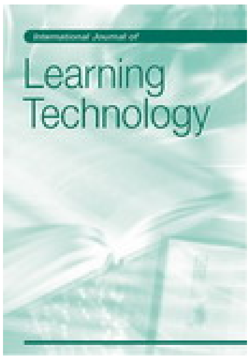


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# An analysis of technological resources to encourage self-regulated learning behaviour in virtual learning environments in the last decade

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# An analysis of technological resources to encourage self-regulated learning behaviour in virtual learning environments in the last decade

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**Abstract:** Virtual learning environments have become increasingly intelligent and supplied with individualised resources for a more engaging and effective learning process. In particular, technologies that not only provide support but also encourage self-regulated learning are desirable, as this competence has numerous benefits. Thus, this work presents a systematic literature review to outline an overview of such technologies, considering works published between 2011 and 2020. This paper presents a process for selecting studies based on Cohen's weighted kappa statistic, intending to decrease the inter-rater bias. Results have shown that information visualisation techniques, interactive learning resources, content recommendations, and strategies for feedback have been used in all phases of the self-regulatory process, mainly in higher education. Therefore, this paper intends to provide an overview of the state-of-the-art and give directions on different technologies used to support self-regulatory features in virtual learning environments.

**Keywords:** self-regulated learning; SRL; virtual learning environments; systematic literature review.

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## 1 Introduction

The increasing development of technological resources in intelligent learning environments has caused changes in the teaching and learning processes. Virtual learning environments (VLEs) apply different resources to support educational processes, which are often implemented to improve academic performance and students' motivation, and to reduce dropout. VLEs are online computational systems used for educational purposes in different areas and levels. One of the possible features present in these environments, but not limited to, is related to the use of virtual reality, in which graphical resources are combined with various display devices and interfaces to provide an immersive effect in the interactive environment.

VLE is a concept that emerged in the mid-1990s, right after the internet popularisation (O'Leary and Ramsden, 2002). Such environments can be understood as information systems specific to the educational context, and provide administrative and didactic support to the teaching and learning process through technological resources through the internet (Mueller and Strohmeier, 2011). These resources can be diverse and have different natures. Still, they generally include shared spaces for the distribution of educational materials and resources, communication between students and teachers/tutors, and mechanisms for evaluation, management, and monitoring of students (Dillenbourg et al., 2002). In addition, a VLE can be used in different contexts, in formal or informal education, and in different modalities, whether face-to-face, distance, or hybrid.

Considering the high availability of information and resources available on the internet, educators have faced difficulties in preparing educational materials to comply with different students considering levels of knowledge on a given subject and, also, different cognitive profiles. VLEs have the potential to provide an instructional and collaborative architecture, considering the particularities of each student. Students also can get to know their apprenticeship pace while creating autonomy in their learning process.

However, technological resources alone are not sufficient to guarantee the success of a VLE. According to the study carried out by Mueller and Strohmeier (2011), its success is related to the design characteristics of the system itself – such as communication skills, usability, reliability, interactivity, accessibility, flexibility, feedback, quality of both content and courses, and relevance and quality of information.

In this scenario, it has been observed the importance of providing technological mechanisms integrated into the learning environments to foster the self-regulated learning process (Viberg et al., 2020). Studies show that self-regulation of learning is related to academic performance (Zimmerman and Martinez-Pons, 1986). In self-regulated learning, the student is the protagonist of his learning and can develop several cognitive, metacognitive, motivational, and emotional/affective strategies to self-regulate his learning (Panadero, 2017). However, the learning environment must provide not only support but also acts proactively to encourage self-regulation. In this work, we consider that a digital environment 'encourages' a self-regulated behaviour when it goes beyond supporting students with different tools at different stages of self-regulated learning (SRL) models and encourages them to use these tools through computational strategies and techniques.

For this, we highlight that VLEs must make students not only active, but also players, that is, members and contributors of the social and informational space

(Dillenbourg et al., 2002). Regarding the relevance of this context, this work aims to provide an overview of the technologies that have been used to proactively stimulate self-regulated learning in VLEs considering works published in the last decade, between 2011 and 2020.

Other secondary studies have also been produced addressing SRL, however, with different goals. Garcia et al. (2018) conducted a systematic literature review that describes e-learning tools that support SRL in the computer science area according to the taxonomy presented by Zimmerman and Martinez-Pons (1986). Other literature reviews sought to identify techniques and tools to measure SRL (Araka et al., 2020) or to identify strategies that positively influence learning in MOOCs (Lee et al., 2019). In all cases, broader learning environments, such as smart learning environments, were not considered, and there was no distinction between 'support' and 'encourage' this behaviour. It is also noteworthy that this work extends a previous work (Lima et al., 2020), including the Scopus database, protocol change with the inclusion of the weighted Cohen's kappa to measure the level of inter-rater agreement, in-depth discussions, and manuscript writing in English.

The article is structured as follows: Section 2 presents a discussion on self-regulated learning; Section 3 presents the research methodology; Section 4 presents results and discussions related to research questions; and, finally, the final considerations are presented in Section 5.

## 2 Self-regulated learning

SRL is a research area of educational psychology that studies personal aspects of students that influence their self-guided learning process. SRL is a conceptual framework for understanding the cognitive, meta-cognitive, behavioural, motivational, and emotional/affective aspects of learning (Panadero, 2017). In competitive and evaluative contexts, human achievements depend very much on the individual's ability to self-regulation (Zimmerman and Martinez-Pons, 1986).

