Capturing Self-Regulated Learning During Search

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Abstract

Researchers in the learning sciences have demonstrated the benefits of effective self-regulated learning (SRL) in improving learning outcomes. The search-as-learning community aims to improve learning outcomes during search, but offers limited research exploring the impact of SRL on learning during search. Current limited research in search-as-learning explores only *perceptions* of SRL processes *after* the search process [1]. Results from such analyses are limited in that SRL is a dynamic, active process and participant perceptions of SRL can be unreliable [2, 3]. In this paper, we propose the implementation of an SRL coding framework to capture SRL processes as they unfold throughout a search session. Additionally, we offer several implications for future work using the proposed methodology.

Keywords

search-as-learning, self-regulated learning, qualitative coding

1. Introduction

The search-as-learning community was established to address the limitations of current search systems in supporting learning during search [4, 5]. Prior search-as-learning work has focused on several main factors that affect learning during search: (1) the user [6, 7, 8, 9]; (2) the task [10, 11, 12]; or (3) the system [13, 14, 15, 16]. Less work has focused on better understanding the learning *process* during search [12, 8, 17]. More exploration is necessary to uncover when, where, why, and how learning occurs during search. Critical to this understanding is the process of self-regulated learning (SRL) during search.

SRL is an active, reflective process in which a learner monitors and controls their own learning to achieve their learning objectives [18, 19, 20]. For decades, researchers in the learning sciences have shown that effective SRL improves learning outcomes [21, 22, 23, 24, 19, 25, 26, 27, 28]. However, little work has considered the role of SRL in learning during search [1, 29]. Such studies have used questionnaire data to explore perceptions of SRL processes *after* a search session, but arguably no work has explicitly explored SRL processes *during* search.

Learning sciences research has shown the limitations of particular methodologies for capturing SRL processes [30]. SRL is an active, dynamic process that occurs over time. Questionnaire data captures SRL perceptions after the learning session, making the methodology less-suited to capturing the changing, evolving process of SRL. Think-aloud protocols, on the other hand, code learning comments and aim to capture specific SRL processes as they unfold across a learning session. In this paper, we propose and apply an SRL coding framework adapted from Greene et al. [3] to an example search-as-learning scenario. Additionally, we discuss how understanding SRL processes during search has several implications for future search-as-learning research.

2. Motivation

Prior search-as-learning research has considered how factors affect learning during search. The majority of this work has investigated the impact of three main factors on learning during search—(1) the user [6, 7, 8, 9]; (2) the task [10, 11, 12]; or (3) the system [13, 14, 15, 16]. Fewer studies have considered the *learning process* during search. Of those that have, Liu et al. [12] investigated knowledge shift patterns during the search process. To capture knowledge shifts, Liu et al. used mind maps. Participants were ask to create a mind map before the task to capture prior knowledge. Participants then modified these initial mind maps throughout the search process to capture how learning evolved. During analysis, the authors categorized different types of changes participants made to their mind maps (e.g., adding, modifying, or deleting nodes). The authors also categorized the location of the change within the mind map (e.g., level 1-2, level 3, or higher level changes). These categories were analyzed to better understand common and uncommon changes to mind maps across participant learning processes (e.g., adding nodes was more common than structural changes to mind maps). Additionally, the changes and locations of changes to mind maps were used to group search sessions (e.g., those learning processes with frequent changes early vs. late in the search session).

Roy et al. [8] also investigated the learning process, exploring the impact of domain knowledge on learning

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across the search session. While searching, participants were *intermittently* presented with vocabulary learning assessments to measure changes in learning. The authors found that prior knowledge impacted when participants had the highest knowledge gains. Participants with less prior knowledge had greater gains at the beginning of the search session and those with more prior knowledge had greater gains toward the end of the search session.

