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Measuring Cognitive Engagement: An Overview of Measurement Instruments and Techniques

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ABSTRACT

This paper adopted an analytical perspective to review cognitive engagement measures. This paper provided a comprehensive understanding of the instruments/techniques used to measure cognitive engagement, which could assist researchers or practitioners in improving their measurement methodologies. In particular, we conducted a systematic literature search, based on which the current practice in measuring cognitive engagement was synthesized. We organized and aggregated the information of cognitive engagement measures by their types, including self-report scales, observations, interviews, teacher ratings, experience sampling, eye-tracking, physiological sensors, trace analysis, and content analysis. We provided a critical analysis of the strength and weaknesses of each measurement method. Recommendations for measuring cognitive engagement were also provided to guide future empirical work in a meaningful direction.

Keywords:
Cognitive engagement; measurement instruments and techniques; systematic literature search; research synthesis; multiple methods

1. Introduction

The literature on student engagement is diverse, reflected in a plethora of engagement-related terminologies (e.g., student engagement, school engagement, academic engagement, and task engagement) and a vague understanding of engagement components. For instance, Fredricks, Blumenfeld, and Paris (2004) differentiated between three dimensions of engagement: behavioural, emotional, and cognitive. Whereas Finn and Zimmer (2012) state that researchers use four dimensions of engagement repeatedly in the literature, namely, academic, social, cognitive, and affective engagement. While many issues are yet to be answered in engagement studies, an essential issue that needs to be content with is the appropriate measurement of engagement. If the measurement instruments cannot precisely capture the construct, the data collected for interpretation would be problematic, and no meaningful conclusions can be guaranteed.

This review pays particular attention to the cognitive component of engagement, focusing on its measurement instruments and techniques. One reason is that educational psychologists and instructors traditionally emphasized cognition and metacognition in predicting students' performance. Another consideration is that this review aims to facilitate a concise but detailed discussion on a specific engagement phenomenon (i.e., cognitive engagement) since a general review of student engagement may raise more questions than it answers. Moreover, recent years have witnessed a surge in the use of advanced techniques, for example, eye tracker, EEG (Electroencephalograph) sensor, and text mining techniques, to capture students' in-time cognitive engagement. However, studies vary radically in how they operationalize cognitive engagement, depending on the researchers' conceptualizations of this construct, the grain size of measurement (e.g., institution, class, or task level), and the types of data that are available for collection in a given circumstance.

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As an illustration, Table 1 shows some definitions of cognitive engagement widely used in the literature. Nevertheless, these definitions differ from each other regarding granularity and focus.

Table 1. *Some Definitions of Cognitive Engagement*

Study	Definition	Level of Granularity	Focuses
Furlong and Christenson (2008)	The extent to which students perceive the relevance of school to future aspirations. It is expressed as interest in learning, goal setting, and the self-regulation of performance	School and Task levels	Motivation - Interest; Being strategic or self-regulating
Rotgans and Schmidt (2011)	The extent to which students are willing and able to take on the learning task at hand	Task level	Motivation – Level of autonomy
Appleton et al. (2006)	It includes less observable, more internal indicators, such as self-regulation, the relevance of schoolwork to future endeavours, the value of learning, and personal goals and autonomy	School and Task levels	Motivation – Level of autonomy, goal, value; Being strategic or self-regulating
Richardson and Newby (2006)	The integration and utilization of students' motivation and strategies in the course of their learning	School and Task levels	Motivation; Being strategic or self-regulating
D'Mello, Dieterle, and Duckworth (2017)	Learners' investment in the learning task, such as how they allocate effort toward learning, and their understanding and mastery of the material	Task level	Psychological investment
Fredricks, Blumenfeld, and Paris (2004)	Students' level of investment in learning. It incorporates thoughtfulness and willingness to exert the effort necessary to comprehend complex ideas and master difficult skills.	School and Task levels	Psychological investment
Helme and Clarke (2001)	The deliberate task-specific thinking that a student undertakes while participating in a classroom activity	Task level	Being strategic or self-regulating
Cleary and Zimmerman (2012)	The extent to which individuals think strategically before, during, and after performance on some learning activity	Task level	Being strategic or self-regulating
Li et al. (2021)	The extent to which individuals think strategically across the learning or problem-solving process in a specific task	Task level	Being strategic or self-regulating

Therefore, a review that summarizes the studies that have measured the construct of cognitive engagement is crucial. On the one hand, it will help researchers better understand this divergent research base. On the other hand, a critical review of cognitive engagement measures will provide more insights into the nature of this construct. This study represents a potentially valuable resource for researchers and practitioners about traditional and cutting-edge methods for capturing cognitive engagement.