However, using SRL strategies and competencies is not a trivial task for anyone, as it is necessary to develop skills related to engagement, self-monitoring, self-assessment, self-perceived skills, and understanding of the context (Garcia et al., 2018). In the work of Zimmerman and Martinez-Pons (1986), 14 categories of self-regulatory strategies were described and an extra category, called 'other', was inserted to indicate behaviour that is not self-regulated. Table 1 presents all categories and their descriptions.

The taxonomy proposed by the authors was developed through interviews with high school students. SRL strategies were applied in different learning contexts: face-to-face and non-face-to-face. Students were asked to indicate which methods were used to participate in a class, study and perform tasks. The strategies defined by the authors have been discussed and used in several self-regulated learning surveys. The results show that the self-regulation of learning is related to academic performance. The group of students with higher academic performance used more SRL strategies than students with lower performance.

In the review carried out by Panadero (2017), six models of SRL were presented and compared: Zimmerman (1986), Boekaerts (1988), Winne and Hadwin (1998), Pintrich and Groot (1990), Efklides (2011) and Hadwin et al. (2011). According to Panadero (2017) and Puustinen and Pulkkinen (2001), SRL models can be defined as cyclical and have different phases and sub-processes of self-regulation. SRL phases with some sub-processes are described in Table 2. Although the models present different nomenclatures for the processes, their understanding allows them to be grouped into three major phases:

a preparatory (or planning)

b execution

c evaluation.

The preparatory phase comprises the analysis of tasks, the planning, the definition of objectives, and the establishment of goals (Panadero, 2017). In this phase, one can use, among other technologies, administrative tools such as a calendar so that the student can plan the course development. Considering the preparatory phase, Kitsantas (2013) mentions two technologies that can be used: blogs/online newspapers and podcasts.

**Table 1** Self-regulated learning strategies

| *Strategy categories* | *Definition* |
|---|---|
| Self-assessment | Assessing the quality or progress of student-initiated work. |
| Organisation and transformation | Students rearrange materials to improve their learning. |
| Set of objectives and planning | Students establish a set of educational goals and sub-goals as well as their planning for completing the activities. |
| Information search | Searching for information in different media in order to perform a task. |
| Record keeping and monitoring | Records of events or results. |
| Structuring of the environment | Organisation of the learning environment in order to improve performance. |
| Self-consequence | Punishment or praise for performing tasks. |
| Listen again and memorise | Memorising the studied material through practice. |
| Seeking social assistance (peers) | Request help from colleagues. |
| Seeking social assistance (teachers) | Request help from the teacher. |
| Seeking social assistance (adults) | Request help from adults (family). |
| Testing review | Review tests. |
| Annotation review | Review annotations. |
| Textbook review | Review textbooks used during the learning process. |
| Other | Statements indicating learning behaviour initiated by others, for example, parents or teachers. |

*Source:* Zimmerman and Martinez-Pons (1986)

**Table 2** Definition of phases and sub-processes

| *Phases* | *Sub-processes* |
|---|---|
| Preparatory | Forecasting, task analysis, definition of objectives and goals. |
| Execution | Performance, monitoring, implementation of strategies. |
| Assessment | Feedback, regulation, adaptation and self-reflection. |

*Source:* Panadero (2017) and Puustinen and Pulkkinen (2001)

Blogs/newspapers allow students to provide and receive feedback from colleagues about the contents and to prepare a study guide. Because it is an open technology, students can post questions, interact, and create a collaborative environment. Podcasts are multimedia resources that students access at any time. Therefore, the recordings of study groups can be used to outline the student's learning objectives. In this phase, students who use SRL strategies demonstrate more self-efficacy, a greater expectation of results, and interest in tasks than other students (Kitsantas, 2013).

The second phase presented in the SRL models is the execution phase, where tasks are performed while monitoring progress and performance (Panadero, 2017). Various web publishing tools to underline, highlight and group teaching materials can be used at this stage. The work of Kitsantas (2013) describes several technologies that can help at this stage: social networks, virtual environments, administrative tools, testing tools, discussion forums, and bookmarks. Social networks are an important tool for student motivation. Most adolescents and adults currently access and dedicate part of their time to some social network. These interactions are important for connecting students and professionals. With the incorporation of social resources, students can self-monitor and define strategies for carrying out tasks.

In the execution phase, it is important to develop and execute a good study plan, with well-defined task strategies. A tool for time management will assist students in the self-control of activities performed. Virtual environments, on the other hand, offer several tools for carrying out learning activities. The student can use virtual tools to perform simulations, modelling, training, and online meetings. Keeping the activity records is important to perform time management on the tasks performed. Wiki is also a virtual, collaborative tool that can be used for students to create, edit, and manage their environment with various publications and receive feedback from colleagues and teachers. The self-regulation process includes self-monitoring, strategy definition, self-control, and peer modelling.

Finally, there is the evaluation phase, where the student reflects, regulates, and adapts his learning process for future executions (Panadero, 2017). In this phase, blogs can also be allies to improve students' understanding of the subject, thus allowing the student to self-monitor and self-evaluate (Kitsantas, 2013). Blogs and Wikis are important tools for collaborative learning and knowledge sharing. Students use these tools to monitor their evolutionary process within the platform and to receive feedback. The dissemination of bulletins with grades can help students in their self-assessments.

Students with higher academic performances tend to self-assess more frequently than those with low performance (Zimmerman and Martinez-Pons, 1986). After evaluating himself, the student can reestablish new goals and outline new learning strategies to improve his academic performance.

## 3 Methodology

The process of conducting this systematic literature review was based on the proposal of Kitchenham (2004), which suggests the division into three main phases: planning, execution, and report of the review. These phases are described below, while the last one, referring to the results, is presented in Section 4.

