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A Coding Mechanism for Analysis of SRL Processes in an Open-Ended Learning Environment

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Abstract: Open-Ended Learning Environments (OELE) support learning conceptually rich domains. However, widespread use of such OELE has posed several challenges for novice learners, for example, decision making tasks such as trade-off analysis, negotiation, etc. Since the nature of OELE is non-linear and open-ended, it requires the need of employing several self-regulatory processes such as planning, cognitive strategies, metacognitive monitoring, etc. To analyse these self-regulated learning (SRL) processes in an OELE, we introduce and discuss a coding mechanism based on Pintrich's framework of SRL and the design of a learning environment. The mechanism discusses several cognitive and metacognitive processes and observable indicators that can be representative/suggestive of a specific regulatory process that a learner might be displaying. To test the mechanism, a retrospective think-aloud (N=10) was conducted. Our primary contribution is developing and implementing the proposed coding mechanism. The findings of the work presented in the paper indicate a detailed understanding of the regulatory processes employed by learners while solving an open-ended problem in an OELE.

Keywords: Self-regulated learning, coding mechanism, open-ended learning environment, retrospective think aloud

1. Introduction

Open-ended learning environments (OELE) provide learners with opportunities for inquiry and complex problem-solving by presenting them with authentic contexts, stimulating learning tasks, and tools and resources to explore. Such learning environments stimulate learner abilities to expound decision making tasks like trade-off analysis, critical thinking, negotiation, etc. (Land, 2000). Thus, novice learners are required to employ several self-regulatory processes such as planning, cognitive strategies, monitoring, etc. (Azevedo et al., 2010).

To learn effectively in an OELE, a learner must analyse the learning context, set sub-goals, decide learning strategies to employ, assess the strategy, and monitor emerging understanding (Azevedo et al., 2010). Such learning involves deploying several cognitive, metacognitive, motivational and behavioural processes (Pintrich, 2000). Therefore, understanding these processes has become important for researchers to grasp the complex nature of SRL (Greene & Azevedo, 2009). Existing frameworks to understand SRL have been applied in hyperlink-based environments, in which the primary task is to read, assimilate, or synthesise text using various learning resources. In comparison, OELEs developed for complex problem solving may include tools such as a simulator, causal map builder, etc. Thus, existing frameworks are not sufficient to identify SRL processes in OELE.

To address the above-mentioned challenge, this paper proposes a coding mechanism based on Pintrich's (2000) framework of SRL to identify SRL processes in a OELE developed for problem-solving. This framework is suitable because it classifies different phases (i.e., forethought and planning, monitoring, control, and reaction/reflection) and areas (i.e., cognition, motivation/affect, behaviour, and context) of regulation as a heuristic to organise and understand SRL. To demonstrate the usability of the proposed mechanism, we have conducted a study with ten learners interacting with MEttLE (Modeling-based Estimation Learning Environment), a web-based OELE for estimation problem-solving using retrospective think-aloud (rTA) protocol. The proposed mechanism contains cognitive and metacognitive processes derived from both Pintrich's framework (2000) and the design of MEttLE.

2. Literature Review

SRL is an extraordinary umbrella that considers several aspects that influence learning (e.g., self-efficacy, volition, cognitive strategies) in a holistic approach (Panadero, 2017). Several SRL frameworks, models, and theories explain how cognitive, metacognitive and contextual factors influence the learning. For example, Zimmerman and Schunk (2001) first outlined SRL process by proposing a cyclic model of SRL with three phases, i.e., forethought, performance, and self-reflection. Pintrich (2000) extended this model to include four phases (i.e., forethought and planning, monitoring, control, and reaction/reflection). In 1998, Winne and Hadwin envisaged a cognitive structure that involved variables at the personal level processes at the task and personal level. Hence, different models predicate slightly distinct views on how learners self-regulate.

Whilst several theoretical models of SRL exist, the measurement of SRL remains a central issue in this field of research. An objective way of identifying and measuring student regulation is using online measures such as think-aloud data (Greene & Azevedo, 2009). Similarly, the stimulated recall method, a type of retrospective think-aloud protocol, can be used. In stimulated recall, learners' interaction data (e.g., screen capture video) is played back. They are asked to verbalise what they did at each point in the problem-solving process and reason for their actions. Such verbalisations can elucidate SRL processes and help us understand the dynamic nature of SRL. Recently, trace data, also known as event logs or log data, is used to measure SRL (Siadaty et al., 2016; Munshi & Biswas, 2019). Traces capture learner actions on the fly along with the context. Although trace data has a methodological advantage over think-aloud and other self-reports, it cannot and should not be considered the only method for measuring SRL processes (Winne, 2010).