In short, this paper aims to provide a synthesis of how students' cognitive engagement is measured across various contexts. In particular, this paper adopts an analytical perspective to provide a comprehensive understanding of the instruments/techniques used to measure cognitive engagement and assist researchers or practitioners in improving their cognitive engagement methodologies. As such, this paper distinguishes itself from a systematic review or a meta-analysis by summarizing all available cognitive engagement instruments/techniques that existed in contemporary literature and, at times, using selected literature to serve as examples of the state-of-the-art. This paper also provides a critical analysis of the strength and weaknesses of each measurement method.

2. Methods Used in the Review

This review is based on a broad conception of cognitive engagement regardless of its definition since the overarching goal of this paper is to provide an overview of the current practice in measuring cognitive engagement. We purposefully selected studies in the literature that best described the use of the instruments/techniques of cognitive engagement. Therefore, the studies reviewed in this paper were by no means exhaustive. As aforementioned, this paper was neither a systematic review nor a meta-analysis. Instead, we used an approach that was similar to qualitative synthesis to accomplish our research goals. To this end, this review included the following three phases: (1) creation of selection criteria and identification of relevant research, (2) critical appraisal and extraction of instruments/techniques concerning the measurement of cognitive engagement, and (3) synthesis of the findings and evaluation of different measurements.

Selection criteria

- Peer-reviewed pieces, ideally full journal papers. Conference proceedings were limitedly used to stay true to the criteria of using peer-reviewed studies. Conference presentations were not included.
- Empirical studies that had sufficient details about the measurement of cognitive engagement. Theoretical discussions and review papers concerning cognitive engagement instruments/techniques were also included as background material.
- Research studies that had explicitly measured the construct of cognitive engagement.
- Studies conducted in student learning or problem-solving settings.
- Studies that had been published in English.
- There were no limitations on the date of publication.

Identification of studies

A systematic literature search was conducted on prominent online databases, including ERIC (ProQuest), Web of Science, Google Scholar, and PsycINFO. The syntax used for the literature search was shown below: (cognitive engagement) AND (measure* OR scale* OR instrument* OR technique* OR tool* OR questionnaire* OR method*) AND (student* OR learn*). The processes of searching for the literature and screening for inclusion were displayed in Figure 1. The search identified 4907 publications in total. By removing duplications and applying the above selection criteria, we narrowed down the publications to 116 full-text articles. Finally, we identified 52 articles that were relevant for this study through full-text reading.

