Tools Designed to Support Self-Regulated Learning in Online Learning Environments: A Systematic Review

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This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3193271

Tools Designed to Support Self-Regulated Learning in Online Learning Environments: A Systematic Review

Ronald Pérez-Álvarez, Ioana Jivet, Mar Pérez Sanagustín, Maren Scheffel, and Katrien Verbert

***Abstract*—Self-regulated learning (SRL) is a crucial higher-order skill required by learners of the 21st century, who will need to become lifelong learners to adapt to the continually changing environments. Literature provides examples of tools for scaffolding SRL in online environments. In this study, we provide the state-of-the-art concerning tools that support SRL in terms of theoretical models underpinning development, supported SRL processes, tool functionalities, used data and visualizations. We reviewed 42 articles published between 2008 and 2020, including information from 25 tools designed to support SRL. Our findings indicate that (1) many of the studies do not explicitly specify the SRL theoretical model used to guide the design process of the tool; (2) goal setting, monitoring, and self-evaluation are the most prevalent SRL processes supported through functionalities such as content navigation, user input forms, collaboration features, and recommendations; (3) the relationship between tool functionalities and SRL processes are rarely described; (4) few tools assess the impact on learners' SRL process and learning performance. Finally, we highlight some lessons learned that might contribute to implementing future tools that support learners' SRL processes.**

***Index Terms*—Self-regulated learning, tools, learning analytics, online, massive open online courses (MOOCs).**

I. Introduction

RECENT studies point out that self-regulation is a crucial higher-order skill required by today's learners, future professionals that will have to continuously learn to adapt to the changing professional environments of the 21st century [1]. Self-Regulated Learning (SRL) is "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment" [2]. Moreover, SRL refers to how learners become masters of their learning processes [3]. Research shows that SRL is an indispensable skill in online learning contexts [4] as it increases the probability of completing the course successfully [5], [6]. Self-regulatory skills are more relevant in online contexts compared to traditional settings because such settings are characterized by the scarcity or lack of tutor guidance during the course and the flexibility of schedules over time [5].

In line with this evidence, researchers have been proposing tools to better understand and support SRL in online learning environments. Thus, the final objective of this review is to provide an overview of the progress made in the area of SRL support in order to understand commonalities between solutions and to outline lessons learned from each solution.

Current literature provides some reviews on the latest tools available for supporting SRL. A majority of these reviews focus on analyzing the effect of the tool on learners' performance [7], [8]. The results of these studies are contradictory. For example, Devolder *et al.* [7] found that SRL prompts are the most effective intervention, while other authors such as Zheng [8] and Wong *et al.* [9] found that integrating SRL tools with multiple functions or embedding various features online are the most effective ways to support SRL. However, these reviews focus on the reported effect of the tools rather than the features included in the design to support SRL processes. To complement this prior work, some authors focused their reviews on the design of tools that support SRL. For example, Matcha *et al.* [10] analyzed learning analytics dashboards (LADs) and showed that LADs are rarely based on learning theory, do not offer suitable support for metacognition, and do not provide feedback about effective learning tactics and strategies. Garcia *et al.* [11] analyzed the extent to which e-learning platforms designed to support computer science learners address the SRL strategies defined by Zimmerman and Martinez-Pons´ taxonomy [12]. They found that 10 of the 14 strategy categories are supported and highlighted emotional regulation as an additional strategy that should be further investigated and supported in such environments.

This work was supported by FONDECYT (11150231), University of Costa Rica (UCR), LALA (586120-EPP-1-2017-1- ES-EPPKA2-CBHE-JP), CONICYT Doctorado Nacional 2017/21170467, Research Foundation Flanders (FWO) [grant agreement no. G0C9515N] and the KU Leuven Research Council [grant agreement no. STG/14/019]. (Corresponding author: R. Pérez-Álvarez).

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This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3193271

Previous literature reviews present a collection of tools to support learners' self-regulation processes in different online learning platforms. However, most of the papers collected in these reviews provide very little evidence that such tools improve SRL [13]–[15]. Moreover, the prior work reviewed has placed greater emphasis on studying the effect of intervening with a particular tool rather than on analyzing how these tools have been designed in terms of functionalities. As a consequence, it remains unclear what type of functionalities are used to support learners' SRL processes and to what extent these are aligned with theoretical SRL models.

In order to address this gap in the literature and advance the design of tools to support SRL in online learning environments, this paper presents a systematic literature review focused on analyzing tools designed to support SRL processes from 2008 to 2020. We placed emphasis on examining how the tools were designed and evaluated and, in particular, (1) how the concept of self-regulation is adopted from the design stage of the dashboard-based tool onwards (in terms of SRL processes supported and tool functionalities defined to support them) and (2) what indicators are used for measuring the impact of the tool on learner behavior. We restricted our analysis to tools developed for online learning environments. The following overarching research question guides this literature review: How is the concept of self-regulation adopted, operationalized and measured in tools designed to support SRL processes in online learning environments? Four more detailed research questions are derived:

1) *RQ1*. What are the most common theoretical SRL models considered as a theoretical framework for the design of a tool? Theoretical models from learning sciences and psychology are sometimes used as the pedagogical underpinning in the design of SRL supporting tools, making it easier to hypothesize about the effects on the learning process and performance. So, the aim of this research question is to identify whether authors do take a particular SRL model as the theoretical underpinning for designing their tools and, if that is the case, what the most common models employed are.
2) *RQ2*. What are the SRL processes that current tools aim to support? This question aims to uncover which processes are the most supported by the existing tools and to identify those that are less supported.
3) *RQ3*. What functionalities, visualizations and indicators do current tools use to support SRL processes in online learning environments? This question aims to shed some light on the variety of functionalities, visualizations and indicators used for supporting SRL processes, and identify whether some of them are used more frequently to address the same processes.
4) *RQ4*. What measures are proposed to evaluate the impact of the tool on learners' SRL processes? This question aims at analyzing what type of evaluation was conducted to understand the effect of the tool on supporting learners' SRL processes and at identifying the type of measures used to do so. The focus is not to understand whether a particular functionality has an effect, rather than understanding how scholars are addressing their evaluations.

The results of this review provide: (1) an overview of the aspects considered in the design and the evaluation of tools for supporting SRL processes; and (2) a list of measures to be considered when evaluating the impact of the tool on learners' SRL.