Several existing learning environments support SRL processes, such as Metatutor (Azevedo et al., 2010) and Learn-B (Siadaty, Gasevic & Hatala, 2016). Although learning environments support SRL processes, very few measure such processes using theoretically grounded frameworks. We identified three such frameworks from the literature, viz. CAMM (Cognitive Affective Metacognition Motivation) model of SRL by Azevedo and colleagues (2010), a framework of self-regulated hypermedia learning by Bannert (2007), and trace-based microanalytic framework by Siadaty and colleagues (2016). While these frameworks to measure SRL processes exist, the tasks associated with the learning environments in question are mostly reading and assimilating. None of the environments supports problem-solving tasks including the use of tools (e.g. simulator). In the following sections, we are motivated to understand SRL processes associated with problem-solving tasks by proposing a coding mechanism based on Pintrich's framework and design of one such OELE, viz. MEttLE.

3. Coding Mechanism to Capture SRL Processes

This section describes the procedure used to combine theory and the pedagogical design of MEttLE to derive the coding mechanism for capturing learners' SRL processes in MEttLE.

3.1 Theoretical Basis

To identify the theoretical underpinning, we reviewed several SRL models, frameworks, and theories synthesised in section 2. We found Pintrich's SRL model (2000) most suited for our task of modelling regulatory processes. The framework describes and classifies several regulation processes to reflect goal setting, monitoring, control, and reaction and reflection regulatory processes across areas of regulation such as cognition, motivation/affect, behaviour, and context. We will be focused on discussing the extent of the area 'regulation of cognition' in the 'context' of MEttLE.
In the area 'regulation of cognition', the 'forethought, planning and activation' phase involves planning, goal setting and activation of relevant knowledge of the task. Similarly, 'monitoring' concerns various monitoring processes representing metacognitive awareness. Likewise, 'control' involves efforts to control and regulate different aspects of the task by selecting and adapting cognitive strategies for thinking and learning. Finally, the 'reaction and reflection' phase represents various reactions and reflections on the task. It is crucial to correctly infer the learners' verbalisation and associate it with the appropriate regulatory process. To do so, we reviewed literature and extracted a list of observable

indicators that are representative/suggestive of a specific regulatory process that a learner might be going through. Table 1 outlines regulatory processes described by Pintrich (2000) and their corresponding indicators found in related literature. For example, if a *"learner begins a task by setting specific goals for learning"*, it suggests that the learner is displaying 'target goal setting'.

Table 1. *Regulatory Processes Defined in Pintrich (2000) and Their Corresponding Indicators*

Phases	Regulatory processes		*Description of indicators*
Planning & activation	i.	Target goal setting	*Learner may begin a task by setting specific goals for learning*
			Learner may set specific goals for time use
			Learner may set specific goals for eventual performance
			Adjust or change the goal during task performance
	ii.	Activation of prior content knowledge	*Learner activates prior knowledge by actively searching their memory for relevant prior knowledge*
			Learner can activate prior knowledge in a planful and regulatory manner through prompts and self-questioning activities
			Learner constructs better problem representation
	iii.	Cognitive tasks	*Learner has knowledge how task variations can influence cognition*
			Learner knows that some tasks are more or less difficult
	iv.	Cognitive strategies, declarative	*Learner has knowledge that some strategies can help in learning*
			Learner has knowledge of 'what of cognition'
			Learner has knowledge of different cognitive strategies, such as rehearsal or elaboration, that can be used for learning
	v.	Cognitive strategies, procedural	*Learner knows how to perform and use a cognitive strategy*
			Learner knows that there are different strategies, and how to use
	vi.	Cognitive strategies, conditional	*Learner knows when and why to use a cognitive strategy*
			Learner knows that one strategy may be appropriate in some contexts, and may not in some.
Monitoring	vii.	Judgement of learning and comprehension monitoring	*Learner becomes aware that he does not understand something they just read or heard*
			Learner becomes aware that he understood something
			Learner becomes aware that he is reading too quickly or slowly
			Learner monitors reading comprehension by asking questions
			Learner decides if he is ready to take a test on the material he read
			Learner judges his comprehension of a lecture
			Learner judges whether he could recall the information for a test
	viii.	Feeling of knowing	*Learner cannot recall something when called upon to do so, but knows it*
			Learner cannot recall something when called upon to do so, but have strong feelings that he/she knows it.
			Learner is aware of reading something in the past and having some understanding of it, but not being able to recall it on demand
			Learner recalls teacher discussing in class, but is not able to recall
Control & regulation	ix.	Selection and adaptation of control strategies	*Strategy may include use of imagery to help encode information*
			Strategy may include use of imagery to help visualise correct implementation of a strategy
			E.g., strategies use of mnemonics, paraphrasing, summarising, outlining, networking, constructing tree diagrams, note-taking, etc.