### *3.1 Planning phase*

The planning phase involved the definition of the research questions, the definition of the academic databases to be searched for, and the inclusion and exclusion criteria. Thus, the following research questions (RQ) were outlined:

RQ1 Which intervention strategies and/or technologies have been used to stimulate self-regulatory capabilities in virtual learning environments?

RQ2 In which contexts and levels of education have these tools been used?

RQ3 Which SRL models are mostly used in this context?

Six academic and research databases that index the main publishing vehicles in the field of computing were selected: ACM Digital Library (ACM DL)[1], IEEE Xplore[2], SpringerLink[3], Scopus[4], Web of Science[5], and Brazilian Symposium on Computers in Education (SBIE)[6]. The latter was included because it is the main Brazilian conference in this area. The inclusion (IC) and exclusion (EC) criteria of the works are defined in Table 3.

**Table 3** Inclusion and exclusion criteria

| *Inclusion criteria (IC)* | | *Exclusion criteria (EC)* | |
|---|---|---|---|
| (IC1) | Article published between the period 2011 to 2020 | (EC1) | Focuses only on the theory/model of SRL |
| (IC2) | Article written in English or Portuguese | (EC2) | It is an abstract or poster |
| | | (EC3) | It is not a primary study |
| (IC3) | It explicitly presents some intervention strategy or resource to promote SRL in VLEs | (EC4) | PDF not available or not found |

### *3.2 Execution phase*

The execution phase comprises five steps:

1 definition of search strings and their processing by databases search engines

2 initial study selection

3 weighted Cohen's kappa, which is used to measure the level of inter-rater agreement

4 complete reading of articles and extraction of information

5 systematisation of the data.

The search for works on scientific databases is allowed by text strings that represent the desired concepts. As the main research question is related to technologies/concepts in a broad and non-specialised aspect, it was decided to create strings considering more generic terms, such as *online learning environments* and *self-regulated learning*. The strings were built according to the instructions and rules provided by each database in order to allow searching in title, abstract, and keywords, using logical operators and wildcards (such as the * character). Table 4 shows the search strings used for each database.

**Table 4** Search strings for each database

| *Database* | *Search string* |
|---|---|
| ACM DL | Title: ('self-regulated learning') AND Title: ('online learning*' 'online* env*' 'e-learning') OR Abstract: ('self-regulated learning') AND Abstract: ('online learning*' 'online * env*' 'e-learning') OR Keyword: ('self-regulated learning') |
| IEEE Xplore | ('all metadata': 'self-regulated learning') AND (('all metadata': 'online learning*' OR 'all metadata': 'online* env*') OR 'All Metadata': 'e-learning') |
| SpringerLink | Title: ('self-regulated learning' AND 'online learning*' 'online* env*' 'e-learning') OR su: ('self-regulated learning' AND 'online learning*' 'online * env*' 'e-learning') OR Key: 'self-regulated learning' |
| SBIE | 'self-reg*' or autorreg* or 'auto-reg*' |
| Scopus | TITLE-ABS-KEY ('self-regulated learning') AND TITLE-ABS-KEY ('online learning*' OR 'online* env*' OR 'e-learning') |
| Web of Science | TS = ('self-regulated learning') AND (TS = ('online learning*') OR TS = ('online* env*') OR TS = ('e-learning')) |

**Table 5** Interpretation of k values

| *Kappa statistic* | *Strength of agreement* |
|---|---|
| <0.00 | Poor |
| 0.00–0.20 | Slight |
| 0.21–0.40 | Fair |
| 0.41–0.60 | Moderate |
| 0.61–0.80 | Substantial |
| 0.81–1.00 | Almost perfect |

*Source:* Landis and Koch (1977)

The selection of papers involves reviewing the papers returned in the search and selecting those that are relevant to the goal of the systematic review according to the defined IC/EC. To ensure the reliability and repeatability of the article selection process, a lack of bias is necessary (Zhang and Babar, 2013). Dybå and Dingsøyr (2008) define bias as "a systematic error, or deviation from the truth, in results or inferences."

The problem of bias can be solved if two researchers perform the selection process. There are statistical methods that help reviewers with this problem, such as weighted kappa (Budgen and Brereton, 2006). Zhang and Babar (2013) suggest that whenever there are discrepancies about whether or not a study should be included, both reviewers should discuss it until an agreement is reached. An agreement/disagreement table (ADT) is created with the selected results. In this work, a third evaluator was included to discuss the disagreements. All disagreements are discussed among all raters and resolved by consensus.

Cohen's weighted kappa measures the concordance between two judges' classifications of N elements into C mutually exclusive categories. The coefficient (k) takes into consideration the different levels of disagreement between categories (Tang et al., 2015). A rater can 'strongly disagree' and another 'strongly agree', and this must be considered a greater level of disagreement than when one rater 'agree' and another 'strongly agree'.

