Measuring Students’ Use of Self-Regulated Learning Strategies from Learning Management System Data: An Evidence-Centered Design Approach

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Introduction

Learners’ ability to take charge and manage their own learning, also referred to as self-regulated learning, has been identified as an important skill for academic achievement. In many empirical studies, self-regulated learning has been shown to be predictive of academic achievement and performance (Clark, 2012; Dignath, Buettner, & Langfeldt, 2008; Sitzmann & Ely, 2011; Zimmerman, 2008). With the rapid changes in society, self-regulated learning has become important not only for academic achievement, but also for personal and work success (Dembo & Seli, 2008). Learners’ ability to manage their goals and time as well as direct their own learning has become crucial for succeeding in work, life, and citizenship in the 21st century (Dede, 2010).

Many studies thus have focused on identifying constructs of self-regulated learning and on measuring students’ use of self-regulated learning (SRL) strategies. In education research, the most dominant method for measuring students’ SRL as well as other forms of knowledge, skills, and abilities has been the standard assessment paradigm, psychometrics, in which learners respond to predefined items with discrete responses (Mislevy, Behrens, Dicerbo, & Levy, 2012; Zimmerman, 2008). With rapid technological developments, however, it is now possible to collect a variety of different data on student learning in various learning contexts. In particular, online learning environments can capture students’ activities at a micro level and in real time. As a result, some innovative and alternative methods have emerged to measure students’ SRL and other forms of knowledge and skills by analyzing the voluminous data captured by online learning environments (Zimmerman, 2008).

Among these is evidence-centered design (ECD), which encompasses concepts from both traditional psychometrics and the emerging field of educational data mining (Behrens, Mislevy, Bauer, Williamson, & Levy, 2004: Mislevy et al., 2012). ECD is a framework for designing, constructing, or implementing education assessments based on evidentiary arguments (Mislevy et al., 2012; Mislevy, Steinberg, Almond, & Lukas, 2006; Riconscente, Mislevy, & Hamel, 2005).

The purpose of this paper is to describe the application of the ECD framework to measure students’ use of SRL strategies by analyzing the trace logs captured by a learning management system and to explore how students’ use of SRL strategies changed over time in an undergraduate online mathematics course.

This paper has two sections. The first section presents the definitions and constructs underlying SRL from a traditional psychometrics perspective and discusses the application of ECD to measure SRL. The second section provides an overview of results measuring students’ use of SRL strategies through time series plots. In particular, this study addressed the following research questions:
1. To what extent can students’ use of SRL strategies be measured using trace logs in a learning management system?

2. To what extent do these measurements show changes in students’ use of SRL strategies over time?

Background

Self-Regulated Learning

When it emerged in the 1980s, research on SRL it shifted the focus of education research from inherent abilities (e.g., intelligence) to students’ initiated strategies (Zimmerman, 2001). Although many studies have shown that students’ use of SRL strategies is predictive of academic achievement (Clark, 2012; Zimmerman, 2001; 2008), there is no universal definition of SRL. In some studies, terms such as self-regulated, self-directed, or strategic have been used interchangeably, and their definitions have tended to vary according to the theoretical framework (Dembo & Seli, 2008; Zimmerman, 2001).

Zimmerman (2001) reviewed the research on SRL and classified the theoretical perspectives on it into seven categories: operant, phenomenological, information processing, social cognitive, volitional, Vygotskian, and cognitive constructivist. Of these perspectives, the social cognitive is dominant (Garcia & Pintrich, 1994; Schunk, 2001; Zimmerman, 2001). For example, according to Schunk, SRL refers to “students’ generated thoughts and behaviors that students instigate, modify, and sustain to attain their learning goals” (p.125). Thus, the social cognitive view encompasses not only students' ability to process information, such as relating new learning to prior knowledge, but also students’ behaviors, such as attending to instruction and establishing social relationships in work environments.

Many researchers have attempted to identify the constructs of SRL and to use them as measurements. In general, the components of SRL can be grouped into three categories: (1) metacognitive strategies (e.g., rehearsal, elaboration, organization), (2) behaviors (e.g., managing time and study environment, effort management, peer learning, help-seeking), and (3) motivation (e.g., expectancy, self-efficacy) (Pintrich, Smith, Garcia, & Mckeeachie, 1993; Schraw, Kauffman, & Lehman, 2002; Weinstein & Palmer, 1990; Zimmerman & Martinez-Pons, 1988; Zimmerman & Risemberg, 1997).