Reaction & reflection	x.	Cognitive judgments	*Learner evaluates his performance*
	xi.	Adaptive attributions	*Learners make attributions to low efforts or poor strategy use*
			Learner make attribution of success to self
			Learner make attribution of success to external factor
			Learner make attribution of failure to self
			Learner make attribution of failure to external factor

3.2 Design of Problem-Solving OELE: Mettle

MEttLE is designed to support novice estimation problem solving (Kothiyal & Murthy, 2018). For instance, learners estimate the electrical power required to design the motor of a racing car, with given specifications such as wheel diameter, distance, etc. MEttLE offers metacognitive prompts, expert guidance and hints to help learners plan, monitor, and reflect. Similarly, it also consists of various tools and resources such as a simulator, calculator, info center, scribble pad, causal map builder, equation builder and a problem map. MEttLE is also capable of logging student data (Pathan et al., 2019). With the help of MEttLE's design, we scoped down the regulatory processes supported in MEttLE by various features and their corresponding indicators (Table 2). For example, 'productive planning' in MEttLE is supported by 'metacognitive prompts' and is indicated by *"learners writing planning statements using planning question prompts"*.

Table 2. *Regulatory Processes Supported by the Design of Mettle and Their Corresponding Indicators*

SRL processes	MEttLE context	*Description of indicators*
1. Planning	Metacognitive prompt	*Learner writes planning statements using prompts*
2. Monitoring		*Learner writes monitoring statements using prompts*
3. Model building techniques	Simulator	*Learner uses variable manipulation simulation, with implicit guidance to incorporate problem context*
	Statement builder	*Learner uses fictive motion words from the word bag*
	Causalmap builder	*Learner uses causal mapping tool*
	Equation builder	*Learner uses drag and drop parameters and mathematical relationships relevant to the problem*
4. Estimation reasoning	Question prompt	*Learner uses prompts to do estimation reasoning*
	Hints & guide me	*Learner uses hint /guide me to do estimation reasoning*
5. Gather context specific knowledge	Problem context	*Learner reads information on the problem context*
	Information center	*Learner uses infocenter to gather context specific knowledge*
6. External representation	Scribble pad	*Learner uses scribble pad*
7. Reflection on process	Reflection prompt	*Learner uses prompts to do reflection*
	Problem map	*Learner uses problem map to do reflection on problem solving process*
8. Evaluation during model building	Evaluation prompt	*Learner uses evaluation and contextualisation prompts*

3.3 Merging SRL Processes from Theory and OELE to Develop a Coding Mechanism

Table 3 delineates the merged coding mechanism. To consolidate the regulatory processes found, we aligned each MEttLE specific indicator to its closest mapping found in Pintrich. For example, the indicator from MEttLE specific process 'planning' *("learner writes planning statements using planning question prompts")* is similar to indicator of Pintrich's process 'target goal setting' (*"learner may begin* *a task by setting specific goals for learning").* Hence, the indicators of 'productive planning' and 'target goal setting' can be merged in the coding mechanism, as shown in Table 3. Likewise, we arranged all the MEttLE specific regulatory processes under Pintrich's classification of metacognitive processes.