A. SRL Models

In order to understand self-regulation, researchers have proposed several theoretical models, which are basic conceptual frameworks for understanding the cognitive, metacognitive, motivational, and emotional aspects happening during self-regulation [16]. n a review of the different SRL models, Panadero [16] analyzes and compares six of the most used models to study SRL. Each of these models proposes a different definition of SRL. However, despite the different definitions, there are four assumptions that most of the SRL models share: (1) learners are active participants in the learning process; (2) learners can monitor, control, and regulate aspects of their cognition, motivation, and behavior; (3) there is a goal or standard that allows learners to compare their learning progress; and (4) self-regulation of cognition, motivation, and behavior of individuals mediates the relationships between the person, the context and the final achievement [17].

Two of the most widely used SRL frameworks are the Pintrich framework and the framework proposed by Zimmerman [16]. Pintrich [17] considered the study of self-regulation from the perspective of processes that learners perform in four different phases: (1) Forethought, planning, and activation: this phase includes processes of planning, goal definition, perception of the tasks to be performed and the context in which they are performed; (2) Monitoring: this phase includes monitoring processes that represent cognitive awareness about the learner, the tasks and the context; (3) Control: this phase includes processes that involve the effort to control and regulate their learning; (4) Reaction and reflection: this phase includes processes that involve learners reflecting on their learning process and actions to be taken. On the other hand, Zimmerman [18] proposed a three-phase cyclical model: (1) the forethought phase involves processes that learners perform to analyze the tasks to be performed, define their learning goals, plan their activities and self-motivate themselves in their learning process; (2) the performance phase includes processes that learners perform to self-monitor while performing the tasks defined to achieve their goals; and (3) the self-reflection phase in which learners self-evaluate their learning process and take actions that help them achieve their learning goals. Considering the diversity of proposed SRL models, their differences and similarities, in this literature review we do not adopt any particular SRL model to guide the systematic analysis, but rather extract from the reviewed articles the particular self-regulatory processes that the analyzed tools address.

B. SRL Support in Online Environments

To support SRL in online environments, researchers have generally followed two lines of research: (1) online SRL behavior analysis, and (2) the proposal of tools to support and understand SRL. The first line of research has focused on studying how SRL occurs in online environments and how the SRL strategies of learners relate to course achievements [5], [19]. For instance, Milligan and Littlejohn [19] found that learners use SRL strategies such as goal setting, self-efficacy, and help seeking to study in MOOCs. Veletsianos *et al.* [20]

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found that learners use strategies that allow them to manage their time to carry out activities in a MOOC (take time from other activities). They also found that learners use strategies such as note-taking to study outside the platform and seek help from sites outside the MOOCs. Kizilcec *et al.* [5] found that goal setting and strategic planning predicted achievement of personal course goals.

The second line of research leverages the potential of technological tools to develop skills while also capturing data to enhance understanding of how SRL is developed. Panadero *et al.* [21] describe this latter line of research as the third wave of SRL measures, in which the data is captured by tools designed specifically to support learner strategies that, in turn, serve both as a scaffold and as a measure of SRL. For example, Mastery Grids system [22], and Learning Tracker [23], [24] are tools designed to support SRL strategies online and, at the same time, both tools are tracking data to measure the impact of the tools on learners' SRL. Specifically, Davis *et al.* [25] proposed a widget for the edX platform, which supports learners in setting weekly goals and provides real-time feedback on the progress of their planning, encouraging learners to become more engaged with the course. Guerra *et al.* [22] proposed an intelligence interface that supports learners in navigating learning content, allowing them to monitor their progress in the course, and comparing their performance with the performance of their peers. In this literature review, we focus on the second line of research to understand how current tools support SRL online.

II. Methodology

We followed the systematic review methodology proposed by Kitchenham [26] for the paper selection and the PRISMA's 2020 guidelines for describing some aspects of the systematic review process [27]. Since the focus of the search is to identify tools designed to support learners' SRL processes, we searched across six of the most commonly used databases in technology enhanced learning (TEL), (see e.g. [28], [29]) (Scopus, ACM Digital Library, IEEE Xplore, Springer Link, ScienceDirect and ERIC), using the following search queries: (Self-regulated Learning OR Self-directed Learning) AND (Tools OR System OR Dashboard) AND (Online OR MOOCs). We included Self-directed Learning (SDL) as a keyword to be sure we were not excluding papers using both terms indistinctly. Since SDL is conceptually linked to SRL [30], some authors refer to both terms. In this study we consider a time frame between 2008 until 2020. This time frame includes two of the events that have marked research in the area of educational technology in these last years: (1) the emergence of the MOOC concept in 2008 [31] and the emergence of the learning analytics community in 2011 [32]. Both events boosted the research on dashboard-based technological solutions using large-scale data.

Five investigators conducted the review. Three reviewers were in charge of selecting, classifying, and analyzing the articles, while the other two participated in solving disagreements regarding the analytical criteria. For the data classification and analysis, we used the NVivo 12 software because it offers the necessary features for organizing the selected documents and conducting the text coding to facilitate subsequent analysis. Six analysis categories were defined based on classifications devised in previous literature reviews or emerged during the review process. Table I shows the categories defined for each research question indicating those that were defined from the beginning and those that emerged during the process.