Measuring SRL with the standard assessment paradigm of psychometrics has been via self-report instruments. Some widely used instruments are the Learning and Study Strategies Inventory (Weinstein & Palmer, 1990), the Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich et al., 1993), and
the Self-Regulated Learning Interview Scale (Zimmerman & Martinez-Pons, 1988). These instruments are considered aptitude measures of SRL, which means that they aggregate students’ responses over time and regard self-regulation as a student’s typical attribute (Zimmerman, 2008; Winne & Perry, 2000).

A learner’s ability to use self-regulated strategies is not static, however, and changes throughout the learning process (Dignath et al., 2008). Also, SRL used to be regarded as relatively stable across learning situations, but several studies found that students’ use of SRL differed by learning environment (Roth, Ogrin, & Schmitz, 2015).

For these reasons, alternative and innovative approaches have emerged to measure changes in the use of SRL strategies, particularly in online or blended learning environments. Some examples of new measures are trace logs, think-aloud verbal protocols, and hyperlink usage (Barnard, Lan, To, Paton, & Lai, 2009). Zimmerman (2008) noted that these alternative approaches are considered as event measures of SRL because they regard SRL as a temporal entity rather than a static attribute.

These innovative online measures of SRL are still in an early stage of development (Zimmerman, 2008). A key challenge is determining how to draw valid inferences between the psychological constructs (students’ cognitive processes) and raw data or individual traces (Schraw, 2010). In this paper, we use ECD to help draw valid inferences between the constructs of SRL and trace logs captured in a learning management system.

Measuring Self-regulated Learning Using Evidence-Centered Design

What is ECD?

Evidence-centered design is a framework developed by Mislevy, Steinberg, and Almond in 2003 to design, construct, or implement education assessments based on evidentiary arguments (Mislevy et al., 2006; Mislevy et al., 2012; Riconscente, Mislevy, & Hamel, 2005).

Over the past 100 years, psychometrics has been the standard framework to assess students’ knowledge, skills, and attitudes. In psychometrics, educational or psychological constructs are measured using predefined items with discrete responses and sparse data (Mislevy et al., 2012). However, with rapid technological development, it has become possible to collect a variety of different data on student learning in authentic, technology-based learning environments. In particular, online learning environments, such as learning management systems, can automatically capture students’ activities and interactions at a fine level of detail and in real time during the entire learning processes.
Several educational data mining (EDM) studies have used data captured by online learning environments to measure student knowledge, skills, or other abilities. Winne and Baker (2013) noted that these EDM studies have the potential to advance research in metacognition, motivation, and SRL. However, Mislevy et al. (2012) pointed out that from the perspective of psychometrics, what is missing from EDM work is a means to form valid inferences between the variables (e.g., detailed logs of student activities in an online learning system) and the psychological constructs of interest (latent variables).

Mislevy et al. (2012) argued that the ECD framework integrates the concepts and methods from traditional psychometrics with EDM perspectives (Behrens et al., 2004; Mislevy et al., 2012). One of the characteristics of ECD is that it uses a construct-centered approach and emphasizes the evidentiary argument, which is a specification of the logic of the assessment. The ECD framework provides explicit evidentiary linkages between the targeted assessment constructs (student model), evidential components (evidence model), and assessment tasks (task model).

In the next section, we discuss the application of ECD to measure student SRL by using trace logs captured by a learning management system. Although the full ECD framework consists of five layers (domain analysis, domain modeling, conceptual assessment framework, assessment implementation, assessment delivery), in this paper we focus on the core layer that is closely related to assessment implementation, the conceptual assessment framework (CAF) (Riconscente, Mislevy, & Hamel, 2005). The CAF consists of several models, and each model asks critical questions such as What are we measuring? or How do we measure it? (Mislevy, Almond, & Lukas, 2003). Each model is described in the next section.

**Student Model: What are we measuring?**

A student model is related to what we wish to measure. It contains those variables or the structure of those variables related to students' knowledge, skills, or abilities that we wish to measure (Mislevy et al., 2012).

