognitive interventions. Especially, cognitive planning and monitoring activities were common. A majority of publications (33) explicitly expressed their focus on self-monitoring on a cognitive level. Similarly, the most common planning activity was prompting to set goals for the learning session. Interestingly, more than half of the studies that did self-monitoring (20 out of the previous 33) aimed to suggest the cognitive and learning strategies employed by the system users or manipulate them. As controlling and monitoring are closely intertwined, we see this as

an opportunity to contribute to research by designing innovative control interventions based on the self-monitoring employed by the learners.

| Source | Cog.* | M.* | B.* | Con.* | Source | Cog.* | M.* | B.* | Con.* |
|---|---|---|---|---|---|---|---|---|---|
| Hew *et al.* (2021) | ● | | | | Poitras and Lajoie (2014) | ● | | | |
| Pesonen (2021) | ● | ● | ● | ● | Bouchet, Harley and Azevedo (2013) | ● | | | |
| Song and Kim (2021) | ● | | | | Poitras, Lajoie and Hong (2012) | ● | | | |
| Cabales (2019) | ● | | ● | | Shafilla subri and Bin Md. Shah (2013) | ● | | | |
| Jones and Castellano (2018) | ● | | ● | | Clarebout and Elen (2006) | ● | | | |
| Kim, Zhang and Park (2018) | ● | | | | Biswas *et al.* (2005) | ● | | | |
| Suleman, Mizoguchi and Ikeda (2016) | ● | | | | Lau *et al.* (2017) | ● | | | |
| Kerly, Ellis and Bull (2008) | ● | | | | Bosch *et al.* (2021) | ● | | | |
| Kerly and Bull (2008) | ● | | | | Tian *et al.* (2021) | ● | ● | ● | |
| Cerezo *et al.* (2020) | ● | | | | Zhang *et al.* (2020) | ● | | | |
| Wortha *et al.* (2019) | ● | | | | Hidayat *et al.* (2018) | ● | | | |
| Hidayah, Adji and Setiawan (2018) | ● | | | | Kautzmann and Jaques (2019) | ● | | | |
| Karaoğlan Yılmaz, Olpak and Yılmaz (2018) | ● | | | | Bouchet, Harley and Azevedo (2016) | ● | | | |
| Kautzmann and Jaques (2018) | ● | | | | Valencia-Vallejo, López-Vargas and Sanabria-Rodríguez (2018) | ● | | ● | |
| Bouchet, Harley and Azevedo (2018) | ● | | | | Cloude et al. (2020) | ● | | | |
| Harley *et al.* (2018) | ● | | | | Duffy and Azevedo (2015) | ● | | | |
| Kim and Bennekin (2016) | ● | ● | ● | ● | Valencia-Vallejo, López-Vargas and Sanabria-Rodríguez (2019) | ● | | ● | |
| Harley *et al.* (2016) | ● | | | | Baylor and Kim (2004) | | ● | | |
| Chatzara, Karagiannidis and Stamatis (2016) | ● | ● | ● | | van der Meij, van der Meij and Harmsen (2015) | | ● | | |
| Lallé *et al.* (2016) | ● | | | | Kuttal *et al.* (2021) | | ● | | |
| Kautzmann, Carlotto and Jaques (2016) | ● | | | | Taub *et al.* (2014) | ● | | | |
| Trevors, Duffy and Azevedo (2014) | ● | | | | Taub *et al.* (2021) | ● | | | |
| Mudrick et al. (2014) | ● | | | | | | | | |
| *Note: *Cog. = Cognition, M. = Motivation, B. = Behavior, Con. = Context* | | | | | | | | | |

*Table 3.        Publications and elements of self-regulated learning.*

In the motivational and affect dimension of SRL, we found only few articles in our sample. Notably is the work by Kim and Bennekin (2016) that demonstrated a volition support-based approach to supporting motivational regulation in learners. They did so by walking learners through four motivation phases: goal initiation, goal formation, action control and emotion control. With the activity of task value activation, Chatzara, Karagiannidis and Stamatis (2016) and Kim and Bennekin (2016) utilized the only motivational forethought activity.