To answer *RQ1*, we used the *SRL model* category. We looked at which models were mentioned by authors as the theoretical underpinning of the tool design. If authors did not specify the SRL model used, these tools were classified as *not specified*. To answer RQ2, we used the category *SRL processes*. These processes were defined using the name of the self-regulation processes indicated by the authors (emerging codes). If the name of a process was not explicitly mentioned by the authors, we used the process definitions shown in Table I. Moreover, as we focused on the most supported processes, only processes that were supported by three or more articles were reported in our review. The process of Rehearsal was identified in 2 articles, while the process of Elaboration was identified in only 1. To answer RQ3, three categories and their related sub-categories were used: *functionality, visual feedback* and *indicators,* as detailed in Table I. The *functionality* category was used to describe tool features that provide SRL support. In the *visual feedback* category, we report on any visual displays that were used to provide feedback to learners. All the displays were classified using codes emerging from the analyzed papers. The *indicators* category was used to identify the type of data displayed to learners. These were organized according to the subcategories proposed by Schwendimann *et al.* [33], which offers a classification of indicators used on dashboards. Not all papers included a screenshot of the tool's visual interface but only described them. In this case, we discussed how to arrive at agreements about their classification. In order to link the indicators used in the different visualizations with the self-regulation processes, we analyzed the information shown in each visualization or functionality and the objective for which the visualization or functionality was designed. When the authors did not explicitly mention the objective of the visualization or functionality, the definition of each SRL process shown in Table I was taken as a reference and we inferred the relationship between the indicator used and the process to be supported. For example, in paper [34] the authors do not explicitly mention the SRL process supported by the "Content navigation" functionality, however, the tool presents a menu with the activities to be carried out during the course. This functionality allows students to browse the content of the course and select an activity to do. For each activity, they associate a counter to record the time dedicated to the activity. In this case, we coded this functionality in the "Time management" SRL process because it helps students to decide which activities they spend their time on in a study session. To answer RQ4 regarding the measures to evaluate the impact of the tools, we considered the subcategories proposed by Jivet *et al.* [13], which analyzed 26 articles describing dashboards and their respective evaluations. As a result, they created a categorization based on the goals defined for the dashboard and the competencies they aim to affect in the learners

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TABLE I
CATEGORIES AND SUBCATEGORIES USED TO CODE THE ARTICLES

Subcategory	***Definition***
1. Functionality category (Codes defined from the beginning of review)	
Class comparison	The tool allows learners to compare their performance with their peers [58].
Recommendations	The tool provides a recommendation to a learner [58].
Interactivity	The tool offers learners the possibility of clicking around to explore their activity [58].
Content navigation	The tool allows learners to access course content through its interface.
Input form	The tool uses forms for data entry [14].
Text explanations	The tool explains the data displayed in a visualization via text [58].
Collaboration	The tool offers the possibility to share materials or knowledge [14].
2. Indicators category, proposed by [33] ***(Codes defined from the beginning of review)***	
Action-related	Provide information about the actions performed by the learner (e.g. time spent on quizzes).
Content-related	Show feedback on the content the learner interacted with or produced (e.g. learning path completed).
Results-related	Provide information about the outcome of learner activities (e.g. average quiz score).
Social-related	Show how learners interacted with others (e.g. number of interactions with other students).
Context-related	Provide information about the context in which the learning took place (e.g. student´s location).
Learner-related	Present information which describes the learner (e.g. level of education).
3. Evaluation measure category, proposed by [13] ***(Codes defined from the beginning of review)***	
Metacognitive	Three criteria are considered in this subcategory: **(1)** *understanding* of the information display on the tool, **(2)** *agreement* with the information, **(3)** *impact of the tool on awareness and reflection*.
Cognitive	Four criteria are considered in this subcategory: **(1)** *impact on effectiveness*, related to the accuracy and completeness for goal achievement, **(2)** *impact on efficiency*, related to the optimal use of resources for goal achievement, **(3)** *impact on performance*, related to grades, quality of learning outcomes or assessment of learning artefacts, **(4)** *workload*, related to mental and effort resources used to accomplish the task.
Behavioral	Four criteria are considered in this subcategory: **(1)** *impact on course engagement*, **(2)** *impact on other behavior*, **(3)** *impact on social engagement*, **(4)** *usage of the SRL tool*.
Emotional	Two criteria are considered in this subcategory: **(1)** *impact on affect*, **(2)** *impact on motivation.*
Self-regulation	One criterion is considered in this subcategory: **(1)** *impact on SRL*, related to the impact of the tool on the SRL of learners.
Tool usability	Three criteria are considered in this subcategory: **(1)** *satisfaction*, **(2)** *usability*, **(3)** *usefulness*.
4. Visual Feedback (Codes emerged during the process)	
No Visualization	The feedback is presented only through text.
Bar chart	The feedback is presented through two or more vertical or horizontal bars.
Table	The feedback is presented through rows and columns.
Line chart	The feedback is presented through data points on a line.
Network graph	The feedback is presented through nodes.
Pie chart	The feedback is presented through circular graphics divide into slices
Progress bar	The feedback is presented through a bar to show learner´s progress.
Gauges	The feedback is presented as a circular arc to show learner´s progress.
Heat map table	The feedback is presented through a table and color variations.
Learning path	The feedback is presented as a learning path through graphs or trees
Spider chart	The feedback is presented through series of values and two or more dimensions
5. SRL processes (Codes emerged during the process)	
Goal setting	The tool allows learners setting of educational goals or sub-goals in order to exert the effort required to achieve those goals [18], [59].
Monitoring	The tool allows learners do metacognitive monitoring oriented to the processes, which includes activities that learners can do to follow up on learning goals [60], [61].
Self-evaluation	The tool allows learners to initiate evaluations of the quality or progress of their work [12].
Help seeking	The tool allows learners ask to other people for help, such as the instructor or one's peers, or consulting external help and resources [60].
Organization	The tool allows learners Student-initiated overt or convert rearrangement of instructional materials to improve learning [12]. The tool allows learners note taking, highlighting - for selecting and organizing the ideas in the material [60].
Strategic planning	The tool allows learners the planning of sequencing, time, and completing activities related to their goals [5].
Time management	The tool allows learners make schedules for studying and allocating time for different activities; make decisions and form intentions about how they will allocate their effort and the intensity of their work [17].
Self-reflection	The tool allows learners to compare self-observed performances to some standard, such as one's own past performance, someone else's performance, or an absolute standard of performance [18].

(*metacognitive, cognitive, behavioral, emotional, self-regulation*) and *tool usability*. These layers also correspond to SRL (cognition, motivation and behavior) as described by Panadero in their SRL model review[16]. The self-regulation code was used only for papers that explicitly describe their goal as supporting self-regulation, a concept that involves all four competencies [35], for this reason we consider that this categorization can be adequate in this review.