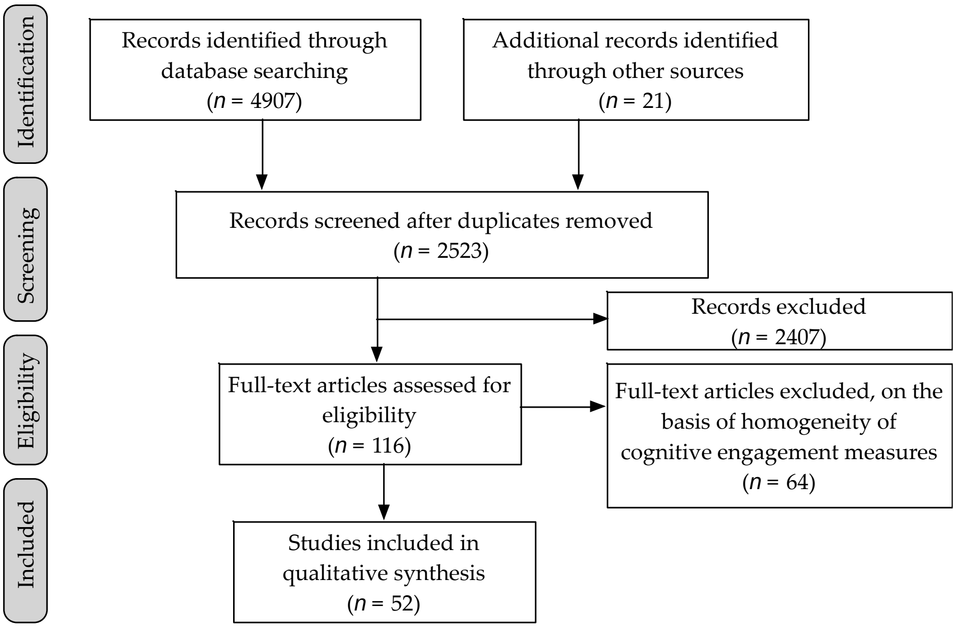

Figure 1. *The Process of Identifying Relevant Studies*

Data extraction and synthesis

We read the full text of each of the 52 articles with a central question in mind: How did the author(s) capture the construct of cognitive engagement? In particular, we extracted applicable information from each study regarding the instrument or technique used to measure cognitive engagement, as well as its definition, characteristics, assumptions, subcomponents, sample items, strength, and weakness. The extracted information served as the basis for literature synthesis. We then organized and aggregated cognitive engagement measures by their types, such as self-reports, observations, or teacher ratings.

3. Current Practice in Measuring Cognitive Engagement

We found that many instruments and methods that intend to measure cognitive engagement exist in the extant literature, including self-report scales, observations, interviews, teacher ratings, experience sampling, eye-tracking, physiological sensors, trace analysis, and content analysis. In general, self-report scales are the most common approach to assessing cognitive engagement (Greene, 2015; Fredricks & Mccolskey, 2012).

Self-report scales

Concerning the operationalization of cognitive engagement, three streams of self-report measures existed in literature, including those scales that emphasized (1) school-related motivations (e.g., students' beliefs about the value of schooling or control of schoolwork), (2) learning strategy use (i.e., cognitive strategies, self-regulatory or metacognitive strategies), and (3) students' mental involvement or psychological investment, such as effort, persistence, and dedication (Fredricks & Mccolskey, 2012). Specifically, the self-report scales that derived from a larger student engagement scale (e.g., cognitive engagement subscale of Student Engagement Instrument) usually contained items that measure school-related motivations and, by their nature, were not context-specific (Fredricks & Mccolskey, 2012; Fredricks et al., 2004). For example, Fredricks et al. (2011) identified 14 self-report scales measuring student engagement, in which only three scales explicitly had subscales labelled *cognitive engagement*: School Engagement Measure (SEM) – MacArthur (Fredricks, Blumenfeld, Friedel, & Paris, 2005), Student School Engagement Survey (SSES) (Finlay, 2006), and Student Engagement Instrument (SEI) (Appleton et al., 2006). Nevertheless, the three instruments asked students about their perceived importance of schooling, control of schoolwork, or future aspirations to represent cognitive engagement in general. None of these instruments measured cognitive engagement in specific learning contexts. The failure of linking cognitive engagement to a target task created confusion among researchers and muddied interpretation of research findings (Greene, 2015). Thus, there is now a growing body of studies reducing the specificity of measuring cognitive engagement to a class or even a specific task.

In terms of the instruments for measuring cognitive engagement in a class- or task-specific environment, much effort has been made to delineate the relevant aspects of this construct and to identify attributes that constitute it. For instance, Greene and her colleagues (2004) viewed cognitive engagement as the same as meaningful cognitive strategies (i.e., deep levels of information processing to connect or integrate new material with one's prior knowledge). Thus their measure of cognitive engagement in the Approaches to Learning Instrument focused on meaningful strategies. Similar to the instruments by Greene et al. (2004), Patrick, Ryan, and Kaplan (2007) also found that a single dimension of self-regulation strategies could constitute the construct of cognitive engagement. Therefore, they measured students' cognitive engagement by assessing the extent to which students plan, monitor, and regulate their cognition. Wolters (2004) also used strategy to represent students' cognitive engagement; however, both cognitive and metacognitive strategies were measured as two dimensions of cognitive engagement in his instrument. Specifically, the measure of cognitive strategies included eight items asking students' use of rehearsal and elaboration strategies. Metacognitive strategies consisted of nine items reflecting students' use of planning, monitoring, and regulatory strategies.

In line with the measure used in Wolters's (2004) research, Meece, Blumenfeld, and Hoyle (1988) assessed students' cognitive engagement in the Science Activity Questionnaire (SAQ) with 15 items on students' use of cognitive strategies and self-regulated learning, such as planning, monitoring, and help-seeking. However, Meece et al. (1988) also included effort-avoidant strategies as indicators of cognitive engagement in the questionnaire, and a sample item was '*I guessed a lot so that I could finish quickly*.' While the SAQ emphasized students' use of effort-avoidant strategies, the Student Engagement in the Mathematics Classroom Scale (SEMCS) that developed by Kong, Wong, and Lam (2003) included reliance along with the other two subscales (i.e., surface strategy and deep strategy) to measure cognitive engagement. According to Kong et al. (2003), reliance refers to students' perceived beliefs about the optimal learning approach and their learning preferences. A sample item was "*I would solve problems in the same way as the teacher does*."