**Figure 1** Overview of the SRL process (see online version for colours)

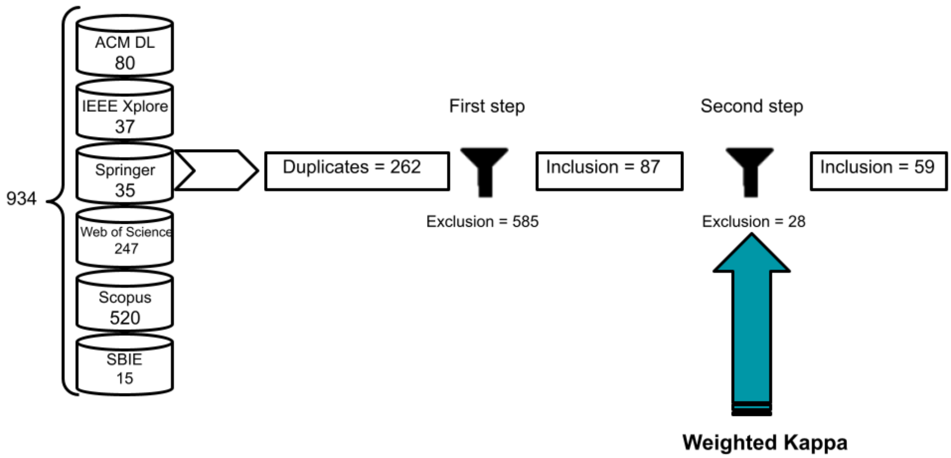
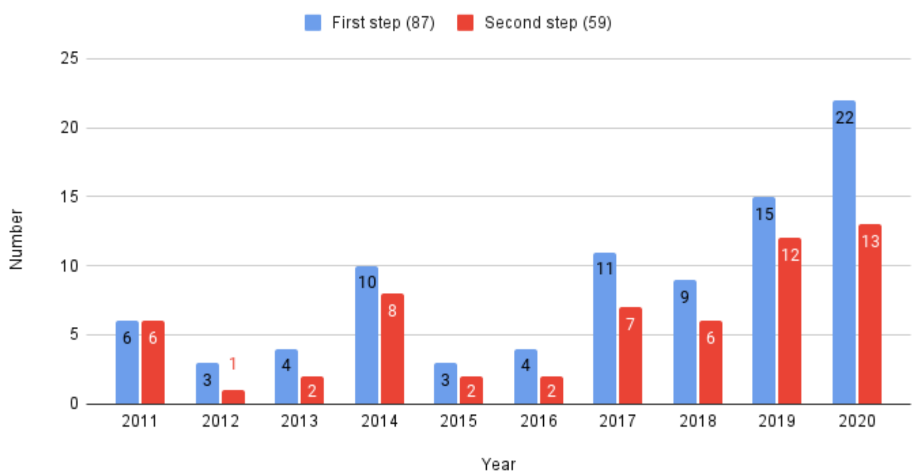



**Figure 2** Number of articles per year in each stage (see online version for colours)




The maximum kappa coefficient is 1, which occurs when (and only when) there is perfect agreement between the judges. The closer to 1, the stronger the agreement. When kappa = 0, the agreement is expected by chance. Values for $k < 0$ correspond to a less-than-chance agreement. Landis and Koch (1977) proposed the categories shown in Table 5 for evaluating intermediate values.

When the search strings were performed on the selected databases, 934 entries were returned. The results were tabulated on an electronic spreadsheet and, it was found that there were 262 duplicate entries. In the first step, the title and summary of the articles were read, applying the inclusion and exclusion criteria by both reviews. After the first selection, 87 articles were included.

In the second step, two reviewers analyse the titles, abstracts, and keywords and, classified the articles using a Likert scale: 1 – strongly disagree, 2 – disagree, 3 – undecided, 4 – agree and 5 – completely agree, based on IC and EC. A third evaluator blindly classified the works that presented disagreements. Then, 28 articles were excluded, resulting in 59 articles included in this review.

The selection process used weighted Cohen's kappa statistics to measure the level of agreement between the inter-evaluators, that is, the two researchers responsible for selecting the studies. The weighted kappa value (k) = 0.7004 is found after the second round; it is assumed that the reviewers substantially applied the IC and EC. Finally, the articles were read in full by one reviewer. Figure 1 presents a summary of this process.

Figure 2 depicts the number of works published per year, after each of the two classification phases. As can be seen, the majority of the found articles (approximately 66%) were published between 2017 and 2020.

It is important to emphasise that the defined protocol brings some limitations to the reported study, such as the reading of the articles by a restricted number of researchers (two) may result in a subjective and limited view and understanding of the selected works. In addition, the decision to choose more comprehensive terms for the search may have excluded relevant works which consider more restricted terms.

In addition, the decision to choose more comprehensive terms for the search leads to two counterpoints:

1. a large number of works retrieved that did not necessarily reflect the answers sought by this research
2. potentially having excluded relevant works with stricter terms.

## 4 Results and discussion

In the last stage of the protocol, 59 articles were selected, 39 from conferences, 19 from journals, and one book chapter, in 47 different publication vehicles. Figure 3 illustrates this ranking. The majority of papers published in conferences were found in the Brazilian Symposium on Informatics in Education and *Computers & Education Journal*, with four articles each, and International Conference on Computer Supported Education with three articles.

In order to obtain an overview of those articles, a word cloud was created considering the papers' abstracts using the online tool Wordcloud.com and shown in Figure 4. This textual representation technique is based on how often words appear in a document. Pre-processing was performed by removing stop words and some recurring words that would not contribute to answering the research questions, such as *student(s)*, *learner(s)*, *user(s)*, *authors*, *paper*, *propose*, and *present*. In addition, variations of writing such as *visualisation* and *visualisation*, *personalised* and *personalised*, *metacognitive* and *meta-cognitive* have been merged into one term, as well as variations of verbal agreement in the third singular person, since, in English, the verb generally receives a letter *s* at the end (for example, *indicate* and *indicates* and *improve* and *improves*).

As shown in Figure 4, the words that give evidence of technologies applied in the analysed context are highlighted. For example, the acronym OLM (open learner model) points to the use of an open student model in this context.

Other words are also noteworthy, such as *visualisation*, *analytics*, *recommendation*, *personalised*, *adaptive*, *interactive*, *social*, *collaborative* and *agents*, which point to specific technologies/concepts that are directly related to self-regulatory sub-processes. Below, the main works found are discussed in order to answer each of the initially proposed research questions.