Two researchers conducted the coding of the articles. Three articles were reviewed by both of them in order to estimate the overall percentage of agreement which was 99.76, with a Cohen's Kappa = 0.37. There is a high degree of agreement on the coded items despite the low Kappa, since the differences are due to the size of the text selected by each coder. The same codes were identified by both researchers, thereby confirming the reliability of the classification. The NVIVO analysis can be

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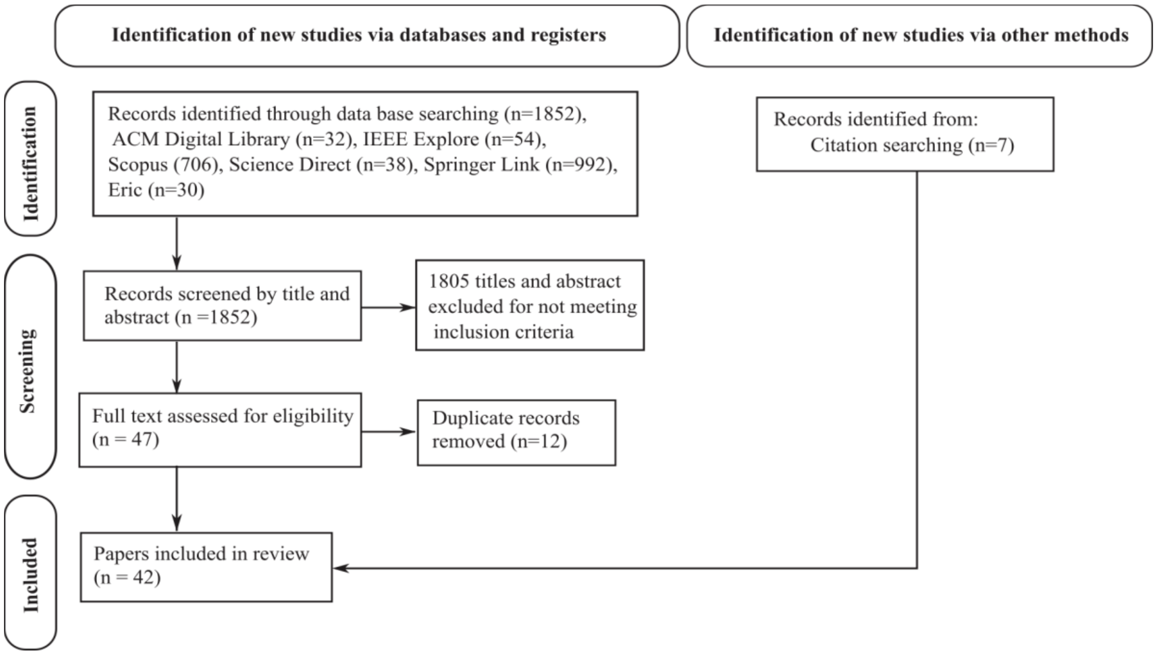

Fig. 1. Flow diagram according to the PRISMA guideline [27].

made available upon request to the authors.

III. Results

A. *Results Details*

A total of 1,852 articles were retrieved from the six queried databases and were screened for eligibility. A total of 1,805 articles were excluded after title or abstract screening because they did not present a tool to support learners' SRL in an online learning environment. Table II shows some examples of excluded articles for each of the exclusion criteria we applied. Only 47 full text articles were assessed for eligibility. Then, duplicate articles were eliminated (12 in all), leaving 35 articles for the review. Additionally, we extended the list of papers to be analyzed with seven relevant articles that were cited by articles discovered through the database search. Therefore, a total of 42 articles were inspected, describing tools designed to support learner self-regulation in several contexts. Within these articles, we identified 25 distinct tools for the analysis (see Appendix 1). The search process is illustrated in Fig. 1.

B. *Results Details*

We first looked at which are the most common theoretical SRL models considered as a theoretical framework for tool design (*RQ1*). The results indicate that 68% (17 of 25) of the articles explicitly mention a specific model, Zimmerman [18] and Pintrich [17] being the most popular options (see Appendix 2). While the majority of authors cited a theoretical model as a starting point for the design of their tool, very few justify their theoretical choice. Some authors explicitly claim to have used Zimmerman's model for it being the one that best represents learning as a cyclical process [23], [25], [36]–[46], while other authors used Pintrich's model because it clearly defines strategies associated with each of the four phases of the SRL process. These strategies can be broken down into "observable actions" that can be subsequently linked to particular learning activities within their tool [36].

In relation to *RQ2* regarding the supported SRL processes, the results show that goal setting (60%, 15 of 25); monitoring (48%, 12 of 25); and self-evaluation (44%, 11 of 25) are the most supported processes by current SRL tools (see Appendix 2). Most of the authors propose solutions that support more than one process. Only four tools support only one process each [42], [47]–[49].

In relation to *RQ3* regarding the analysis of functionalities**,** visualizations and indicators, our analysis showed that authors propose similar solutions to support different processes. Table III shows how each tool uses functionalities, visual displays and indicators to provide support in relation to each SRL strategy. Regarding the functionalities, most tools use two different approaches to support SRL processes: (1) non-interactive, i.e. those that do not offer interaction on the part of the learner with the support offered, and (2) interactive, i.e. those which require an input or an interaction from the learner. Those following a non-interactive approach use *recommendations* of learning resources (40%, 10 of 25) based on learners' learning goals, targeted competencies, or missing competencies; *text displays* showing certain indicators (24%, 6 of 25) such as the five tags most recently used, notifications, prompts for guiding the learning process or learners' percentage of progress; *visual display* using different indicators about learners' progress, performance, or interaction with the resources (68%, 17 of 25), and *text explanations* in the form of personalized feedback on learners' progress (8%, 2 of 25). Tools following an interactive approach use *content navigation* (52%, 13 of 25) to allow learners to browse the goals defined by teachers or competencies required by organizations, and get additional information about learning activities; *input forms* (60%, 15 of

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TABLE II
EXCLUSION CRITERIA AND EXAMPLES OF EXCLUDED ARTICLES

Exclusion criteria	Justification	Example of excluded paper
Articles that do not describe a tool.	Articles that included in the title and/or the abstract the searched terms, but whose main focus is not on the development of a tool for supporting learners' self-regulation.	[62]
Articles about supporting self-regulation but not through a tool.	Articles that focus on supporting self-regulation through interventions conducted with a tool or a system (such an LMS) that was not specifically designed for this purpose.	[63]
Articles about tools that support self-regulation but not in an online environment.	Articles propose a tool to support self-regulation skills or strategies in face-to-face contexts, rather than online contexts.	[64]
Articles that address the use of tools such as social networks and e-portfolios to support self-relation but not development are proposed.	Articles proposing any intervention through, for example, e-portfolios to support self-regulation were excluded.	[65]
Articles about tools that support self-regulation but are not designed for learners. Articles that are not written in English.	Articles that propose tools for supporting SRL designed for other users than learners.	[66]

25) to allow learners to indicate their location, create notes, set their goals, select learning paths, plan their task, and justify interruptions; *interactive visualizations* (28%, 7 of 25) to allow learners to enable/disable social comparison, change the order of the course content, filter information of the visualization, or view additional information.