Several conclusions can be drawn from the aforementioned self-report measures of cognitive engagement. First, strategies are generally considered an indicator of cognitive engagement, although researchers frame students' use of strategies differently (e.g., cognitive, metacognitive, deep, shallow or surface strategies). Second, the measures tended to stay close to information processing and self-regulation theories as to the foundational framework. Thus, it is no wonder that some studies applied the Motivated Strategies for

Learning Questionnaire (MSLQ) as a measure of cognitive engagement since it was initially designed to measure strategy use and self-regulation (Pintrich & de Groot, 1990; Fredricks & Mccolskey, 2012). Greene (2015) developed the Motivation and Strategy Use Survey to measure cognitive engagement, which contained similar subscales with the MSLQ, namely, self-regulation, deep strategy use, shallow strategy use, and persistence. Third, little consensus has been reached among researchers about the indicators of cognitive engagement, which are reflected from the variations in dimensions and subcomponents of the measures.

Instead of focusing on strategy use, some researchers measured cognitive engagement the other way around, such as assessing 'how often' students perform self-regulatory behaviours when solving a task. Linnenbrink (2005) proposed that cognitive engagement included both quality and quantity of self-regulation, so she developed two scales (i.e., the Quality of Self-regulation Scale and the Quantity of Self-regulation Scale) for students to report their cognitive engagement. Specifically, the Quality of Self-regulation Scale asks students how often they plan, monitor, and evaluate their problem-solving processes. The Quantity of Self-regulation Scale assesses students' persistence behaviours but emphasizes how often they do so. According to Rotgans and Schmidt (2011), cognitive engagement consisted of three elements: (1) engagement with the task at hand, (2) effort and persistence, and (3) experience of flow or having been completely absorbed by the activity. Based on this understanding, they developed the 4-item Situational Cognitive Engagement Measurements (SCEM) to assess students' levels of cognitive engagement. Similar to the SCEM, the Utrecht Work Engagement Scale for Students (UWES-S) also had nothing to do with students' use of strategies (Schaufeli et al., 2002). In the UWES-S, cognitive engagement was characterized by three components of vigour, dedication, and absorption. In sum, the three scales (i.e., the Quality and Quantity of Self-regulation Scale, SCEM, and UWES-S) contributed to the effective measurement of cognitive engagement by bringing in more variables as indicators of this construct and by trying to capture cognitive engagement without any further inferences.

Table 2 lists the student self-report measures of cognitive engagement discussed earlier and their underlying theoretical foundations, components, and sample items. Along with the challenges for measuring cognitive engagement, such as theoretical contentions on its dimensions and components, the items across different scales are different even though they are designed to describe the same indicator of cognitive engagement. As pointed out by D'Mello et al. (2017), methodological advances have unfortunately lagged behind theoretical developments in this area of research.

Table 2. *Prominent Cognitive Engagement Scales*

Questionnaire	Foundations	Components (items) and Sample Items
Motivation and Strategy Use Survey (Greene, 2015)	Depth of Processing and Self-regulation Theories	**Self-Regulation** (9): *"I organize my study time well for this class."* **Deep Strategy Use** (7): *"I classify problems into categories before I begin to work them."* **Shallow Processing Strategy** (4): *"I try to memorize the steps for solving problems presented in the text or in class."* **Persistence** (8): *"If I have trouble understanding a problem, I go over it again until I understand it."*
Approaches to Learning Instrument (Greene et al., 2004)	Depth of Processing	**Meaningful cognitive strategies** (12): *"I have a clear idea of what I am trying to accomplish in this class."*
The Quantity and Quality of Self-regulation Scale (Linnenbrink, 2005)	Self-regulation Theories	**The Quantity of Self-regulation** (4): *"Even when I do not want to work on math, I force myself to do the work."* **The Quality of Self-regulation** (5): *"When I do math, I ask myself questions to help me understand what to do."*
Situational Cognitive Engagement Measurements (SCEM) (Rotgans & Schmidt, 2011)	Contextual Dependence of Cognitive Engagement	**Engagement at hand** (1): *"I was engaged with the topic at hand."* **Effort & Persistence** (2): *"I put in a lot of effort."* **Experience of flow** (1): *"I was so involved that I forgot everything around me."*
Utrecht Work Engagement Scale for Students (UWES-S) (Schaufeli et al., 2002)	A Positive Psychology View of Engagement	**Vigor** (5): *"When I study, I feel like I am bursting with energy."* **Dedication** (5): *"My studies inspire me."* **Absorption** (4): *"When I am studying, I forget everything else around me."*