Behavioral regulation does not appear to be in the research focus. Very few studies investigated time regulation support (Valencia-Vallejo, López-Vargas and Sanabria-Rodríguez, 2018, 2019; Tian *et al.*, 2021) and supporting help-seeking behavior (Jones and Castellano, 2018; Pesonen, 2021). This might be related to the short temporal frame of many studies since many behavioral interventions like effort planning require a longitudinal experimental design.

Similarly, the regulation of the context seems to be underexplored. One of the few examples in the sample was Kim and Bennekin (2016) which suggest students to change their environment in order to avoid distractions. Further, Pesonen (2021) offered the ability to seek help in general learning related matters. Figure 4 aggregates the distribution of the sample papers on the SRL phases and dimensions based on the SRL model by Pintrich (2000).
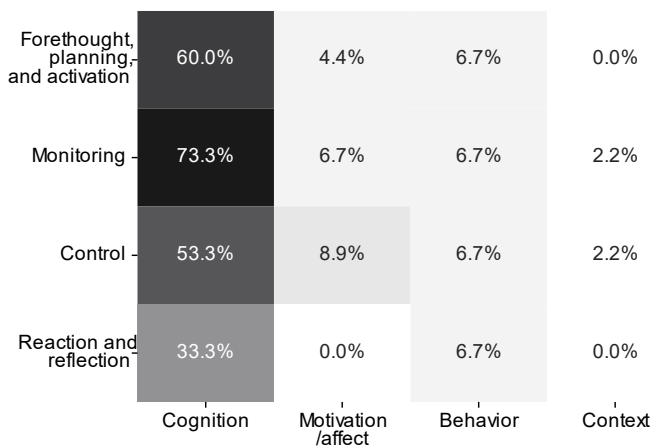
| | Cognition | Motivation /affect | Behavior | Context |
|---|---|---|---|---|
| Forethought, planning, and activation | 60.0% | 4.4% | 6.7% | 0.0% |
| Monitoring | 73.3% | 6.7% | 6.7% | 2.2% |
| Control | 53.3% | 8.9% | 6.7% | 2.2% |
| Reaction and reflection | 33.3% | 0.0% | 6.7% | 0.0% |

*Figure 4.        SRL intervention heatmap*

# 5   Conclusion and Future Research

In this research-in-progress paper, we presented preliminary results of our SLR to answer the research question of *"What is the state-of-the-art in research of digital assistants supporting self-regulated learning?"*. In our literature search, we identified 45 studies that we analyzed based on the theory of SRL by Pintrich (2000). Our results show that research on SRL support by digital assistants mainly focuses on cognition regulation, whereas motivation and affect, behavioral, and context regulation remain underexplored. We see this focus of the study samples as problematic, especially when looking at the lack of motivation and affect regulation since affect regulation has a strong influence on cognition (Boekaerts, 2011). Future work should, therefore, investigate more SRL dimensions beyond cognition regulation and develop digital assistants that address all dimensions of SRL.

Further, our results showed that most studies are conducted over short timeframes, which makes it impossible to assess the long-term effects the interactions with the digital assistants induce. As we view the acquisition of SRL capabilities as the ultimate goal of digital assistants in education that requires continuously less support from the assistant, we believe that this research field would greatly benefit from longitudinal studies. These studies should investigate the change of SRL capabilities in users over time and how to best fade out the support provided by the assistant.

In future work, we will deepen the descriptive analysis of the SLR results. Thereby, we hope to provide interesting findings for the research domain of digital assistants supporting SRL. As a first step, we will focus on the artifacts to better understand which phases and dimensions of SRL are most often supported. Similarly, we want to look at which specific support interventions were used and to what extent. With this study, we hope to provide stimulating findings and new perspectives on the innovative system class of digital assistants in education research in self-regulated learning.

## References

Adamopoulou, E. and Moussiades, L. (2020) 'Chatbots: History, technology, and applications', *Machine Learning with Applications*, 2, p. 100006. doi:10.1016/j.mlwa.2020.100006.