The two most common functionalities are (1) *input forms* (60%, 15 of 25) and (2) recommendations (20%, 5 of 25). Input forms ask the learners to complete certain information about their goals, learning paths, notes and scheduling and are usually used for supporting all strategies except help seeking. Recommendations about goals, competences or activities are used for supporting all strategies except monitoring and organization. The least supported strategy is *help seeking,* where authors propose functionalities of peer collaboration and search, as well as forums, and shared workspaces, resources, knowledge and answers.

Certain **visualizations** are used to support more processes than others. The *bar charts* were used to support 6 processes (goal setting, monitoring, self-evaluation, strategic planning, time management and self-reflection). The *spider chart* was only used by one tool to support 4 processes (goal setting, strategic planning, time management and self-reflection). We observed few visualizations that support the following processes: organization (the only proposal is to use network graphs), self-reflection (bar charts and spider charts being the only solutions) or strategic planning (bar charts, spider charts and learning path representations being the proposed solutions).

Concerning the **indicators** used for these functionalities and visualizations, we identified only four of the six defined by Schwendimann *et al.* [33]: *content-related* and *action-related* (60%, 16 of 25) *results-related* (12%, 3 of 25), and *context-related* (4%, 1 of 25). All SRL processes except for help seeking were supported with *content-related* indicators. Among these, indicators related to goals and learning achievements are typically used to support goal setting or monitoring processes, while progress indicators are related to self-evaluation. Tags, highlighted terms, or lists of video clips created by learners are indicators used for organization, while indicators concerning the time spent on course content activities are used for supporting time-management. Finally, indicators related to performance are usually used for supporting strategic planning. *Results-related* indicators and *context-related* indicators are the least common indicators used by the tools analyzed in this review. *Results-related* indicators have been used for indicating the reason for interruptions learners had during a study session and supporting goal setting, while grades and assessment outcomes have been mainly used for supporting self-evaluation processes. Regarding *context-related* indicators, we identified only one tool that used the learner's location for supporting time management.

In relation to *RQ4*, the measures proposed to evaluate the impact of the tool are diverse (see Appendix 3). The most important result is that only 12% (3 of 25) of the analyzed tools were evaluated in terms of their impact on the SRL processes of learners. Participants in the tool evaluations were primarily higher education and secondary school learners. In these three articles, the authors used self-reported questionnaires to identify and measure changes in the SRL processes of learners. While the findings of these papers show a positive effect on learner's time management skills and on their overall SRL processes when using goal setting functionalities, there are still very few studies analyzing the effects of existing tools on learners' SRL processes.

The other tools were evaluated in terms of usability, usefulness and user satisfaction (40%, 10 out of 25 tools) or changes in learners' behavior (36%, 9 of 25). Those reporting changes on learners' behavior analyzed learners' study planning actions [23], and navigation or interaction patterns [6], [22]. Finally, 36% (9 of 25) of the tool evaluations measured criteria related to cognitive and metacognitive skills by measuring level of knowledge attained or the increment of learners' knowledge. Finally, 36% (9 of 25) of the tool evaluations measured criteria related to cognitive and metacognitive skills by measuring level of knowledge attained or the increment of learners' knowledge.

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TABLE III
HOW FUNCTIONALITIES, VISUALIZATIONS AND INDICATORS SUPPORT SRL PROCESSES. A1, A2, ..., A25, CORRESPOND LABEL THE ARTICLES PRESENTED IN APPENDIX 1

Subcategory	*Goal setting*	*Monitoring*	*Self-evaluation*	*Help seeking*	*Organization*	*Strategic planning*	*Time management*	*Self-reflection*
Content navigation	Browse the goals defined by teachers (A2, A3, A4) or competencies required by organizations (A4).		Activities change color according to learner progress (A14, A21).				Provide extra information about learning activities on the menu (A18).	
Input form	Set goals (A1, A3, A8, A19, A20, A22, A23, A24) interests or competences (A2, A4, A22).	Register reason for interruptions (A5).	Location (A5), evaluation of emotions and performance (A24).		Create notes (A8, A12) and terms for web pages (A12).	Select learning paths (A4), plan task execution (A8, A17, A19), create concept map(A25).	Plan tasks and time to spend (A8, A17), record time spent on learning activities (A18).	Add new reflections (A23).
Recommendations	Content based on learning goals or competencies (A2, A4), missing competencies (A4).		Widget for self-evaluation of learner knowledge (A2).	Peer and search widget (A2).		Learning path (A4, A17).	Learning path (A4, A17), learning resources (A5, A6).	Widget for self-reflection on their activities (A2).
Collaboration				Add chats or forums (A2, A12, A15, A21), shared workspaces (A2, A12), resources and knowledge (A4, A7, A16, A19, A21) and answers (A1).				
Interactivity		Enable/disable social comparison feature (A8, A14), show extra information (A25).	Filter information to be analyzed (A8, A12).		Learners can move content order (A21).		Filter information to be analyzed (A8).	Show extra information (A13).
Class comparison	Show goal achieved by previously successful learners during goal setting process (A8).	Compare learner performance with other course mates (A4), previously successful learners (A8, A13), previously unsuccessful learners (A8), peers (A14).				Show performance indicators of previously successful learners during goal-setting process (A8).	Show time spent by previously unsuccessful learners (A8), previously successful learners (A8, A13), peers (A18).	