Science Activity Questionnaire (SAQ) (Meece et al., 1988)	Depth of Processing and Self-regulation Theories	**Active engagement** (8): *"I tried to figure out how today's work fit with what I had learned before in science."* **Superficial engagement** (7): *"I guessed a lot so that I could finish quickly."*
Not applicable (Patrick et al., 2007)	Self-regulation Theories	**Self-regulation strategies** (6): *"When I finish my math work, I check it to make sure it was done correctly."*
Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich & de Groot, 1990)	Self-regulation Theories	**Cognitive and metacognitive strategies** (31): *"I try to relate ideas in this subject to those in other courses whenever possible."* **Resource management strategies** (19): *"I make good use of my study time for this course."*
Strategy Use Questionnaire (Wolters, 2004)	Self-regulation Theories	**Cognitive strategies** (8): *"When I study for math, I try to connect what I am learning with my own experiences."* **Metacognitive strategies** (9): *"If what I am working on for math is difficult to understand, I change the way I learn the material."*
The Student Engagement in the Mathematics Classroom Scale (SEMCS) (Kong et al., 2003)	Depth of Processing and Approaches to Learning	**Surface strategy** (7): *"I find memorizing formulas is the best way to learn mathematics."* **Deep strategy** (7): *"When I learn mathematics, I would wonder how much the things I have learned can be applied to real life."* **Reliance** (7): *"I would learn what the teacher teaches."*

Note: The UWES-S and the scale used by Patrick et al. (2007) were not explicitly mentioned to measure cognitive engagement, but the items used in these instruments were to measure the cognitive aspect of engagement; Some studies used MSLQ to measure cognitive engagement, but they varied in subscales and items of MSLQ for capturing cognitive engagement.

Observations

Cognitive engagement has also been measured by observational methods at both the individual and classroom levels (Fredricks & Mccolskey, 2012). The underlying assumption is that cognitive engagement can be reliably recognized by specific behavioural and linguistic indicators, verified by some research (Helme & Clarke, 2001; Greene, 2015; Lee & Anderson, 1993). For instance, Helme and Clarke (2001) assessed students' cognitive engagement in a math class using classroom videotape data as a primary source, whereby linguistic indicators of strategy use (e.g., explanations and verbalization of thinking) and non-verbal correlates of cognitive engagement (e.g., gestures and body orientation) had been taken into consideration for measuring this construct. Lee and Anderson (1993) observed science classrooms for indicators of cognitive engagement such as initiating activities to understand science topics, requesting clarification, and applying scientific knowledge to solve real-world problems. Another example is Greene (2015) and her team's observations of students' interactions with teachers to infer students' levels of cognitive engagement in science classes, noting that the observational method was effective in detecting different engagement patterns.

The primary advantage of using observations to measure cognitive engagement is that this approach can provide detailed descriptions of both students' responses and contextual factors to help researchers understand the steady states of students' cognitive engagement (Fredricks & Mccolskey, 2012). Despite this advantage, as pointed out by Helme and Clarke (2001), very few studies have used direct observations of students' behaviours to assess levels of cognitive engagement. Fredricks et al. (2004) also noticed that the observational method was less common as a choice for researchers to measure cognitive engagement. There are several reasons: First, the information obtained via observational methods is highly inferential, especially when assessing the quality of students' mental investments such as effort or thinking (Fredricks et al., 2004; Appleton et al., 2006). Some students observed to be off-task may be highly cognitively engaged in problem-solving. Thus, there are some concerns about the reliability of the observational method since this technique relies heavily on the observers' ability to make accurate observations and their judgments about what should be observed (Turner & Meyer, 2000). Second, observational methods sometimes blur the boundary between cognitive engagement and behavioural engagement measures, although the literature is robust to tell them apart. Finally, observational methods are labour-intensive and usually applicable to a relatively small amount of participants (Fredricks & Mccolskey, 2012).