Table 3. *Coding Mechanism Based on Pintrich and Design of OELE to Capture SRL Processes*

Phase	Regulatory processes	Phase	Regulatory processes
Planning and activation	i. Target goal setting 1. Planning	Control and regulation	ix. Selection and adaptation of control strategies
	ii. Activation of prior content knowledge		3. Model building techniques
	iii. Cognitive tasks		4. Estimation reasoning
	iv. Cognitive strategies, declarative		5. Gather context specific knowledge
	v. Cognitive strategies, procedural		6. External representations
	vi. Cognitive strategies, conditional	Reaction and reflection	x. Cognitive judgements
Monitoring	vii. Judgement of learning and comprehension monitoring 2. Monitoring		xi. Adaptive attributions 7. Reflection on process
	viii. Feeling of knowing		8. Evaluation during model building

4. Modelling SRL Processes Using the Coding Mechanism in MEttLE

The research goal of this study was to implement the proposed mechanism using rTA verbalisations of learners interacting with MEttLE and thus validate the existence of the indicators. Ten learners (6 male, 4 female) who had completed at least one year in Engineering participated in the study. The study was conducted in a lab set-up; wherein individual learners solved a complex engineering problem in MEttLE. within 60-90 minutes.

Two researchers independently coded 40% of learner data collected from 10 learners' interviews to establish the reliability of our coding mechanism. The researchers interpreted each phrase with the help of indicators provided in Tables 1 and 2, and used the closest one to code the phrase. For example, the learner statement *"I learned the concept of friction that if a body is moving at constant speed, the floor or the track, or on anything that its moving, that thing will oppose it"*, is closely identified with the indicator "Learner activates prior knowledge by actively search their memory for relevant prior knowledge". Thus, this phrase is coded as 'Activation of relevant prior content knowledge'. The inter-rater reliability of the coded interviews was calculated as cohen's kappa 0.83, indicating a strong agreement level. The rest of the interviews were then coded by one of the two researchers. Total 970 phrases were coded, and the rest were marked NA if they did not comply with any indicator.

We analysed the coded interviews to examine and understand the occurrence of various regulatory processes and their indicators. The average frequency of total processes per learner was 97. We found all the indicators listed in the proposed mechanism. The most common indicators found were related to 'model building' and 'judgement of learning and comprehension monitoring'. Out of 19 processes described in the mechanism, 14 processes commonly occurred. The SRL processes that occurred scarcely are activation of metacognitive knowledge (declarative, procedural, conditional), productive reflection on the process, and use of external representation. On grouping the indicators under their respective major categories, we found that learners displayed the maximum number of average processes under 'Control and regulation' (31%) and planning & activation (31%), followed by monitoring (23%) and reaction and reflection (15%).

5. Discussion and Conclusion

This paper demonstrates developing and implementing a coding mechanism to capture SRL processes in an OELE. The mechanism built on the theoretical basis of Pintrich and the pedagogical design of the OELE classifies SRL processes into four major categories. Although in its preliminary design stage, such a mechanism is developed because no existing frameworks are specifically designed to capture SRL processes in an OELE to solve complex problems. To demonstrate the use, we implemented the mechanism on verbalisations produced by ten learners.

We found 31% of regulatory processes associated with regulation of control, i.e., employing several learning strategies. Similarly, in a study conducted by Azevedo et al. (2010), learners think-aloud data indicated that learning strategies were deployed most often. In the control phase, indicators associated with model building strategies, such as simulation, causal map builder, etc., are employed most times. These indicators are particularly associated with tools found in complex problem-solving OELE and are hence essential to capture. While frequency analysis using rTA was useful, it did not capture time-sensitive information, such as the relationship between two processes. Thus, devoiding us opportunities to apply relationship mining algorithms such as sequential pattern/process mining. Hence, to capture temporal data, we plan to collect concurrent think-aloud data in the future.

While the existing coding mechanism is designed for MEttLE, the procedure to extract and merge the processes and indicators remains generic for OELE's designed to solve complex problems. We believe it is generalisable because our procedure ensures the inclusion of observable behaviour using both theory and design of the OELE. To implement the coding mechanism in another OELE, the following steps will have to be ensured, 1) identify features/affordances in the new OELE, and the SRL processes it braces, 2) extract a list of observable indicators that suggest the use of SRL processes supported by OELE, 3) find the closest alignment between OELE specific indicators and Pintrich indicators outlined in Table 1, and 4) merge the OELE specific SRL processes with the processes described in Pintrich. In future, we plan to conduct think-aloud studies with a larger sample to validate our coding mechanism. The resulting time-sequenced process series can be annotated with corresponding trace data to identify learner SRL processes automatically in an unobtrusive manner.

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