RQ1 Which intervention strategies and/or technologies have been used to stimulate self-regulatory capabilities in virtual learning environments?

**Figure 3** Number of publications per type (see online version for colours)

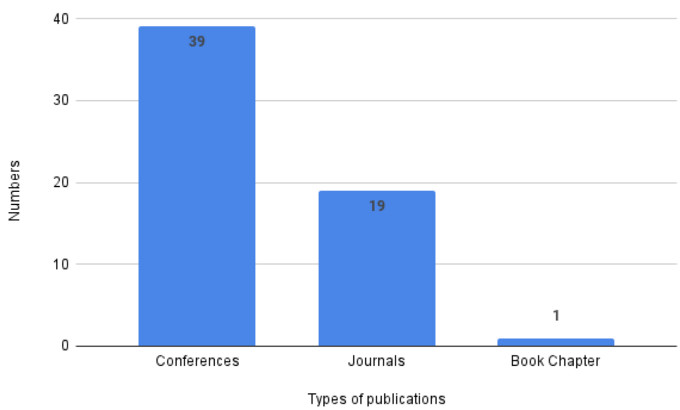



**Figure 4** *Wordcloud* considering selected papers' abstracts (see online version for colours)


After carefully analysing 59 selected articles, different forms of technological interventions were found to stimulate students' self-regulation in online learning environments. In general, several technologies have been used in different phases of the SRL process. Many of them have intrinsic characteristics that support SRL. However, the main goal of this work is to find those that, in addition to providing support, also promote the development of SRL capabilities in students. For example, an open student model supports SRL, but it, by itself, does not offer a proactive intervention that stimulates SRL behaviour in students.

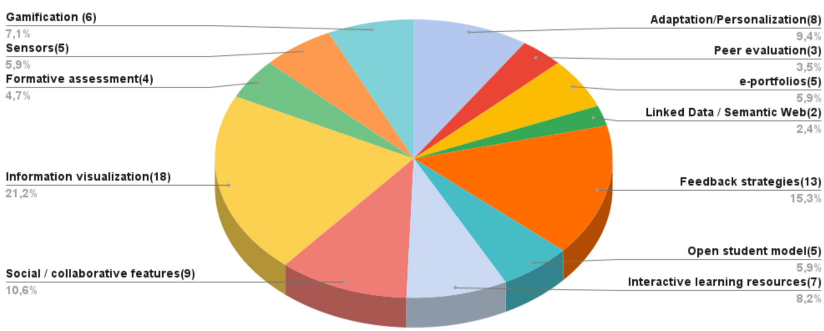
Analysis carried out in the work was built with a focus on the technologies used to promote SRL in each phase. Table 6 presents an overview of the technologies used as interventions in online learning environments to stimulate SRL behaviour in students. It is worth noticing that educational data mining and learning analytics techniques have been used frequently to support the deployment of features in VLEs. However, they do not appear in the table because, by themselves, they do not provide proactive interventions that stimulate SRL behaviour.

**Table 6** Technological interventions to stimulate SRL

| *Technologies* | *SRL phases* | | |
|---|---|---|---|
| | *Preparatory* | *Execution* | *Evaluation* |
| Adaptation/personalisation/recommendation | X | X | X |
| Peer evaluation | | X | X |
| e-portfolios | | | X |
| Linked data/semantic web | X | X | X |
| Feedback strategies | X | X | X |
| Open student model | | | X |
| Interactive learning resources | X | X | X |
| Social/collaborative features | X | X | X |
| Information visualisation | X | X | X |
| Formative assessment | | | X |
| Sensors | | X | X |
| Gamification | X | X | X |

Figure 5 shows a pie chart to highlight the percentage of each technology found in selected works. Note that information visualisation and feedback strategies were the most used technologies to promote the SRL. All technologies found in the selected articles are listed in Table 7 with their respective references.

**Figure 5** Percentage of technologies found in articles (see online version for colours)



It was evident that some technologies can be used in the three SRL phases or only in some phases. The following is a summary of the technologies and the way they are used to promote SRL in the works analysed.