Araka, E. *et al.* (2020) 'Research trends in measurement and intervention tools for self-regulated learning for e-learning environments—systematic review (2008–2018)', *Research and Practice in Technology Enhanced Learning*, 15, p. 6. doi:10.1186/s41039-020-00129-5.

Azevedo, R. (2005) 'Using hypermedia as a metacognitive tool for enhancing student learning? The role of self-regulated learning', *Educational psychologist*, 40(4), pp. 199–209. doi:10.1207/s15326985ep4004_2.

Azevedo, R. (2008) 'The role of self-regulated learning about science with hypermedia', in *Recent innovations in educational technology that facilitate student learning*. Information Age Publishing, Inc. Charlotte, NC, pp. 127–156.

Azevedo, R. and Hadwin, A.F. (2005) 'Scaffolding Self-regulated Learning and Metacognition – Implications for the Design of Computer-based Scaffolds', *Instructional Science*, 33, pp. 367–379. doi:10.1007/s11251-005-1272-9.

Baylor, A.L. and Kim, Y. (2004) 'Pedagogical Agent Design: The Impact of Agent Realism, Gender, Ethnicity, and Instructional Role', in Lester, J.C., Vicari, R.M., and Paraguaçu, F. (eds) *Intelligent Tutoring Systems. ITS 2004*, Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 592–603.

Behr, A. *et al.* (2020) 'Dropping out of university: a literature review', *614-652*, 8(2), p. 39. doi:10.1002/rev3.3202.

Biswas, G. *et al.* (2005) 'LEARNING BY TEACHING: A NEW AGENT PARADIGM FOR EDUCATIONAL SOFTWARE', *Applied Artificial Intelligence*, 19(3–4), pp. 363–392. doi:10.1080/08839510590910200.

Bjork, R.A., Dunlosky, J. and Kornell, N. (2013) 'Self-Regulated Learning: Beliefs, Techniques, and Illusions', *Annual Review of Psychology*, 64, pp. 417–444. doi:10.1146/annurev-psych-113011-143823.

Boekaerts, M. (1999) 'Self-regulated learning: where we are today', *International Journal of Educational Research*, 31(6), pp. 445–457. doi:10.1016/S0883-0355(99)00014-2.

Boekaerts, M. (2006) 'Self-Regulation and Effort Investment', in *Handbook of child psychology: Child psychology in practice, Vol. 4, 6th ed.* Hoboken, NJ, US: John Wiley & Sons Inc, pp. 345–377.

Boekaerts, M. (2011) 'Emotions, Emotion Regulation, and Self-Regulation of Learning', in *Handbook of Self-Regulation of Learning and Performance*. Routledge. doi:10.4324/9780203839010.ch26.

Bosch, N. *et al.* (2021) 'Students' Verbalized Metacognition During Computerized Learning', in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems. CHI '21*, Yokohama Japan: ACM, pp. 1–12. doi:10.1145/3411764.3445809.

Bouchet, F., Harley, J.M. and Azevedo, R. (2013) 'Impact of Different Pedagogical Agents' Adaptive Self-regulated Prompting Strategies on Learning with MetaTutor', in Lane, H.C. et al. (eds) *Artificial Intelligence in Education. AIED 2013*, Berlin, Heidelberg: Springer Berlin Heidelberg (Lecture Notes in Computer Science), pp. 815–819. doi:10.1007/978-3-642-39112-5_120.

Bouchet, F., Harley, J.M. and Azevedo, R. (2016) 'Can Adaptive Pedagogical Agents' Prompting Strategies Improve Students' Learning and Self-Regulation?', in Micarelli, A., Stamper, J., and Panourgia, K. (eds) *Intelligent Tutoring Systems. ITS 2016*, Cham: Springer International Publishing (Lecture Notes in Computer Science), pp. 368–374. doi:10.1007/978-3-319-39583-8_43.

Bouchet, F., Harley, J.M. and Azevedo, R. (2018) 'Evaluating Adaptive Pedagogical Agents' Prompting Strategies Effect on Students' Emotions', in Nkambou, R., Azevedo, R., and Vassileva, J. (eds) *Intelligent Tutoring Systems. ITS 2018*, Cham: Springer International Publishing (Lecture Notes in Computer Science), pp. 33–43. doi:10.1007/978-3-319-91464-0_4.