Interviews

The interview is another method that has been used to measure students’ cognitive engagement. Dent and Koenka (2016) pointed out that researchers who viewed cognitive engagement as the use of cognitive and metacognitive strategies often applied structured interviews to obtain information about students’ strategy use by asking for further explanations of their prospective or retrospective behaviours. For example, a frequently used structured interview was the Self-Regulated Learning Interview Schedule (SRLIS) developed by Zimmerman and Martinez-Pons (1986), which asked students to describe how they would use self-regulated learning strategies in a hypothetical learning scenario. The study by Helme and Clarke (2001) with students in mathematics classes was another example of using an interview technique to examine students' cognitive engagement levels. To be specific, twenty-four students were interviewed multiple times through the study, resulting in one hundred and nine interviews, which were then analyzed for evidence of cognitive engagement. Beyond the twenty behavioural indicators of cognitive engagement identified from class observations, four additional indicators were discovered from the interview records, such as 'claims to have been engaged during the lesson (e.g., I really put my minds to it)'. The SRL (Self-regulated Learning) microanalysis, which measures cognitive engagement in cyclical SRL processes, is designed to assess students’ regulatory behaviours and thoughts in context-specific tasks (Cleary & Zimmerman, 2012). An essential feature of this approach is the use of a structured interview protocol whereby context-specific questions delineated the three-phase model of SRL (i.e., forethought, performance, and self-reflection) in a temporally appropriate sequence. Specifically, forethought phase questions are administrated “before” a task, performance questions “during” the task, and self-reflection questions “after” performance on the task (Cleary & Zimmerman, 2012).

Interviews provide additional information to help researchers interpret the observed actions or self-report results. Besides, interviews allow for the construct of cognitive engagement to be redefined by the participants and for new understandings of theoretical claims to emerge (Turner & Meyer, 2000). However, the interviewing method is not without disadvantages. First of all, the validity of the interview method depends on the degree to which the participants are willing and able to share their ideas. Second, the interviewers' knowledge and skills could affect the type, quality, and depth of participants’ responses. A third disadvantage is the problem of social desirability. Students may answer questions in order to ‘look good’ or please the interviewers (Fredricks & Mccolskey, 2012; Turner & Meyer, 2000).

Teacher ratings

A few studies have used teacher ratings to assess students’ cognitive engagement. As an example, Wigfield et al. (2008) developed the Reading Engagement Index (REI) for teachers to rate each student’s engagement in a reading task. Specifically, teachers rated students’ cognitive engagement on the following three items: (1) works hard in reading (effort), (2) uses comprehension strategies well (strategies), and (3) thinks deeply about the content of texts (conceptual orientation). The rating was based on teachers' perceptions, with 1 = *not true* to 4 = *very true*. Thus, students received a score of 3 to 12 in terms of their levels of cognitive engagement. To avoid overburdening teachers in a study with 340 participants, the Teacher Rating Scale developed by Lee and Reeve (2012) asked teachers to assess each student’s cognitive engagement with only one comprehensive item of “this student uses sophisticated learning strategies, is a planful and strategic learner, and monitors, checks, and evaluates work”. Teachers made their ratings using a 7-point response scale, with 1 = *strongly disagree* to 7 = *strongly agree.* Fredricks and Mccolskey (2012) pointed out that teacher ratings can be beneficial for studies with younger children since they may have limited comprehension and literacy skills to complete self-report surveys. However, it is vital to notice that teacher ratings have their challenges. A recurring problem is that teachers are aware of students’ task performance and their past class-specific abilities. Thus, teachers tend to use both performance-based and ability-based information to inform their inferences of students’ cognitive engagement, which could inflate teachers' confidence in ratings (Lee & Reeve, 2012).