**Table 7** Summary of technology strategies to stimulate SRL in the articles analysed

| *Technologies* | *Articles* |
|---|---|
| Adaptation/personalisation/ recommendation | Bremgartner et al. (2017), Fung et al. (2019), Broadbent et al. (2020), Neitzel et al. (2017), Spiliotopoulos et al. (2019), Khiat (2019), Lee et al. (2011) and Selvi and Panneerselvam (2012) |
| Peer evaluation | Wang (2011), Bremgartner et al. (2017) and Soares and Cabral (2014) |
| e-portfolios | Manso-Vázquez et al. (2015), Romero et al. (2019), Karami et al. (2019), Law et al. (2017) and Hsu (2020) |
| Linked data/semantic web | Gaeta et al. (2011) and Romero et al. (2019) |
| Feedback strategies | Moccozet and Tardy (2014) , Huang et al. (2014), Sirotheau et al. (2011), Tan et al. (2018), Mentari et al. (2020), Lawrie et al. (2016), Lee et al. (2011), Kinnari-Korpela and Suhonen (2020), Sinatra (2014), Pérez-Álvarez et al. (2018), Kapp et al. (2016), Delen et al. (2014) and Li et al. (2017) |
| Open student model | Barria-Pineda et al. (2018), Law et al. (2017), Leonardou et al. (2019), Bremgartner et al. (2017) and Molenaar et al. (2020) |
| Interactive learning resources | Huang et al. (2014), Jansen et al. (2020), Wong et al. (2019), Kauffman et al. (2011), Liu et al. (2019), Delen et al. (2014) and Bahri et al. (2021) |
| Social/collaborative features | Moccozet and Tardy (2014), Gaeta et al. (2011), Tan et al. (2018), Soares and Cabral (2014), Tang and Fan (2011), Junus et al. (2014), Lee et al. (2011), Morgan et al. (2020), Paraskeva et al. (2017) and Bahri et al. (2021) |
| Information visualisation | Molenaar et al. (2020), Barria-Pineda et al. (2018), Su (2020), Kia et al. (2020), Ilves et al. (2018), Manso-Vázquez et al. (2015), Lawrie et al. (2016), Soares and Cabral (2014), Pérez-Álvarez et al. (2018), Chen and Huang (2014), Haynes (2020), He et al. (2019), Farahmand et al. (2020), Pérez-Álvarez et al. (2017), Phodong et al. (2019), Khiat (2019), Li et al. (2017), Carter et al. (2020) and Chen et al. (2019) |
| Formative assessment | Wang (2011), Lima and Pimentel (2013), Kapp et al. (2016) and Selvi and Panneerselvam (2012) |
| Sensors | Robal et al. (2018), Yun et al. (2017), Rosales et al. (2013), Sinatra (2014) and Chen and Huang (2014) |
| Gamification | Morris et al. (2019), Leonardou et al. (2019),Al-Hatem et al. (2018), Moccozet and Tardy (2014), Spiliotopoulos et al. (2019) and Tang and Kay (2014) |

Strategies for visualising personalised information have been used in the three phases of the self-regulatory process. In the work of Molenaar et al. (2020), for example, log data was used to provide mechanisms for visualising personalised information that allows students to establish learning goals at different times, whether in current lessons or lessons reinforcement (performed again) or for general proficiency. It allows students to indicate how proficient to become in a specific skill. In addition, while activities are being performed, visualisations are changed in colours, shapes, and sizes to allow monitoring of the progress in skills. A feedback strategy called feed-forward is used, taking students directly to the content (or learning path) to be followed in order to achieve their learning goals. In Barria-Pineda et al. (2018), the authors present an open model that uses information visualisation techniques to indicate progress in the course topics. It allows students to identify specific knowledge components needed to be studied in a topic, pointing directly to the content.

In the work presented by Su (2020), strategies for visualisation of information are used to propose a self-regulated rule-based learning assistance scheme to intelligently facilitate personalised learning with support from SRL-based adaptive scaffolds for learning computer software. Kia et al. (2020) provided a visual display of relevant information needed to achieve one or more goals, consolidated and arranged on a single screen so the information can be monitored at a glance. Ilves et al. (2018) studied how different visualisations can affect academic performance and behaviour in an online learning environment.

The Doubtfire++ tool was proposed in Law et al. (2017) to encourage SRL. The tool has been enhanced with several visualisations of open learner models showing the connections between tasks, progress toward achieving learning outcomes, and student reflection on task, covering all three SRL phases.

The work presented by Robal et al. (2018) depicts a proposal for automatic detection, in real-time, of loss of attention in videos in order to alert students to maintain the focus on learning through proactive interventions.

Gamification is used in all three phases of self-regulated learning. In the work presented by Morris et al. (2019), students receive digital badges (i.e., digital credentials) as a form of recompense for the achievements of proposed learning objectives. Digital badges were used both to motivate the student during the execution of their activities, as well as to provide implicit learning goals.

The work by Leonardou et al. (2019) proposes an adaptive educational game on the multiplication table with OLM elements. The tool aims to discover each student's weaknesses and by focusing on them, to help overcome them. This intervention is related to the self-regulation evaluation phase (self-assessment). Gamification has also been considered in Al-Hatem et al. (2018), through the game Second Life. Scenarios based on real nursing situations are created within the game to increase students' confidence and motivation.

Moccozet and Tardy (2014) proposed a social learning platform based on peer production and feedback. A group is organised in order to represent a contextualised learning activity. Each group shares its own social tools (wikis, blogs, forums, …). Gamification is used to compute the indicators of user participation in groups and individually. Peer feedback is also used as an SRL resource. In addition, Tang and Fan (2011) described the implementation of a networked SRL platform enhanced with the Web 2.0 technology (RSS, Tag, Wiki, blog and SNS), in all three SRL phases.

The work proposed by Gaeta et al. (2011) is a web-based metacognitive environment that leverages semantic web and social web methods and technologies in all phases of SRL.

The work of Manso-Vázquez et al. (2015) presented activity records (log data) as a technological resource. In the three SRL phases, this resource can be used. In the first phase, students can organise the learning environment through records, to define goals. In the execution phase, self-monitoring assists in time management, using information visualisation techniques. And in the last phase, called evaluation, tools such as electronic portfolios can be made available based on the activities' records.

In Huang et al. (2014), the authors also use the concept of interactive learning resources through real-time screen sharing, where students share their executed code or provide feedback for codes made available by other students. The *JavaTool* tool integrated into the Moodle platform, considers feedback between students as a way to stimulate the development of assessment skills (Sirotheau et al., 2011). This strategy is directly related to the self-regulation evaluation phase.

In Jansen et al. (2020), short informative videos were used as interactive learning resources in all three phases. The intervention consisted of three short videos containing SRL instruction and study suggestions to improve learners' SRL.