Urgo & Arguello [17] explored how a searcher's learning objective may impact the learning process during a search session. To manipulate learning objectives, the authors leveraged the Anderson & Krathwohl (A&K) taxonomy [31]. Specifically, learning objectives were situated at the intersection of a specific cognitive process (apply, evaluate, create) and knowledge type (factual, conceptual, procedural). Similarly, the A&K taxonomy was used to analyze the learning *pathways* followed by study participants toward a given objective. Pathways were defined as sequences of learning instances that were also assigned to a cell from the A&K taxonomy. Results found several important trends. First, procedural knowledge objectives had longer pathways, mostly due to participants iterating on create-level processes (e.g., iteratively modifying a procedure based on preferences or constraints). Second, irrespective of the objective, participants tended to iterate more on simple processes (e.g., remember, understand) than complex processes (e.g., analyze, evaluate). Finally, the authors explored common and uncommon cognitive process transitions conditioned on the objective. For example, conceptual objectives had fewer transitions from analyze to evaluate.

Although a small number of studies have investigated the learning process during search, there are still large gaps in our understanding of when, where, how, and why learning occurs during search. Additionally, very limited research has investigated SRL in search-as-learning [1, 29]. Importantly, these studies have exclusively used questionnaire data to examine participants' post-task *perceptions* of engagement in SRL processes during the search session. In this paper, we argue that search-as-learning research should investigate SRL processes as they unfold across the search session, to better understand the role of SRL on learning during search. We describe an existing SRL coding framework [3] that is well-suited for this purpose. Additionally, we describe how think-aloud data (in conjunction with recorded search activities) can be used to detect and characterize SRL processes during search.

3. SRL Models

Self-regulated learning (SRL) is an active and reflective process that involves a learner monitoring and controlling their learning to achieve specific learning goals [18, 19, 20]. Research in the learning sciences has underscored the important role of effective SRL in improving learning outcomes [21, 22, 23, 24, 19, 25, 26, 27, 28]. From prior work, several models of SRL have emerged [32, 33, 34, 35, 21]. These models originate from various fields (e.g., social foundations of cognition and behavior [36]), theories (e.g., Action Control Theory [37]), and/or motivating factors (e.g., learner motivation). We propose the Winne & Hadwin (W&H) model [23] because it is supported by evidence from much prior work [38, 39, 40, 41, 42, 43, 44] and it emphasizes *metacognitive knowledge* (i.e., a learner's knowledge of their own learning and general knowledge of learning strategies) and *metacognitive skills*. Metacognitive skills include monitoring and control and are integral to the W&H model discussed next.

The W&H model of SRL consists of four phases—(1) task definition; (2) planning and goal-setting; (3) studying tactics; and (4) adaptation. In the task definition phase, a learner generates an understanding of the requirements of the task. In the planning and goal-setting phase, a learner sets goals to monitor progress. In the studying tactics phase, a learner uses strategies (e.g., summarizing, note-taking, selecting sources) to accomplish their goals. Finally, in the adaptation phase, the learner reflects on their choices, progress, successes, and failures to make decisions about what to do next. Conditions (e.g., motivation, task understanding, time, resources), operations (e.g., note-taking, summarizing), and standards (e.g., criteria learner deems important to achieve task) are important components throughout the W&H model. During each phase of the model, a learner uses conditions to make decisions about operations and standards. Metacognitive monitoring and control are the "pivots upon which each of the four phases turn." [45, p. 469] Metacognitive monitoring is the learner's process of using standards to judge what has been learned and produced in order to assess progress toward their learning goals. Metacognitive control is the implementation of strategies based on feedback from monitoring. For example, a learner may read through a section of text and, after monitoring, realize they are not understanding anything. In response, the learner enacts control by selecting a new informational source that may be better suited to their level of understanding. In the next section, we discuss how the W&H model has been operationalized to capture SRL in prior work outside of search-as-learning.

4. Capturing SRL Outside of Search-as-Learning

SRL processes can be difficult to capture because they are dynamic and adaptive [46]. To address this challenge, researchers in the learning sciences have developed two primary means of capturing SRL, using—(1) questionnaires [47, 48, 49]; or (2) coded think-aloud data [50, 51, 3]. While static questionnaire data captures perceptions of SRL *after* the learning session, coded think-aloud data is more suited to capturing the dynamic, adaptive process of SRL by coding processes as they occur *across* the learning session. Greene et al. [30] have proposed a "right tool for the job" approach to collecting SRL data. Greene et al. assert that while "motivational and dispositional aspects of SRL may be best captured by self-report data [...] more transient, dynamic task-specific aspects may be best captured by TAPs [think-aloud protocols]." [30, p. 323] We argue that in search-as-learning research it is precisely the transient, dynamic, task-specific aspects that are unknown and crucial to understanding how best to support learning during search. For this purpose, we propose the Greene et al. framework [3] to understand SRL processes during search.