In this paper, we focus on measuring one type of SRL strategy: resource management. To measure student use of SRL strategies, we use the theoretical constructs from the MSLQ (Pintrich et al., 1993). We chose the MSLQ because it is one of the most widely used instruments and the subconstructs of SRL are clearly defined. According to the MSLQ, students' SRL consists of four components: motivation (value, expectancy, affect), cognitive strategies (rehearsal, elaboration, organization, critical thinking), meta-cognitive strategies (planning, monitoring, regulating strategies), and resource management strategies (or behavior). Pintrich et al. further divided resource management strategies into four subconstructs: (1) time management, (2) effort management, (3) peer learning, and (4) help seeking.
Evidence Model: How do we measure it?

The evidence model is associated with how we measure students’ knowledge, skills, or abilities. It refers to students’ behaviors that reveal the constructs described in the student model and also links the student model with the task model.

The first subconstruct, time management, refers to students’ efficient use of time (Pintrich et al. 1993). Following Jo, Kim and Yoon (2015), we used the regularity of log-in intervals (intervals between log-in points) to measure time management strategy.

The second subconstruct, effort management, refers to students’ regulation of their own effort (e.g., persisting on difficult or boring tasks) (Pintrich et al., 1993). Students’ use of the effort management strategy was measured using log-in frequency and the number of views of video lectures and lecture notes.

The third and fourth subconstructs, peer learning and help seeking, indicate using others when needed during learning. Students’ use of peer learning and help-seeking strategies was measured using the number of views and number of times they participated in online discussions and online tutoring, respectively.

Task Model: Where do we measure it?

The task model is related to where we measure student knowledge, skills, or abilities. It describes the tasks, situations, or environments that elicit the behaviors described in the evidence model.

In this study, we measured students’ SRL in a learning management system. Here, students’ activities related to SRL strategies (e.g., viewing learning materials, participating in online discussions) were used to elicit the variables described in the evidence model.

Figure 1 summarizes the CAF model to measure students’ use of SRL strategies using trace logs in the learning management system and how the student, evidence, and task models are related to each other.
Figure 1. Conceptual assessment framework (CAF) to measure students’ use of SRL strategies

Methods

Research Context and Participants

The digital learning environment that our data were drawn from was Canvas, which is used at a university in the western United States. The Canvas system automatically captures various instructor and student activities, such as the number of views or the number of postings for various Canvas system features (e.g., attachment, discussion, wiki).

For the present study, we extracted the student interaction data from an online introductory mathematics course ($N = 139$) taught during the fall 2014 semester. In this course, the instructor uploaded lecture videos and lecture notes using the attachment feature and used social features (e.g., discussion and wiki) for classroom discussions (e.g., discuss a problem with the class) and online tutoring. Table 1 shows the frequency distribution of the students’ final grades in this course.
Table 1. Frequency of students’ final grades

<table>
<thead>
<tr>
<th>Final grade</th>
<th>Pass (n = 82)</th>
<th>Fail (n = 57)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>A-</td>
<td>B+</td>
</tr>
<tr>
<td>Frequency</td>
<td>20</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Percent</td>
<td>14.4</td>
<td>4.3</td>
<td>3.6</td>
</tr>
</tbody>
</table>

As shown, 82 students (59.0%) passed the course, and 57 (41.0%) either received a grade of F or withdrew from the course (received a W grade). For further analysis, students were categorized into two groups (pass: A to D-; fail: F, W) to compare the use of SRL strategies between the students who passed and those who failed the course.

### Measures

Table 2 summarizes the student model (variables, operational definitions of each construct), and the evidence model (Canvas variables and how those variables measure students’ use of SRL strategies).

To measure students’ use of the time management strategy, we computed the regularity or irregularity of the log-in interval by using the standard deviation of the log-in interval (intervals between log-in points) \( S_t = \sqrt{\frac{\sum_{i=1}^{n-1} (t_i - \bar{t}_i)^2}{n-1}} \). Higher values indicate more irregularity in log-in intervals.