Cabales, V. (2019) 'Muse: Scaffolding Metacognitive Reflection in Design-Based Research', in *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems. CHI '19: CHI Conference on Human Factors in Computing Systems*, Glasgow Scotland Uk: ACM, pp. 1–6. doi:10.1145/3290607.3308450.

Cerezo, R. *et al.* (2020) 'Differential Efficacy of an Intelligent Tutoring System for University Students: A Case Study with Learning Disabilities', *Sustainability*, 12(21), p. 9184. doi:10.3390/su12219184.

Chatzara, K., Karagiannidis, C. and Stamatis, D. (2016) 'Cognitive support embedded in self-regulated e-learning systems for students with special learning needs', *Education and Information Technologies*, 21(2), pp. 283–299. doi:10.1007/s10639-014-9320-1.

Clarebout, G. and Elen, J. (2006) 'Open Learning Environments and the Impact of a Pedagogical Agent', *Journal of Educational Computing Research*, 35(3), pp. 211–226. doi:10.2190/3UL1-4756-H837-2704.

Cloude, E.B. *et al.* (2020) 'How do Emotions Change during Learning with an Intelligent Tutoring System? Metacognitive Monitoring and Performance with MetaTutor', in *Proceedings of the 42nd Annual Conference of the Cognitive Science Society*. *CogSci*, Cognitive Science Society, pp. 423–429.

destatis (2021) *Prüfungen an Hochschulen*. Fachserie 11 Reihe 4.2.

Devolder, A., van Braak, J. and Tondeur, J. (2012) 'Supporting self-regulated learning in computer-based learning environments: systematic review of effects of scaffolding in the domain of science education: Scaffolding self-regulated learning with CBLES', *Journal of Computer Assisted Learning*, 28(6), pp. 557–573. doi:10.1111/j.1365-2729.2011.00476.x.

Duffy, M.C. and Azevedo, R. (2015) 'Motivation matters: Interactions between achievement goals and agent scaffolding for self-regulated learning within an intelligent tutoring system', *Computers in Human Behavior*, 52, pp. 338–348. doi:10.1016/j.chb.2015.05.041.

Efklides, A. (2011) 'Interactions of Metacognition With Motivation and Affect in Self-Regulated Learning: The MASRL Model', *Educational Psychologist*, 46(1), pp. 6–25. doi:10.1080/00461520.2011.538645.

Feine, J. *et al.* (2019) 'A Taxonomy of Social Cues for Conversational Agents', *International Journal of Human-Computer Studies*, 132, pp. 138–161. doi:10.1016/j.ijhcs.2019.07.009.

Garcia, R., Falkner, K. and Vivian, R. (2018) 'Systematic literature review: Self-Regulated Learning strategies using e-learning tools for Computer Science', *Computers & Education*, 123, pp. 150–163. doi:10.1016/j.compedu.2018.05.006.

Graesser, A.C. *et al.* (1999) 'AutoTutor: A simulation of a human tutor', *Cognitive Systems Research*, 1(1), pp. 35–51. doi:10.1016/S1389-0417(99)00005-4.

Hadwin, A. and Oshige, M. (2011) 'Self-Regulation, Coregulation, and Socially Shared Regulation: Exploring Perspectives of Social in Self-Regulated Learning Theory', *Teachers College Record*, 113(2), pp. 240–264. doi:10.1177/016146811111300204.

Harley, J.M. *et al.* (2016) 'Examining the predictive relationship between personality and emotion traits and students' agent-directed emotions: towards emotionally-adaptive agent-based learning environments', *User Modeling and User-Adapted Interaction*, 26(2–3), pp. 177–219. doi:10.1007/s11257-016-9169-7.

Harley, J.M. *et al.* (2018) 'Let's Set Up Some Subgoals: Understanding Human-Pedagogical Agent Collaborations and Their Implications for Learning and Prompt and Feedback Compliance', *IEEE Transactions on Learning Technologies*, 11(1), pp. 54–66. doi:10.1109/TLT.2017.2756629.