5. Applying SRL Coding Framework to Search-as-Learning

In response to the gaps left behind by questionnaire data alone, SRL coding frameworks have been developed to analyze think-aloud data exhibited by users of computer-based learning enivironments [52, 53]. Greene et al. developed an SRL coding framework [3] (adapted from [52, 53]) that is rooted in the W&H model of SRL. The framework breaks SRL processes into five macro-SRL processes—(1) planning; (2) monitoring; (3) strategy use; (4) task difficulty & demands; and (5) interest. Each macro-SRL process is associated with one or more components of the W&H model and contains micro-SRL processes that can be coded using think-aloud comments. In this section, we review the macro-SRL processes and the micro-SRL processes contained within each. Many of the descriptions are pulled directly from Greene et al., while some have been slightly modified. Extending the application proposed by Greene et al., we also provide novel example think-aloud comments and *search activities* that may be indicative of each micro-SRL process. The example, fictional think-aloud comments and search activities are inspired by actual participant comments and behaviors from a learning-oriented search task operationalized in a search-as-learning study: "Determine, which best explains the notion of lift and why: Bernoulli's principle or Newton's laws of motion?" [17] In the study, participants were provided with a search system and word document to take notes (as is common to many search-as-learning studies).

Macro-SRL: Planning The macro-SRL process of *planning* is associated with the second phase of the W&H model: *planning and goal-setting*. Shown in Table 1, there are four micro-SRL processes associated with *planning*. While the examples provided are all think-aloud comments, there may be search activities that are also indicative of these micro-SRL processes. For example, the *subgoals* process may be engaged when a searcher adds an additional heading to their notes or queries "definition of Bernoulli's principle".

Macro-SRL: Strategy Use The macro-SRL process *strategy use* is associated with the third phase of the W&H model *studying tactics*. Shown in Table 2, there are nineteen micro-SRL processes associated with *strategy use*. Many of the micro-SRL processes associated with *strategy use* quite naturally fit with typical search-as-learning participant behaviors (e.g., *summarization*, *taking notes*, *select new informational source*, *manipulate representation*).

We omitted one *strategy use* micro-SRL process from the original Greene et al. framework: *search*. *Search* has been excluded as it arguably encapsulates an entire search-as-learning session and is therefore not relevant to this field as a specific micro-SRL process.

Macro-SRL: Monitoring The macro-SRL process *monitoring* is associated with the central component *metacognitive monitoring* that functions throughout the W&H model. Shown in Table 3, there are twelve micro-SRL processes associated with *monitoring*. While many of these processes are quite intuitive (e.g., *monitoring progress toward subgoals*, *time monitoring*), there are two important concepts related to *monitoring* that may be less familiar to search-as-learning researchers, *feeling of knowing* and *judgment of learning*. Feeling of knowing (FOK) involves a learner reflecting on whether or not they are familiar with a piece of information. [52, 53]. Judgment of learning (JOL) involves a learner reflecting on whether or not they currently understand a piece of information [54, 55]. There are two micro-SRL processes associated with JOL: *JOL* and *JOLT*. *JOL* involves a learner expressing that they explicitly do or do not understand something. *JOLT*, on the other hand, involves a learner expressing that they have some understanding that may not be fully accurate. They will then continue learning with their current understanding until something proves or disproves that their understanding is correct.

Macro-SRL: Task Difficulty & Demands The macro-SRL process *task difficulty & demands* is associated with the *conditions* component of the W&H model. Shown in Table 4, there are three micro-SRL processes associated with *task difficulty & demands*. Such processes offer a more nuanced look at task difficulty than questionnaire methods typically used in search-as-learning [56].