The works of Wong et al. (2019) and Liu et al. (2019) also used video as an interactive tool. In the latest work, interactive functions are realised by adding interactive elements to videos, such as subtitles, barrage, video drawing board, whiteboard, and control board. The timepoint-based collaborative video annotation supplemented by a live interactive chat board and rapid digital formative feedback in the form of teacher and learner dashboards are the technological resources proposed by Tan et al. (2018). The SRL phases considered in this work are the execution phase and evaluation.

The work presented by Mentari et al. (2020) is an online learning environment and it was created to support the three SRL phases. In the forethought phase, students plan for the execution of a project within a certain period time. In the performance phase, pretests are held on the topic that will be covered in the class. In this step, students are expected to independently learn material that they do not understand yet. In the last phase, students independently take a final test on the topic they learned and receive automated feedback.

Online learning modules that support the construction of conceptual understanding in chemistry within five topics are designed to foster self-regulated learning through, visual representations, formative feedback, and scaffolding by Lawrie et al. (2016). The student will be able to monitor and reflect on their learning progress.

In Wang (2011), the authors describe the development of a web-based assessment system. Some SRL strategies are adopted by the system such as: adding answer notes, stating confidence, reading peer answer notes, recommending peer answer notes, and querying peers' recommendations on personal answer notes. This strategy is directly related to the self-regulation evaluation phase.

The work presented by Bremgartner et al. (2017) used the recommendation of content through an open student model, seeking to find educational resources that best-fit students considering a reflection on assessment results in the evaluation phase. A peer review instrument is also used, where students are encouraged to expand their knowledge through interactions with colleagues. All participants can evaluate the work of other colleagues.

In Fung et al. (2019), the authors propose a personalised journal for student self-reflection in the evaluation phase. The use of digital learning journals could have sustained the students' motivation. In addition, the work by Broadbent et al. (2020) also suggests a mobile app-based daily diary. Neitzel et al. (2017) present the concept and design of a mobile learning diary application, which extends standard functionality like planning, documenting, and reacting to learning behaviour in the SRL preparatory phase.

Romero et al. (2019) presented a conceptual model of an intelligent system to support self-regulated learning. This model is based on semantic technologies and uses the concepts of learning paths and student e-portfolios. The e-portfolio was used as an evaluation tool, where each learner performs their activities under the orientation of the teacher.

Soares and Cabral (2014) proposed a collaborative model for learning computational thinking coupled with self-regulation – PenC. The model consists of four parts: pre-reflection, resolution, peer evaluation, and post-reflection. In pre-reflection, the student reflects on the current state of his knowledge and self-assessment the understanding and difficulty of the problem by answering some questions. In the resolution phase, the student will solve the proposed programming problem. In the peer evaluation, the solutions given by the students will be evaluated by their peers. And, finally, post-reflection aims to involve the student in the evaluation and reflection of the problem-solving experience. It is at this stage that the monitoring of the learner's knowledge in learning computational thinking occurs.

The self-regulation system (SRS) tool proposed by Lima and Pimentel (2013) incorporates mechanisms for self-regulation of learning. The architecture of the tool contains three modules: diagnostics, continuous, and monitoring. The three modules combined completely satisfy the phases proposed in Zimmerman's model. The diagnostic module coincides with the prior knowledge phase, the continuous module with the performance or volitional control phase, and the monitoring module is related to the self-reflection phase.

In Yun et al. (2017), the authors proposed that self-regulated learning skills can be promoted using sensor technology. The sensor used in the work is the smartphone, which contains at least 15 sensors that detect user behaviour and context. For example, a camera can detect a learner's execution phase and can recognise a learner's gaze, a presence of a user, and facial expression. A microphone is also widely used to detect ambient noise, context, and activity of users. According to the authors, positive self-talk can increase self-efficacy and minimise negative effects in SRL phases.

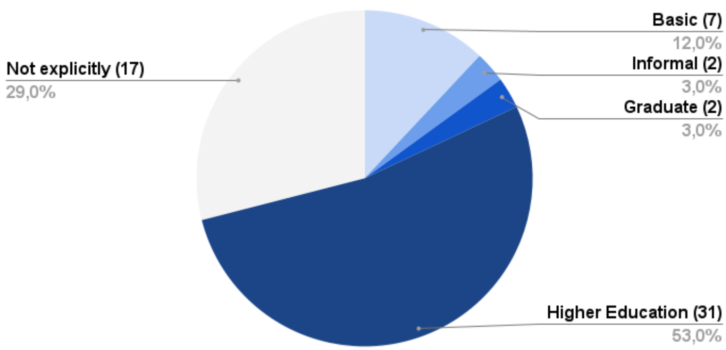
Rosales et al. (2013) proposed a tool to serve as initial support for students' SRL promotion, called of ViTracker – tracking data visualisation and personalised recommendations. ViTracker uses Bayesian networks (BN) to model students' behaviours and automatically make predictions about their academic progress in each learning resource. Information about the student's learning progress is collected by physical and logical sensors in the execution phase. ViTracker computes behaviour and provides various analyses about students' academic performance and also allows students to compare their performance with other students in the group during the SRL evaluation phase.

In Chen and Huang (2014), the authors propose a web-based reading annotation system with an attention-based self-regulated learning mechanism (ASRLM). First, the student makes the SRL sheet configuration, answering a questionnaire with some information, such as learning time, the number of learning units, effort level, sustained attention level, expected learning ability, current learning location, and learning partners. After setting the SRL sheet values, the learner can start an online reading of annotated English texts and an SRL radar chart will appear on the left of the system user interface to indicate the learner's SRL status. The learning time achievement index, the sustained attention index, and effort index scores were determined based on the attention detection of brainwaves. If the system detects that the student's attention is waning, messages with attention reminders are displayed through the user interface. At last, the learner can reflect the SRL outcomes using the self-inspection interface, and then determine the new SRL goals.