HESA (2021) *Higher Education Student Statistics: UK, 2019/20*, *Higher Education Student Statistics: UK, 2019/20 | HESA*. Available at: https://www.hesa.ac.uk/news/27-01-2021/sb258-higher-education-student-statistics (Accessed: 18 March 2022).

Hew, K.F. *et al.* (2021) 'Using Chatbots in Flipped Learning Online Sessions: Perceived Usefulness and Ease of Use', in Li, R. et al. (eds) *Blended Learning: Re-thinking and Re-defining the Learning Process. ICBL*, Cham: Springer International Publishing, pp. 164–175.

Hidayah, I., Adji, T.B. and Setiawan, N.A. (2018) 'A Framework for Improving Recommendation in Adaptive Metacognitive Scaffolding', in *2018 4th International Conference on Science and Technology (ICST)*. *2018 4th International Conference on Science and Technology (ICST)*, Yogyakarta: IEEE. doi:10.1109/ICSTC.2018.8528664.

Hidayat, W.N. *et al.* (2018) 'What is informatics education students' impression of using metacognitive training system at the first time?', in *2018 International Conference on Advanced Computer Science*

*and Information Systems (ICACSIS)*. ICACSIS, Yogyakarta: IEEE, pp. 213–218. doi:10.1109/ICACSIS.2018.8618171.

Jones, A. and Castellano, G. (2018) 'Adaptive Robotic Tutors that Support Self-Regulated Learning: A Longer-Term Investigation with Primary School Children', *International Journal of Social Robotics*, 10, pp. 357–370. doi:10.1007/s12369-017-0458-z.

Karaoğlan Yılmaz, F.G., Olpak, Y.Z. and Yılmaz, R. (2018) 'The Effect of the Metacognitive Support via Pedagogical Agent on Self-Regulation Skills', *Journal of Educational Computing Research*, 56(2), pp. 159–180. doi:10.1177/0735633117707696.

Kautzmann, T.R., Carlotto, T. and Jaques, P.A. (2016) 'Adaptive Training of the Metacognitive Skill of Knowledge Monitoring in Intelligent Tutoring Systems', in Micarelli, A., Stamper, J., and Panourgia, K. (eds) *Intelligent Tutoring Systems. ITS 2016*, Cham: Springer International Publishing, pp. 301–306.

Kautzmann, T.R. and Jaques, P.A. (2018) 'Improving the Metacognitive Ability of Knowledge Monitoring in Computer Learning Systems', in Cristea, A.I., Bittencourt, I.I., and Lima, F. (eds) *Higher Education for All. From Challenges to Novel Technology-Enhanced Solutions. HEFA 2017*, Cham: Springer International Publishing, pp. 124–140.

Kautzmann, T.R. and Jaques, P.A. (2019) 'Effects of adaptive training on metacognitive knowledge monitoring ability in computer-based learning', *Computers & Education*, 129, pp. 92–105. doi:10.1016/j.compedu.2018.10.017.

Kerly, A. and Bull, S. (2008) 'Children's Interactions with Inspectable and Negotiated Learner Models', in Woolf, B.P. et al. (eds) *Intelligent Tutoring Systems. ITS 2008*, Berlin, Heidelberg: Springer Berlin Heidelberg (Lecture Notes in Computer Science), pp. 132–141. doi:10.1007/978-3-540-69132-7_18.

Kerly, A., Ellis, R. and Bull, S. (2008) 'CALMsystem: A Conversational Agent for Learner Modelling', in Ellis, R., Allen, T., and Petridis, M. (eds) *Proceedings of AI-2007, 27th SGAI International Conference on Innovative Techniques and Applications of Artificial Intelligence. AI*, London: Springer London, pp. 89–102.

Kim, C. and Bennekin, K.N. (2016) 'The effectiveness of volition support (VoS) in promoting students' effort regulation and performance in an online mathematics course', *Instructional Science*, 44(4), pp. 359–377. doi:10.1007/s11251-015-9366-5.