Macro-SRL: Interest The macro-SRL process *task interest* is associated with the *conditions* component of the W&H model. *Task interest* most closely aligns with a sub-

Table 1
Macro-SRL Process: **Planning**

Micro-SRL Process	Description	Example
Planning	Stating two or more subgoals simultaneously	[Writes numbered list of multiple subgoals in text editor.]
Recycle Goal in Working Memory	Restating the goal (e.g., question or parts of a question) in working memory.	"Ok, so I need to understand how Bernoulli's principle is different from Newton's third law of motion."
Subgoals	Learner articulates a specific subgoal that is relevant to the overall goal.	[Writes "Define Bernoulli's principle in simple terms" in text editor.]
Time Planning	Participant refers to the number of minutes remaining AND indicates whether a goal can be met during this time.	"Ok, I have 5 minutes left and this section is only 3 paragraphs long. Yes, I have time to read it."

set of conditions called *cognitive conditions*. Cognitive conditions include variables such as prior knowledge, motivation, and task understanding. Shown in Table 5, there is one micro-SRL process, *interest statement*. Similar to *task difficulty & demands*, documenting interest statements may offer a more nuanced look at task interest than questionnaire methods alone [56].

6. Implications

While effective SRL has been shown to improve learning outcomes, little research in search-as-learning has explored where, when, why, and how frequently SRL processes occur while learning during search. The proposed coding framework adapted from Greene et al. affords a nuanced look into SRL processes during search-as-learning studies. We offer five major implications for future search-as-learning work given the proposed methodology.

First, capturing SRL *during* the search process (versus post-search perceptions with questionnaire data) allows researchers to explore the effects of *observed* SRL on learning outcomes. Prior search-as-learning research has not investigated the effects of SRL processes on learning outcomes. Regardless of particular micro- or macro-SRL processes, SRL-coded think-aloud and search activity data may give researchers the opportunity to better understand the overall effect of SRL on learning.

Second, capturing SRL processes during search may enable search-as-learning researchers to better understand the impact of *specific* SRL processes on learning. By coding think-aloud comments and search activities into micro- and macro-SRL processes, researchers can calculate the frequency of each process. This information can then be analyzed to better understand the relationship between particular SRL processes and learning outcomes.

Third, a major goal of search-as-learning is to develop tools that better support learning during search. Effective SRL is critical for learning. Therefore, future work should develop tools to directly support SRL processes. We propose four types of tools to encourage and support distinct SRL processes during search. One, future work should consider tools that allow searchers to develop subgoals, take notes with respect to subgoals, and mark subgoals as completed. Such tools can encourage and support *planning* and *monitoring*. Two, future work should consider note-taking tools with different types of structures to organize information. Different structures might be able to support different micro-SRL processes within *strategy use*. For example, tables might support *comparing and contrasting*, lists might support *establishing chronology*, concept maps might support *drawing inferences*, and diagram capabilities might support *drawing*. Three, future work should consider tools that prompt self-reflection in contextually relevant ways. Such tools might encourage and support both *strategy use* and *monitoring*. For example, tools might prompt searchers with various questions: "How does this relate to the article you just read?"; "What do you already know about this topic?"; and "What remaining questions do you still have about this topic?" Finally, future work should consider tools that search for alternate representations of a given piece of information to support *task difficulty & demands*. For example, such a tool might enable a searcher to highlight a passage of text and search for non-textual representations of the content, such as images, videos, and tables.

Fourth, future search-as-learning research should investigate the relationship between particular SRL processes and search activities that can be logged by a system. In this paper, we offer several potential examples (e.g., a new header in a note-taking tool may suggest *planning*). Better understanding the types of search activities that are associated with particular SRL processes would allow future work to potentially predict the occurrence of SRL simply using search interaction data.