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No Visualization	X				X		X	
Bar chart	X	X	X			X	X	X
Table		X	X				X	
Line chart							X	
Network graph			X		X			
Pie chart							X	
Progress bar	X		X					
Gauges	X							
Heat map table		X						
Learning path						X		
Spider chart	X					X	X	X
Action-related	Indicators about most effective peer week by day and hour (A8), progress in goals (A8, A20, A23, A24), learner performance (A8).	Indicators related to learner schedules (A19), learner behavior (A19), performance of other learners (A19, A14), progress on activities (A14), time spent(A25).				Learning path (A4).	Time spent (A4, A8, A12, A13, A18, A22), procrastination time (A8, A13), time required by teacher (A8, A18).	Indicators about annotated text and concepts used (A2), interaction with learning resources (A19).
Content-related	Indicators related to learning path and shared knowledge (A4), goal setting to achieve learning activities (A8, A23), learning activities required by teacher (A8).	Indicators related to interaction with learning activities (A8, A13).	Indicators about progress on knowledge nodes (A21), progress on learning activities (A1, A8, A14, A15), interaction with learning activities (A8, 14).		Indicators about tags/terms highlighted in text and used by learners (A12), video clips created by learners (A7).	Indicators related to performance of other learners (A1, A13).	Indicators related to interaction with learning activity categories (A8, A22).	Indicators about content produced by learners (A2), prerequisite knowledge (A21), state of competencies (A6).
Results-related	Reason for interruptions (A5).		Grades of assessments (A1, A20, A21).					
Context-related							Location (A5).	

With respect to cognitive abilities, the assessment of the impact on student performance is the most frequent, 5 out of 8 papers included in this category measured performance (see annex 3). The results of these evaluations show a positive effect of the tool on student performance. For example, [36] finds that by using the tool students improve their programming skills.

IV. Discussions

This study has provided a detailed overview on the current state of tools designed between 2008 and 2020 that support SRL in online learning environments.

A. Summary of Results

This article tries to organize and systematize solutions proposed in the literature to support self-regulation and sheds some light on the type of indicators and measures most commonly used that could offer a guide for future implementations. The results show that during the period covered, a considerable number of tools (25 tools) aimed at investigating and supporting SRL processes have been developed. Most of the articles describing these tools or their evaluation were published after 2013. Our main findings show that, firstly, most authors do take an SRL model as a reference to guide their tool design, with Zimmerman's model being the most commonly used one. In spite of that, few authors justify why they selected a specific model. Secondly, the results show that goal setting, monitoring and self-evaluation are the SRL processes supported the most by current existing tools, whereas help seeking, organization and self-reflection are not sufficiently addressed. Thus, more studies should focus on this direction to complement existing solutions. Thirdly, the authors implement a variety of functionalities, such as recommendations or content navigation, to support the different SRL processes. Additionally, bar charts are the visualization type used most often to provide learners with feedback about their SRL. However, current approaches do not use theoretical frameworks for establishing a link between the functionalities supported by the tool and the processes each one supports. As a consequence, it is difficult to conduct interventions and evaluate the impact of the tool on the learners' SRL processes. Moreover, most of the indicators proposed for supporting these functionalities and visualizations are content-related. Studies exploiting context-related and results-related indicators might therefore open new research avenues for supporting SRL. This literature review aimed to capture what indicators have been used for supporting each strategy so far. This effort might serve as a guideline for other authors to design and implement innovative functionalities directly linked with theoretical

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approaches.

Finally, this study identifies some studies that evaluated the impact of a tool on learners' SRL process through the use of self-reports. However, few developments have moved beyond a prototype phase and reached the evaluation phase. We suggest that future designs should explicitly propose a relationship between the activities that the learner performs with the different functionalities of the tool and the SRL processes that are being supported so that indicators can be defined to measure its impact on the self-regulation process.

B. Implications for the Design of Tools to Support SRL

This literature review shows that current tools support a diversity of SRL processes: help seeking, organization, strategic planning, and self-reflection being the most underrepresented. Although most authors use SRL models as a theoretical framework for the tool design and they generally address the concept of self-regulation and how self-regulation contributes to learner achievement, they often fail to clearly specify how exactly the tool supports self-regulation. Similar findings were presented by Jivet *et al*. [13] in their review of learning analytics tools. In that research, the authors found that studies do not define the educational concept they are seeking to support with the tool. Although the tools included in their review define SRL as an educational concept to support learners, there is a mismatch between the SRL model, the design of the tool and its evaluation. Each SRL model presents differences in how learners regulate their learning and in the self-regulation activities that are carried out [16]. Consequently, prior to the design process, the people involved in planning and designing SRL-supporting tools should justify the choice of a particular SRL model to guide the design of functionalities implemented in the tool in order to support the SRL activities of learners. Likewise, studies often do not describe a clear association between the functionalities of the tool and the SRL phases or processes that the tool seeks to support although they should. The lack of association between the design of the tool, its features and the SRL model makes it difficult to track the self-regulation activities a learner performs with the tool. We hypothesize that this association between theory and design could bring authors a step closer to being able to measure the impact of a tool on learners' SRL processes.

Also, in this review we propose a descriptive analysis of the tools, but it does not establish a relationship between their functionalities and the self-regulation processes being supported. There are certain functionalities for which it could be easier to establish an association with a specific SRL strategy. For example, the input form functionality could be linked to the goal setting strategy. However, studies should provide a more detailed description about this relationship.

Moreover, given that the focus of the literature review is oriented to dashboard-based tools, we observed that many of the functionalities of the tools analyzed are intended to support the self-regulation processes of students, for example, allowing goal setting, seeking help from other students, monitoring their learning process, and managing their time. However, only few proposals incorporating incorporate prompts or scaffolds to encourage students to carry out SRL processes during their learning, even if prior work show that prompts are an effective way of scaffolding to support the cognitive [7] and metacognitive [50], [51] SRL processes. For instance, Molenaar et al. [51] examined the effects of metacognitive scaffolds on students' learning outcomes. They used computerized scaffolding, which consisted of displaying messages or questions to motivate students' development of metacognitive activities. Their findings show that metacognitive scaffolding in a computer-supported learning environment can influence students' metacognitive activities. This type of prompts can easily be incorporated into the design of future tools based on dashboards in order to, not only supporting self-monitoring and reflection processes but also of encouraging students towards action.

Overall, it is necessary to design a tool according to a theory-based model and explicitly report the rationale behind the design. This will enable functionalities to be defined and integrated within the tool in line with the processes explained in the model.