Kim, S., Zhang, K. and Park, D. (2018) 'Don't Want to Look Dumb? The Role of Theories of Intelligence and Humanlike Features in Online Help Seeking', *Psychological Science*, 29(2), pp. 171–180. doi:10.1177/0956797617730595.

Kim, Y. and Baylor, A.L. (2006) 'A Social-Cognitive Framework for Pedagogical Agents as Learning Companions', *Educational Technology Research and Development*, 54(6), pp. 569–596. doi:10.1007/s11423-006-0637-3.

Kitchenham, B. and Charters, S. (2007) *Guidelines for performing systematic literature reviews in software engineering*.

Kornell, N. and Bjork, R.A. (2007) 'The promise and perils of self-regulated study', *Psychonomic Bulletin & Review*, 14(2), pp. 219–224. doi:10.3758/BF03194055.

Kornell, N. and Bjork, R.A. (2008) 'Learning Concepts and Categories: Is Spacing the "Enemy of Induction"?', *Psychological Science*, 19(6), pp. 585–592. doi:10.1111/j.1467-9280.2008.02127.x.

Kornell, N. and Bjork, R.A. (2009) 'A stability bias in human memory: Overestimating remembering and underestimating learning.', *Journal of Experimental Psychology: General*, 138(4), pp. 449–468. doi:10.1037/a0017350.

Kuttal, S.K. *et al.* (2021) 'Trade-offs for Substituting a Human with an Agent in a Pair Programming Context: The Good, the Bad, and the Ugly', in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems. CHI '21: CHI Conference on Human Factors in Computing Systems*, Yokohama Japan: ACM, pp. 1–20. doi:10.1145/3411764.3445659.

Lallé, S. *et al.* (2016) 'Impact of Individual Differences on Affective Reactions to Pedagogical Agents Scaffolding', in Traum, D. et al. (eds) *Intelligent Virtual Agents. IVA 2016*, Cham: Springer International Publishing (Lecture Notes in Computer Science), pp. 269–282. doi:10.1007/978-3-319-47665-0_24.

Lau, C. *et al.* (2017) 'Transitioning self-regulated learning profiles in hypermedia-learning environments', in *Proceedings of the seventh international learning analytics & knowledge conference. LAK '17*, New York, NY, USA: Association for Computing Machinery (LAK '17), pp. 198–202. doi:10.1145/3027385.3027443.

Lee, D., Watson, S.L. and Watson, W.R. (2019) 'Systematic literature review on self-regulated learning in massive open online courses', *Australasian Journal of Educational Technology*, 35(1), pp. 28–41. doi:10.14742/ajet.3749.

Maedche, A. *et al.* (2019) 'AI-Based Digital Assistants: Opportunities, Threats, and Research Perspectives', *Business & Information Systems Engineering*, 61(4), pp. 535–544. doi:10.1007/s12599-019-00600-8.

Mega, C., Ronconi, L. and De Beni, R. (2014) 'What makes a good student? How emotions, self-regulated learning, and motivation contribute to academic achievement.', *Journal of Educational Psychology*, 106(1), pp. 121–131. doi:10.1037/a0033546.

van der Meij, H., van der Meij, J. and Harmsen, R. (2015) 'Animated pedagogical agents effects on enhancing student motivation and learning in a science inquiry learning environment', *Educational Technology Research and Development*, 63, pp. 381–403. doi:10.1007/s11423-015-9378-5.

MIT Registrar (2022) *Degrees Awarded, Degrees Awarded / MIT Registrar*. Available at: https://registrar.mit.edu/stats-reports/degrees-awarded/all (Accessed: 18 March 2022).

Mudrick, N. *et al.* (2014) 'A Study of subjective emotions, self-regulatory processes, and learning gains: are pedagogical agents effective in fostering learning?', in *Learning and becoming in practice: The International Conference of the Learning Sciences (ICLS) 2014. ICLS*, International Society of the Learning Sciences, pp. 309–316.