Finally, researchers in the learning sciences assert that the relative importance of particular SRL processes vary based on academic domain (e.g., science versus history) and context (e.g., physical space, time constraints, available resources) [3]. For this reason, future search-as-

Table 2
Macro-SRL Process: **Strategy Use**

Micro-SRL Process	Description	Example
Comparing & contrasting	Examining two separate representations or ideas (i.e., text, picture, simulation, etc.) to determine how they are similar and/or different.	[Navigates back and forth between two images that show examples of Bernoulli's principle acting on a sailboat's sail versus an airplane's wing]
Coordinating informational sources	Using pointing, highlighting, or verbalizing the matching elements of two different representations, e.g., drawing and notes. Either representation can be in the environment or in participant's notes.	[Copy/pastes text in webpage to table in word document] "I'm going to add this blurb to the table."
Corroborating sources	Comparing information from two separate sources, in the search environment, to verify their content as accurate.	[Copy/pastes two or more sources underneath factual information in notes]
Draw	Making a drawing or diagram to assist in learning.	[Draws diagram of wing with forces acting on it]
Establishing Chronology	Participant determines when a historical event occurred; often in relation to another event but not necessarily.	"Oh, interesting, Newton's laws and Bernoulli's principle were developed *before* people understood how lift worked."
Historical Perspective Taking	Participant puts self in position of a historical figure; infers that figure's perspective, thinking, emotions; expresses understanding of that figure's decision making at that time.	"Based on the timeline of when these were developed, I would guess that Bernoulli wasn't trying to apply this idea specifically to lift."
Hypothesizing	Making a tentative conclusion or informed guess (about content relevant to the task) based upon information either in the environment or from prior knowledge.	"I think the paper will move upward when he blows across it because the air will be moving faster on the top rather than the bottom of the paper."
Inferences	Drawing a conclusion based on two or more pieces of information that were read, seen, or heard in the search session.	"Ok, so if pressure is important to lift in the wing example and the paper example, then I think Bernoulli's principle is important to lift."
Inferring Source Content	Participant makes a guess as to the content available in a source.	"The snippet [on the SERP] mentions energy in a system, so I think this site should be about conservation of energy."
Knowledge elaboration	Making a definitive conclusion by elaborating on what was just read, seen, or hear with prior knowledge.	[Viewing diagram of a wing indicating pressure, velocity, and lift] "Ok, so if this diagram were showing forces from Newton's third law, then it would show the flow of the air here and downwash here from conservation of momentum."
Manipulate representation	Using pause, start, rewind, zoom, or other controls with a graphical representation.	[Rewinds YouTube video of Bernoulli's principle explanation]
Memorization	Learner tries to memorize text, diagram, etc.	"Once again without looking, Bernoulli's principle is the inverse relationship between velocity and pressure of a fluid."
Prior Knowledge Activation	Learner searches memory for relevant prior knowledge either before beginning performance of a task or during task performance.	"Oh yes! I do remember that Bernoulli's principle has something to do with pressure…"
Reading notes	Learner reads over notes, drawings, etc.	"I'm going to read over my notes." [Reads through notes]
Re-reading	Re-reading or revisiting a section of the search environment.	"I'm going to read through this section again."
Self-knowledge activation	The participant verbalizes that they are going to invoke a strategy because it is personally helpful, or that they are NOT going to invoke a strategy because it is NOT helpful to them, or, they say something about their own knowledge, beliefs, disposition, etc.	"I'm going to summarize what I just read in my notes because that will help me remember it better."
Select new informational source	Using the search environment to access a new representation of the desired information (e.g., navigating to new webpage).	[Returns to SERP and clicks on a different result]
Summarization	Verbally restating or writing what was just read, inspected, or heard in the search session.	[Writes summary in text editor]
Taking notes	Learner writes down information.	[Writes notes in text editor]