C. Implications for Defining SRL Indicators and Evaluating the Tools

Our results show that the majority of tools were not evaluated with regards to the impact that they have on the learners' self-regulation processes. However, in order to understand whether the current tools affect SRL processes of learners it is necessary to define ways to measure them. Siadaty *et al.* [52] proposed an approach to establish some type of relationship between the support provided by the tool and the SRL processes. They associate the functionalities of the tool with one or more SRL processes. Subsequently, learner interactions with the different functionalities serve as a proxy for measuring the processes that learners are deploying. This approach has been used by other researchers in the area of TEL [38] to relate functionalities with SRL processes. the best of our knowledge, this approach has not been used to define indicators to measure the impact of tools on the SRL processes of learners, but Pérez-Álvarez et al. [53] use a tool to support different learner self-regulation processes in MOOCs and measure their correlation to learner engagement in a course. Thus, further experiments are needed to implement Siadaty *et al.*'s [52] approach and a new perspective is required to measure SRL processes. Panadero et al. [21] suggests using different approaches to measure the impact of the tools. That is, it is possible to combine the analysis of learner interaction with the functionalities of the tool, as well as to use self-reporting instruments such as the one proposed by Pintrich & Groot [54]. Araka et al. [55] use different approaches to measure self-regulation in e-learning. The study highlights the use of self-reports and the analysis of platform or tool logs. From our perspective, tool logs can generate a lot of data to better understand which self-regulation processes are being supported. However, Pintrich [17] notes that self-regulation processes are not sequential and that learners may perform several processes simultaneously. This, however, may make it difficult to establish a suitable approach to measure self-regulation from the use of the tool, but this approach could be

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valuable to explore.

Moreover, although some of the studies included in this review used self-reported questionnaires as the instruments with which to evaluate the impact of the tool on learners' SRL, they are not evaluating how learner activities relate to the tool functionalities and SRL processes [52]. Thus, in order to have a better understanding of how the designed tools support learners' SRL processes, new measures or indicators considering the learners' activity on the platform, the activity of the learners with the tool, and the performance of learners in the course are needed. This paper shows that one of the processes most supported by the tools is goal setting, but none of the papers analyzed what impact the support of goal setting has on learners' SRL processes. One way to measure this goal-setting support could be by analyzing the learners' behavioral patterns and comparing them with the objectives they define. Another way of measuring the impact of these tools could be using trace data of learners' interaction with the different functionalities. In this case, and if each tool functionality has previously been associated with a particular SRL strategy, different correlations could be made to understand whether the tool has an effect on learners' performance and behavior. These correlations could also serve to understand if the functionality should be re-designed. However, we state that the association between the tool functionalities and the processes of SRL they support should be central to the design process. In this literature review, we observed that many tools do not clearly define how the tool's design supports the different SRL processes. Finally, we also observed that the existing tools are designed only as a pilot, and evaluated in controlled scenarios, but most of them do not reach a functional stage to be used in actual learning settings.

D. *Limitations*

We want to highlight two main limitations of this work. Firstly, this literature review may not have included all the tools designed to support self-regulation given the keywords used. Although the keywords were selected from a preliminary review of articles that developed tools to provide some support for learners' self-regulation processes, it is possible that other terms may also have been used to describe a development. Besides the central focus which in our case is self-regulation, recent reviews use few key words in their queries to identify the software used. For example, Araka et al. [55] only uses the concept of a dashboard to search for tools that apply learning analytics techniques to support self-regulation. Garcia et al. [11] use only the word system to search for tools aimed at supporting self-regulation. However, using words such as tools, dashboard and system, we consider that some publications may have been excluded. In addition, given our selection criteria this review did not include articles written in languages other than English in which some tools may have been reported. Another example of articles that may have been left out of the review are those articles that were published during the review process of this article or articles published in databases that were not considered. One way to mitigate this limitation is to periodically update the reviews. And secondly, although this article has presented an analysis of how tool functionalities, visualizations and indicators support SRL processes, these associations were not always made explicit in the studies, so such relationships were merely inferred from the main purposes and evaluations disclosed in the articles. As a consequence, we could have missed what the authors actually intended to do with these indicators.

In addition, this work also entails other limitations inherent to the methodological approach selected that should be considered for the interpretation of the results presented. First, the analysis of the articles was carried out by 5 researchers in a qualitative manner, who analyzed the articles following the established research questions and analysis codes. Although we conducted analyses of the level of agreement among the researchers, the results cannot be considered completely objective since they are based on subjective analysis. Second, the heterogeneity of the selected articles, both in the contexts of application of the tool and in the way of reporting methods and results, makes it difficult to make direct comparisons between the different studies. Third, we should consider the publication bias [56], [57], which occurs when the publication or non-publication of a scientific result is determined by the strength of its results. This means that, usually, we mainly find articles reporting positive results in our searches. Finally, we only considered in this review those tools designed for online learning settings, since our focus was to analyze environments in which learner's autonomy is key for succeeding and SRL is essential. However, this review could be extended adding tools designed for other digital environments, not only for online learning.

V. Conclusions

This article presented a systematic review of the literature on the development of tools designed to support students' self-regulation processes in the context of online learning. Following the methodology proposed by Kitchenham and the PRISMA's 2020 guidelines, we ended up with a pull of 25 tools developed between 2008 and 2020 that we analyzed. Among the main results we found that: (1) authors use different SRL models as a the theoretical framework for their tool design, with Zimmerman being the most used model; (2) existing tools differ on the SRL processes they support, but goal setting is the most frequent one; and (3) existing tools propose different types of functionalities to support the selected SRL processes, but most of them use forms that students have to fill in to support them. Although the focus of the paper was not to analyze the impact of the proposed tool in students SRL processes, those who report results in this regard show that these types of tools can improve them.

In addition to these main findings, this paper discussed the main implications for the design of tools for supporting SRL and the definitions of indicators that should be considered. In addition, this paper identified that there are still research opportunities on how the proposed tools impact student's SRL processes. We believe that this review set the basis for future research on the area, especially for those researchers evaluating the effects of SRL scaffolds.

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APPENDICES

APPENDIX 1.
DESCRIPTION OF TOOLS DESIGNED TO SUPPORT LEARNERS' SRL IN ONLINE ENVIRONMENTS.