Nass, C. and Moon, Y. (2000) 'Machines and Mindlessness: Social Responses to Computers', *Journal of Social Issues*, 56(1), pp. 81–103. doi:10.1111/0022-4537.00153.

OECD (2019) *Education at a Glance 2019: OECD Indicators*. Paris: OECD Publishing (Education at a Glance). doi:10.1787/f8d7880d-en.

OECD (2021) *Education at a Glance 2021: OECD Indicators*. Paris: OECD Publishing (Education at a Glance). doi:10.1787/b35a14e5-en.

Page, M.J. *et al.* (2021) 'The PRISMA 2020 statement: an updated guideline for reporting systematic reviews', *BMJ*, 372, p. n71. doi:10.1136/bmj.n71.

Pérez, J.Q., Daradoumis, T. and Puig, J.M.M. (2020) 'Rediscovering the use of chatbots in education: A systematic literature review', *Computer Applications in Engineering Education*, 28(6), pp. 1549–1565. doi:10.1002/cae.22326.

Pesonen, J.A. (2021) '"Are You OK?" Students' Trust in a Chatbot Providing Support Opportunities', in Zaphiris, P. and Ioannou, A. (eds) *Learning and Collaboration Technologies: Games and Virtual Environments for Learning. HCII 2021*, Cham: Springer (Lecture Notes in Computer Science), pp. 199–215. doi:10.1007/978-3-030-77943-6.

Pintrich, P.R. (2000) 'The Role of Goal Orientation in Self-Regulated Learning', in *Handbook of Self-Regulation*. Elsevier, pp. 451–502. doi:10.1016/B978-012109890-2/50043-3.

Poitras, E., Lajoie, S. and Hong, Y.-J. (2012) 'Using the MetaHistoReasoning Tool Training Module to Facilitate the Acquisition of Domain-Specific Metacognitive Strategies', in Cerri, S.A. et al. (eds) *Intelligent Tutoring Systems. ITS 2012*, Berlin, Heidelberg: Springer Berlin Heidelberg (Lecture Notes in Computer Science), pp. 511–516. doi:10.1007/978-3-642-30950-2_66.

Poitras, E.G. and Lajoie, S.P. (2014) 'Developing an agent-based adaptive system for scaffolding self-regulated inquiry learning in history education', *Educational Technology Research and Development*, 62(3), pp. 335–366. doi:10.1007/s11423-014-9338-5.

Rawson, K.A. and Kintsch, W. (2005) 'Rereading Effects Depend on Time of Test.', *Journal of Educational Psychology*, 97(1), pp. 70–80. doi:10.1037/0022-0663.97.1.70.

Reiser, B.J. (2002) 'Why scaffolding should sometimes make tasks more difficult for learners', in *Proceedings of the Conference on Computer Support for Collaborative Learning Foundations for a CSCL Community - CSCL '02. CSCL*, Boulder, Colorado: Association for Computational Linguistics, pp. 255–264. doi:10.3115/1658616.1658652.

Schunk, D.H. and Greene, J.A. (2018) 'Historical, contemporary, and future perspectives on self-regulated learning and performance', in Schunk, D.H. and Greene, J.A. (eds) *Handbook of self-regulation of learning and performance*. Routledge/Taylor & Francis Group, pp. 1–15.

Shafilla subri, M.A. and Bin Md. Shah, M.F. (2013) 'Perception towards Pedagogical Agents and Their Effects on Self-regulated Learning and Performance in Physics among Form-4 Students', *The International Journal of Science, Mathematics and Technology Learning*, 19(4), pp. 13–37. doi:10.18848/2327-7971/CGP/v19i04/49016.

Smelser, N.J. and Baltes, P.B. (eds) (2001) *International encyclopedia of the social & behavioral sciences*. 1st ed. Amsterdam ; New York: Elsevier.

Song, D. and Kim, D. (2021) 'Effects of self-regulation scaffolding on online participation and learning outcomes', *Journal of Research on Technology in Education*, 53(3), pp. 249–263. doi:10.1080/15391523.2020.1767525.