We computed students’ use of the effort management strategy by using the number of log-ins and the number of views of video lectures and lecture notes. Students’ use of peer learning was calculated by using the number of views and the number of postings in online discussions. Finally, students’ use of help seeking was computed by using the number of times students participated in online tutoring. To explore how student use of SRL strategies changed over time, we created time series plots using Tableau software version 9.3.
Table 2. Summary of the variables and the measures

<table>
<thead>
<tr>
<th>Variables</th>
<th>Student Model (what are we measuring)</th>
<th>Operational definition</th>
<th>Evidence Model (how do we measure it)</th>
<th>Canvas variables</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time management</td>
<td>Using their time well (well-planned time use)</td>
<td>(Ir)regularity of log-in interval</td>
<td>$S_i = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Effort management | - Persisting in tasks  
- Active participation | Log-in frequency  
View frequency | # of log-ins  
# of views (videos)  
# of views (lecture notes) |
| Peer learning | Using a study group or friends to help learn | # of participations in group discussion | # of views (discussion)  
# of postings in discussion |
| Help-seeking | Seeking help from peers or instructors when needed | # of participations in online tutoring | # of participations in online tutoring |
Results

Figure 2 is a time series plot of the mean number of times the two groups of students (pass and fail) used the effort management strategy (the number of views of video lectures) over the semester.

Figure 2. Mean use of the effort management strategy of viewing video lectures over the semester for pass (N = 82) and fail (N = 57) students

The students in the fail group (red) showed a higher average level of use of the effort management strategy than the pass group (blue) at the beginning of the semester. However, as time went by, they viewed videos more irregularly than the pass group students. Students who passed the course showed consistent use of the video viewing effort management strategy throughout the semester.

We made another time series plot to investigate changes in the use of the help-seeking strategy of participating in online tutoring over time (Figure 3). Again, students in the pass group showed a more consistent use of the help-seeking strategy over the semester. In contrast, the students in the fail group participated in online tutoring at a greater rate than the pass group only at the end of the semester.
Discussion and Future Directions

In this paper, we applied the ECD framework to measure students’ use of SRL strategies by using trace logs captured in a learning management system, and also investigated how the students’ use of SRL strategies changed over time by building time series plots.

First, we used the ECD framework to link the constructs of SRL from traditional psychometrics to the raw data captured by the learning management system. We found that the ECD framework, particularly the conceptual assessment framework, is helpful for building evidentiary arguments in measuring SRL, particularly in connecting theoretical constructs and student behaviors in online learning management systems. However, we also faced some challenges in applying the ECD framework to our data. ECD is often used to assess student knowledge or skills on various tasks (e.g., GRE test) rather than to measure student attitudes or behaviors (e.g., the use of a time management strategy). Moreover, there are not many existing examples of applying the ECD framework to log data collected by various learning environments. Thus, more research is needed on the application of ECD to analyze data collected by different learning environments.
Second, we explored how students’ use of SRL strategies changed over time by building time series plots. As mentioned, a learner’s use of self-regulated strategies is not static and can change during learning (Dignath et al., 2008; Roth et al., 2015). Thus, time-series plots provided a useful view of how students’ use of SRL strategies changed over time. In particular, we found a difference in the use of SRL strategies between the students who passed and those who failed the course.

In terms of future work, more variables are needed to measure the full range of SRL. In this study, we measured only students’ use of resource management strategies (behaviors), which is only one of the components of SRL. A future study should measure other constructs, such as cognitive strategies or metacognitive strategies, by using other learning management system variables, such as quiz data or discussion text data.

Finally, validation of the measuring method is necessary. Winne and Perry (2000) found that students tended to overestimate their use of SRL strategies in self-reports as compared with the trace log measures of SRL processes. They cautioned that trace log measures should be interpreted in conjunction with other measures, such as interviews, to draw more valid conclusions.
References


Appendix: Design Pattern

Author

<table>
<thead>
<tr>
<th>First Name</th>
<th>Ji-Eun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last Name</td>
<td>Lee</td>
</tr>
<tr>
<td>Affiliation</td>
<td>Utah State University</td>
</tr>
<tr>
<td>E-Mail</td>
<td><a href="mailto:jieun.lee@aggiemail.usu.edu">jieun.lee@aggiemail.usu.edu</a></td>
</tr>
</tbody>
</table>