	Article	Description
A1	[36]	A system that aims to improve learner performance through several theory-based functionalities, such as real-time screen-sharing, synchronous demonstration and learner portfolio monitoring.
A2	[37], [67]–[69]	This framework provides 15 SRL widgets to support learners to search for information, activity planning, goal setting, etc.
A3	[38], [70]	Learning environment designed to detect, model, trace and foster learner SRL with regard to the human body system. Learners can generate several sub-goals for the session, self-evaluate their knowledge and monitor their learning process.
A4	[6], [71]	This tool allows learners to define and track their learning objectives in a business environment. In addition, it allows to select learning paths for achieving certain goals.
A5	[49], [72]	It is a tool to support learners' time management by recommending materials and study time set by learners.
A6	[73]	This tool recommends content based on learners' goals.
A7	[74]	It is a tool that allows annotations in the lectures, supports collaborative work, and organizes the contents.
A8	[75]	It is a tool that allows learners to set and monitor their learning goals in MOOC settings.
A9	[40]	A goal-setting plugin to facilitate the capacity of individuals to self-regulate learning and strengthen motivation and self-efficacy in an ePortfolio.
A10	[47]	A tool designed to motivate learner participation in MOOCs, which works through interactive assessment to solve industrial problems.
A11	[41], [76]	It is a framework that allows the development of laboratory tests and allows the of learning paths.
A12	[77]	This tool seeks to support self-regulation by tracing the information search activities, creating notes on the study material, and organizing the most relevant terms of a topic.
A13	[23], [24]	It is a widget that supports time management through a set of visualizations on learners' performance.
A14	[22]	This tool supports self-regulation by allowing learners to monitor their progress and that of their groups.
A15	[42]	This tool allows learners to define goals and learning paths.
A16	[78]	A tool that supports learners by integrating external resources for organizing and managing their time.
A17	[48], [79]	This tool supports learners in time management and in planning their activities.
A18	[34]	A mobile application that tracks the time invested by learners in learning activities in order to support time management.
A19	[43]	A tool to support collaboration, self-monitoring, goal-setting and strategic planning.
A20	[44]	A web-based portfolio for planning objectives or milestones and assessing progress.
A21	[80]	This tool uses knowledge maps to support organization and monitoring of learners' progress.
A22	[45]	It is a widget to support learners with goal setting and time management.
A23	[25]	Tool to support learners in setting weekly goals by providing real-time feedback on the progress of their planning.
A24	[46]	A Chrome plugin to help learners improve their SRL skill in MOOCs by setting and evaluation their goals.
A25	[81]	A learning analytics dashboard to improve self-regulated learning in online environments.

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APPENDIX 2.
MODELS, STRATEGIES, FUNCTIONALITIES, VISUALIZATIONS AND INDICATORS USED BY THE 25 TOOLS ANALYZED IN THE REVIEW.

Subcategory	*Freq.*	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	*A10*	*A11*	*A12*	*A13*	*A14*	*A15*	*A16*	*A17*	*A18*	*A19*	*A20*	*A21*	*A22*	*A23*	*A24*	*A25*
SRL model's category																										
Zimmerman	13	X	X	X			X			X		X		X		X				X	X		X	X	X	
Pintrich	4	X		X					X	X																
Winne and Hadwin	2			X									X													
Schunk	1			X																						
Not specified	9				X	X		X			X				X		X	X	X			X				
SRL strategies category																										
Goal setting	15	X	X	X	X		X		X	X		X		X					X	X	X		X	X	X	
Monitoring	12	X	X	X	X				X	X				X	X		X			X				X		X
Self-evaluation	11	X	X				X			X	X				X	X	X			X		X			X	
Help seeking	7		X	X				X					X				X			X		X				
Organization	7	X	X					X	X				X				X					X				
Strategic planning	8	X		X					X	X				X			X	X								X
Time management	8		X			X			X	X				X					X				X		X	
Self-reflection	7		X				X					X		X						X		X		X		
Functionality category																										
Content navigation	13		X	X	X		X	X				X	X		X	X		X	X	X		X				
Input form	15	X	X	X	X	X			X				X					X	X	X	X		X	X	X	X
Recommendations	10		X		X	X	X					X			X			X	X	X		X				
Collaboration	10	X	X		X			X				X	X			X	X			X		X				
Interactivity	7		X						X			X		X	X							X				X
Class comparison	5				X				X					X	X				X							
Text explanations	2													X					X							
Visualization's category																										
Text	7			X			X						X						X		X			X	X	
Bar chart	4		X		X				X										X							
Table	4		X														X	X		X						
Line chart	3				X				X										X							
Network graph	4							X					X									X				X
Pie chart	2								X										X							
Progress bar	3				X				X							X										
Gauges	1																							X		
Heat map table	1														X											X
Learning path	1	X																								
Spider chart	1													X												
Indicator's category																										
Action-related	16		X	X	X				X				X	X	X			X	X	X	X	X	X	X	X	X
Content-related	16	X	X		X		X	X	X		X		X	X	X	X		X			X	X	X	X		
Results-related	3	X																			X		X			
Context-related	1					X																				

APPENDIX 3.
MODELS, STRATEGIES, FUNCTIONALITIES, VISUALIZATIONS AND INDICATORS USED BY THE 25 TOOLS ANALYZED IN THE REVIEW.

Criteria	*Freq*	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	*A10*	*A11*	*A12*	*A13*	*A14*	*A15*	*A16*	*A17*	*A18*	*A19*	*A20*	*A21*	*A22*	*A23*	*A24*	*A25*
1. Behavioral subcategory																										
Impact on course engagement	3													X	X									X		
Impact on social engagement	0																									
Impact on other behavior	6			X			X			X				X	X									X		
Usage of SRL tool	6		X	X					X						X				X					X		
2. Cognitive subcategory																										
Impact on effectiveness	3						X				X				X											
Impact on efficiency	0																									
Impact on performance	5	X												X	X				X					X		
Workload	1		X																							
3. Metacognitive subcategory																										
Agreement	0																									
Impact on awareness, reflection	0																									
Understanding	1		X																							
4. Self-regulation subcategory																										
Self-regulated learning	3																		X	X	X					
***5.* Tool usability subcategory**																										
Satisfaction	3						X														X	X				
Usability	6		X					X	X						X				X			X				
Usefulness	8		X		X			X	X						X				X	X	X					
***6.* Emotional category**																										
Impact on affect	0																									
Impact on motivation	3														X					X				X		

ACKNOWLEDGMENT

This work was supported by FONDECYT (11150231), University of Costa Rica (UCR), LALA (586120-EPP-1-2017-1- ES-EPPKA2-CBHE-JP), CONICYT Doctorado Nacional 2017/21170467, Research Foundation Flanders (FWO) [grant agreement no. G0C9515N] and the KU Leuven Research Council [grant agreement no. STG/14/019].

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This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3193271

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