Suleman, R.M., Mizoguchi, R. and Ikeda, M. (2016) 'NDLtutor: An Automated Conversational Agent to Facilitate Metacognitive Skills in Fully-Negotiated OLMs', in Micarelli, A., Stamper, J., and Panourgia, K. (eds) *Intelligent Tutoring Systems. ITS 2016*, Cham: Springer International Publishing (Lecture Notes in Computer Science), pp. 354–360. doi:10.1007/978-3-319-39583-8_41.

Taub, M. *et al.* (2014) 'Can the use of cognitive and metacognitive self-regulated learning strategies be predicted by learners' levels of prior knowledge in hypermedia-learning environments?', *Computers in Human Behavior*, 39, pp. 356–367. doi:10.1016/j.chb.2014.07.018.

Taub, M. *et al.* (2021) 'How are students' emotions related to the accuracy of cognitive and metacognitive processes during learning with an intelligent tutoring system?', *Temporal and adaptive process of regulated learning -what can multimodal data tell?*, 72, p. 101200. doi:10.1016/j.learninstruc.2019.04.001.

Tian, X. *et al.* (2021) 'Let's Talk It Out: A Chatbot for Effective Study Habit Behavioral Change', *Proceedings of the ACM on Human-Computer Interaction*, 5(CSCW1), p. 97. doi:10.1145/3449171.

Trevors, G., Duffy, M. and Azevedo, R. (2014) 'Note-taking within MetaTutor: interactions between an intelligent tutoring system and prior knowledge on note-taking and learning', *Educational Technology Research and Development*, 62, pp. 507–528. doi:10.1007/s11423-014-9343-8.

Usher, E.L. and Schunk, D.H. (2018) 'Social cognitive theoretical perspective of self-regulation.', in Schunk, D.H. and Greene, J.A. (eds) *Handbook of Self-Regulation of Learning and Performance*. Routledge/Taylor & Francis Group (Educational Psychology Handbook Series), pp. 19–35.

Valencia-Vallejo, N., López-Vargas, O. and Sanabria-Rodríguez, L. (2018) 'Effect of Motivational Scaffolding on E-Learning Environments: Self-Efficacy, Learning Achievement, and Cognitive Style', *Journal of Educators Online*, 15(1). doi:10.9743/JEO2018.15.1.5.

Valencia-Vallejo, N., López-Vargas, O. and Sanabria-Rodríguez, L. (2019) 'Effect of a metacognitive scaffolding on self-efficacy, metacognition, and achievement in e-learning environments', *Knowledge Management & E-Learning: An International Journal*, 11(1), pp. 1–19. doi:10.34105/j.kmel.2019.11.001.

Webster, J. and Watson, R.T. (2002) 'Analyzing the Past to Prepare for the Future: Writing a Literature Review', *MIS Quarterly*, 26(2), p. 12.

Wong, J. *et al.* (2019) 'Supporting Self-Regulated Learning in Online Learning Environments and MOOCs: A Systematic Review', *International Journal of Human–Computer Interaction*, 35(4–5), pp. 356–373. doi:10.1080/10447318.2018.1543084.

Wortha, F. *et al.* (2019) 'Multiple Negative Emotions During Learning With Digital Learning Environments – Evidence on Their Detrimental Effect on Learning From Two Methodological Approaches', *Frontiers in Psychology*, 10, p. 2678. doi:10.3389/fpsyg.2019.02678.

Zhang, Y. *et al.* (2020) 'The relationship between confusion and metacognitive strategies in Betty's Brain', in *Proceedings of the Tenth International Conference on Learning Analytics & Knowledge. LAK '20*, Frankfurt Germany: ACM, pp. 276–284. doi:10.1145/3375462.3375518.

Zimmerman, B.J. (2000) 'Attaining self-regulation: A social cognitive perspective', in *Handbook of Self-Regulation*. Elsevier, pp. 13–39. doi:10.1016/B978-012109890-2/50031-7.

Zimmerman, B.J. and Pons, M.M. (1986) 'Development of a Structured Interview for Assessing Student Use of Self-Regulated Learning Strategies', *American Educational Research Journal*, 23(4), pp. 614–628. doi:10.3102/00028312023004614.