Table 3
Macro-SRL Process: **Monitoring**

Micro-SRL Process	Description	Example
Content Evaluation	Realization that what was just read and/or seen is or is not useful for the overall goal or subgoal; i.e., recognition of relevance.	[After scanning through results, reformulates query with more specific search terms from *Bernoulli's principle* to *Bernoulli's principle applied to lift*]
Emotion monitoring	Participant realizes that he/she is having an emotional response due to some aspect of the learning task.	"I'm just getting frustrated because this definition is very math heavy."
Emotion regulation	Participant actively attempts to control emotional response to some aspect of the learning task.	"I'm getting frustrated, I just need to take a deep breath and relax."
Evaluate Content as Relevant to Task Goal	Statement that what was just read and/or seen is or is not useful for a *specific* subgoal.	[After scanning through results, reformulates query with exact terms from subgoal in text editor from *Newton's Laws* to *Newton's Third Law applied to lift*]
Expectation of adequacy of content	Expecting that a certain type of representation will prove either adequate or inadequate given the current goal.	"…this section will probably give me the information I need to know whether Bernoulli's principle or Newton's third law makes the most sense." "I don't think this section on Venturi flow will help me understand how Bernoulli's principle applies to lift."
Feeling of Knowing (FOK)	Learner is aware of having read something in the past and having some understanding of it, but is not able to recall it on demand or learner states this is information not before seen.	"...I remember this was on the test from before the task" "I've never heard of Venturi flow before."
Judgment of Learning (JOL)	Learner becomes aware that they do or do not know or understand everything they read.	"Oh! I get it now.""I'm not understanding any of this, it's hard."
Judgment of Learning Tentative (JOLT)	Participant has some understanding, is not sure that it is accurate, but indicates that s/he will proceed with that understanding until further evidence confirms/ disconfirms it.	"I'm not sure I totally understand Bernoulli's principle from this, but I'm going to go with it for now."
Monitor progress toward subgoals	Assessing whether learner's previously-set subgoal and/or learner's own standard for understanding has been met.	"Oh, I said I was going to get 3 examples and I only have 2. Let me find one more."
Monitor use of strategies	Participant comments on how useful a strategy is/was.	"Yeah, making this table is really helping me understand the differences between Bernoulli's principle and Newton's third law of motion."
Self-Questioning	The participant asks a question relevant to the task, but does not articulate a specific plan to investigate the answer. Indicates that the participant has recognized a gap in understanding.	"So, what is the difference between Bernoulli's principle and Newton's third law of motion?"
Time monitoring	Participant refers to the number of minutes remaining.	"Ok, I only have 3 minutes left."

learning research should investigate whether and how the importance of particular SRL processes vary based on the task domain (e.g., biology, statistics); specific task constraints (e.g., task importance, timeframe); or the learning objective (e.g., cognitive process, knowledge type). For example, undergraduate biology students searching to learn about osmosis and diffusion may need support for different SRL processes than professional data analysts searching to learn about a new statistical method.

7. Conclusion

For decades, researchers in the learning sciences have observed the positive impacts of effective SRL on learning outcomes. Additionally, researchers have developed methods for capturing SRL within computer-based learn-

Table 4
Macro-SRL Process: **Task Difficulty & Demands**

Micro-SRL Process	Description	Example
Help-seeking behavior	Learner seeks assistance regarding either the adequacy of their understanding or their learning behavior, regardless of whether the instructions indicate that the experimenter/tutor will provide assistance.	“Why is the lift arrow pointed the wrong way in the diagram?”
Representation difficulty	Learner indicates the representation (i.e., picture, text, simulation) is not clear and/or unusable in general, regardless of one’s learning goal.	“This paragraph about Bernoulli’s principle and lift is really confusing. I would just like to see a diagram of the forces acting on a wing.”
Task difficulty	Learner indicates one of the following: (1) the task is either easy or difficult, (2) the questions are either simple or difficult, (3) using the search environment is easier or more difficult than using a book.	“It seems like they are still undecided on which best explains lift. This is so hard!”

Table 5
Macro-SRL Process: **Interest**

Micro-SRL Process	Description	Example
Interest Statement	Learner has or does not have a certain level of interest in the task or in the content domain of the task.	“Oh, this is really interesting.” “This is boring.”

ing environments. Leveraging these existing coding frameworks is important to advancing future search-as-learning research. While prior work has considered the extent to which searchers *perceive* engagement in SRL processes, it is critical to explore when, where, why, and how frequently SRL processes actually occur *during* a search session. Doing so will allow researchers to explore—(1) the overall effect of SRL on learning during search; (2) the impact of particular SRL processes on learning during search; (3) tools that support important SRL processes during search; (4) the relationship between particular SRL processes and search activities; and (5) factors that may impact which SRL processes are most critical to supporting learning during search.

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