RQ2 In which contexts and levels of education have these tools been used?

The tools described in the selected works have been used in different contexts and educational levels. Figure 6 shows the educational levels of the 59 selected works. The analysis carried out allowed us to conclude that 29% of them do not explicitly define the educational level at which the proposed technologies were tested and applied.

**Figure 6** Levels of education found in the selected articles (see online version for colours)



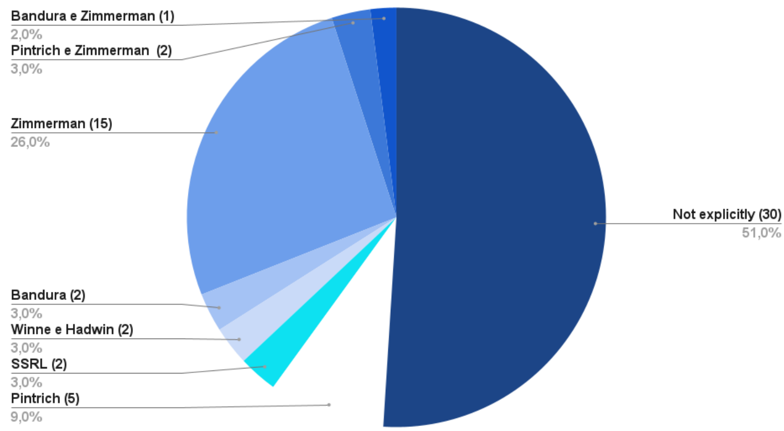

Approximately 53% of the works indicated that the proposals were tested with higher education students (undergraduate level) in different areas of knowledge. Around 12% of studies indicated that the experimentation was carried out with students of basic education, and 3% of studies of them applied specifically in informal education. Only two studies were conducted at the graduate level. Thus, this analysis points out that the literature lacks works that promote self-regulated learning in basic, graduate, informal, and professional education. This may indicate the existence of specific characteristics in these contexts that should be better known to allow for designing specialised technologies.

RQ3 Which SRL models are mostly used in this context?

In general, the selected works do not establish an explicit relationship with specific SRL models. Considering the selected works, 51% does not explicitly define the model on which the work was based. Among the works that explicitly indicated the theoretical model, the majority (about 52% of all analysed papers) used the model proposed by Zimmerman (1986), as shown in Figure 7.

Some of these works indicated that they had established more than one model as a basis, such as Zimmermann and Pintrich and Groot (1990), which can be justified by the similarity of these models. For example, an area of the Pintrich model was built based on the model by Zimmerman (Panadero, 2017).

**Figure 7** Different SRL models found in the selected articles (see online version for colours)




The proposals presented by Winne and Hadwin (1998), Panadero (2017) and Hadwin et al. (2011) were used for more than one goal. Thus, it is important to point out the need to establish explicit relations between the proposed technologies and SRL models so that experiments, validations, and conclusions may have a theoretical basis evidenced by well-known theories.

## 5 Conclusions

This article presents a systematic literature review considering works published between 2011 and 2020 that use intervention strategies and/or technological resources to stimulate self-regulation capacities/behaviour in online learning environments. In this work, it was possible to trace a detailed view of the state-of-the-art in the field of technologies to enhance SRL in learning environments. In the definition phase of the articles for analysis, was used weighted Cohen's kappa to reduce the selection bias and the amount of time that is devoted to selecting studies.

An analysis of the publications was presented, showing a concentration of works in the last four years. By looking at the vehicles that published the selected articles, the Brazilian Symposium on Informatics in Education and *Computers & Education Journal* stood out.

The results showed that several technological interventions have been applied to promote self-regulated learning considering its three phases. Adaptation, personalisation, recommendation technologies, linked data, semantic web, feedback strategies, interactive learning resources, social and collaborative resources, information visualisation, and gamification are resources used in the three common phases of self-regulation processes. Peer evaluation and sensors have been used to proactively encourage SRL during the execution and evaluation phases. Other technologies such as e-portfolios and open student models are also applied to foment the SRL behaviour.

In addition, it was noticed that most of the studies have been done in the context of higher education, indicating a lack of studies in basic education as well as in informal and professional contexts. Finally, it was evidenced that most of the works do not clearly mention the adopted SRL theoretical model. Considering those that explicitly indicated the employed model, the majority used the Zimmermann model.

It is worth noting that studies that evaluated student performance showed that these types of tool improve student results. In addition to these main findings, this article showed the main strategies that can be used to proactively foster self-regulated learning.

A suggestion for future work is to carry out a comparative study concerning the SRL models, taking into account the technologies used. Specific technologies may provide more satisfactory results when regarding certain SRL models. In addition, further work to analyse which technologies are more assertive to encourage students to become self-regulated learners is needed.

### *5.1 Limitations*

We want to highlight some limitations of this work. First, this literature review may not have included all the articles that support self-regulation through technology given the search strings with general terms. Possibly, some articles supporting SRL may use other terms or are not in the searched databases. The databases used are indexed in the main international vehicles and are recognised as the most relevant in the field of Computer Science. Also, articles that were published during the writing and review process of this work may have been left out. One way to mitigate this limitation is to periodically update the reviews.

Finally, this paper also entails limitations related to the selected methodological approach that should be considered for the interpretation of the results presented. First, the analysis of the articles was carried out by two researchers in a qualitative manner, who analysed the articles following the proposed methodology. Although we conducted analyses on the level of agreement among the researchers by using a widely known metric, the results cannot be considered completely objective since they are based on subjective analysis.

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## Notes

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