Overview

Summary

- We applied the ECD framework to measure students’ use of SRL strategies by using trace logs captured in a learning management system and also investigated how the students’ use of SRL strategies changed over time by building time series plots.
- Construct: We focused on measuring one kind of SRL strategy: resource management. Students’ resource management strategies consist of four components: (1) time management, (2) effort management, (3) peer learning, and (4) help seeking.
- Learning environment: Our data were drawn from the digital learning environment Canvas. The Canvas system automatically captures various instructor and student activities, such as the number of views or the number of postings for various Canvas system features (e.g., attachment, discussion, wiki).
- Data used: The data collected by the system include students’ use of time management strategies (e.g., regularity or irregularity of log-in intervals), effort management strategies (e.g., log-in frequency), peer-learning strategies (e.g., number of times participated in group discussion), and help-seeking strategies (e.g., number of times participated in online tutoring).


Rationale

- Learners’ ability to manage their goals and time as well as direct their own learning has become crucial for succeeding in work, life, and citizenship in the 21st century.
- In many empirical studies, self-regulated learning has been shown to be predictive of academic achievement and performance.
The most dominant method for measuring SRL has been the standard assessment paradigm (psychometrics), using self-report instruments. However, a learner’s ability to use self-regulated strategies is not static and changes throughout the learning process. Alternative and innovative approaches thus have emerged to measure changes in the use of SRL strategies, particularly in online or blended learning environments. However, these innovative online measures of SRL are still in an early stage of development.

We used ECD as an approach to help draw valid inferences between the constructs of SRL and trace logs captured in a learning management system.

### Student Model

<table>
<thead>
<tr>
<th>Focal Construct</th>
<th>Students’ use of resource management strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time management: Using their time well (well-planned time use)</td>
</tr>
<tr>
<td></td>
<td>Effort management: Persisting in tasks, active participation</td>
</tr>
<tr>
<td></td>
<td>Peer learning: Using a study group or friends to help learn</td>
</tr>
<tr>
<td></td>
<td>Help seeking: Seeking help from peers or instructors when needed</td>
</tr>
<tr>
<td>Additional knowledge, skills, and abilities</td>
<td>Student’s use of metacognitive strategies</td>
</tr>
<tr>
<td></td>
<td>Motivation (e.g., expectancy, self-efficacy)</td>
</tr>
</tbody>
</table>

### Task Model

<table>
<thead>
<tr>
<th>Characteristic features of the task</th>
<th>In the task environment (Canvas learning management system), students engage in various learning activities such as accessing the learning management system, viewing learning materials, submitting assignments, participating in online discussions, and communicating with the instructor and other students.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data should be logged during students’ learning</td>
<td>Students’ access to the system</td>
</tr>
<tr>
<td>Number of views of learning materials and contents</td>
<td>Number of times participated in discussion, online tutoring</td>
</tr>
<tr>
<td>Student data should be collected from the system</td>
<td>Students’ final grades</td>
</tr>
</tbody>
</table>

### Potential task products

| Assignments (e.g., assignment completion rate to measure students’ use of effort management strategies) | Quizzes (e.g., the number of quiz attempts to measure students’ use of effort management strategies) |
| Time spent viewing video lectures or completing quizzes |

### Evidence Model

<table>
<thead>
<tr>
<th>Potential observations</th>
<th>Content of discussion (how students used peer-learning strategies)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Content of online tutoring (how students used help-seeking strategies)</td>
</tr>
<tr>
<td></td>
<td>Individual differences</td>
</tr>
<tr>
<td></td>
<td>Prior knowledge (SAT math score, high school math GPA)</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
</tr>
</tbody>
</table>

### Variable features of the task

- Students’ motivation for the course
- Students’ prior knowledge of the subject (introductory mathematics)
- Instructor or teaching assistant’s feedback

### Potential task products

- Assignments (e.g., assignment completion rate to measure students’ use of effort management strategies)
- Quizzes (e.g., the number of quiz attempts to measure students’ use of effort management strategies)
- Time spent viewing video lectures or completing quizzes
Potential frameworks

- Validation of the measuring method is necessary.
- Text mining using students' discussion or online tutoring content data
- Sentiment analysis
- Also, a future study should measure other constructs, such as cognitive strategies or metacognitive strategies, by using other LMS variables, such as quiz data or discussion text data.