Experience sampling

Another technique for assessing student cognitive engagement is the experience sampling method (ESM), which usually involves the use of electronic or digital devices to interrupt students to probe their thoughts and feelings at that moment (Xie et al., 2018). The essential characteristic of ESM is that students' feelings, thoughts, and/or actions are measured regularly as they are experiencing in an authentic context (Zirkel et al., 2015). In general, researchers who conceptualized engagement from the perspective of flow (i.e., considering engagement as highly dynamic, fluctuating, and interactive) often used this technique to capture students' subjective experiences (Shernoff et al., 2016; Fredricks & Mccolskey, 2012). One example of ESM-based data collection is Salmela-Aro and her team's (2016) study to measure situational engagement with smartphone applications that triggered short questionnaires several times in the science classes. Specifically, students received smartphones with an application that prompted questionnaires and emitted short acoustic signals at fixed time intervals in science lessons. The students were asked to report on the 4-point Likert scale immediately on the application after hearing the signal. Instead of relying merely on fixed sampling, Xie et al. (2018) designed two sampling methods, i.e., fixed and event-based ESM. Students were required to answer mini-surveys for event-based ESM, which contained cognitive engagement items, as they triggered certain study events in a mobile-learning environment.

The ESM is a promising technique to explore an individual's intra-psychological states, such as cognitive engagement, so that the individual is being asked to respond when required in repeated manners (Järvelä et al., 2008). Moreover, ESM is considered a more sensitive method of measuring cognitive engagement than traditional self-report measures since it collects data in the moment of learning or problem-solving. The experience sampling technique, although it provides researchers with an innovative approach to assess cognitive engagement as it occurs in a context, suffers from several limitations. The idea of ESM is to interrupt students regularly at unexpected times, which may disturb their thinking processes or even irritate participants due to its intrusiveness nature. Studies with ESM can also be time-consuming; thus, such research requires a high level of commitment from participants (Zirkel et al., 2015). Moreover, considering participant fatigue, the survey is usually kept short, which may not be suitable for research consisting of a wide range of variables.

Eye-tracking

Researchers have also embraced eye-tracking, a non-intrusive but informative technique, to collect the eyes' positions and movements of students to infer their cognitive engagement (Antonietti, Colombo, & Nuzzo, 2015; D'Mello et al., 2017; Miller, 2015). Using eye-tracking to measure engagement is based on three foundational assumptions: (1) The baseline of engagement is the simple act of paying attention, while eye-tracking can identify this act by measuring if students' eyes have rested on an object for a minimum amount of time. This assumption is based on that students cannot be even minimally cognitively engaged in a task if they are not paying attention to the stimulus. (2) Secondly, the eye-mind-engagement assumption asserts that fixation duration (i.e., the length of time an eye is still for extracting information from a particular stimulus) reflects the quantity and quality of one's cognitive effort; and (3) Increase in pupil size associates with an individual's increased cognitive effort once the external factors (e.g., the brightness of objects) are controlled (Miller, 2015).

Benefits of using the eye-tracking technique to assess cognitive engagement include real-time analysis of eye movement data, a precise indication of visual attention distribution, and availability of a rich quantified dataset for establishing user models (Kruger, Hefer, & Matthew, 2014; van Gog & Jarodzka, 2013). However, as pointed out by Miller (2015), more research is still needed to develop mature procedures for collecting eye movements and pioneer methodological techniques for extracting reliable engagement-related information. For one, multiple eye movement indices were recommended to advance a more precise measurement of engagement, but meanwhile, it also made interpretation more difficult (Miller, 2015).

Physiological measures

Most of the physiological methods aim to measure electrical signals produced in the skin (Electrodermal activity, EDA), brain (Electroencephalograph, EEG), or muscles (electromyogram, EMG), and to provide researchers physiological data to make inferences about participants' emotional and cognitive states (D'Mello et al., 2017; Stevens, Galloway, & Berka, 2007). Since the physiological methods provide rich data sources in fine-grained size, there has been a surge in using these techniques to measure engagement. To step further, EDA and EMG are usually used to measure emotional engagement, and EEG is used to measure cognitive engagement (Charland et al., 2015; Schuurink, Houtkamp, & Toet, 2008).

EEG is an electrophysiological monitoring technique that measures electrical activities of the brain, with the electrodes attached to different locations on the scalp (Berka et al., 2007). Researchers commonly analyze the power spectral density (PSD) of specific frequency spectrums of electrical signals to quantify cognitive engagement during a task (Charland et al., 2015). The analysis of PSD can be done with various EEG systems. For example, Kruger, Hefer, and Matthew (2014) used an Emotiv™ Neuro-headset EEG to record 68 students' brain activities while watching a recorded lecture. Precisely, the EEG was placed on students' heads as they were seated comfortably on a stable chair. Once accurate recordings were confirmed and the baselines for analyzing various EEG channels were identified, students were instructed to watch a video recording of a Psychology lecture, during which the information of their brain activities was collected. Based on the raw EEG data, engagement as one of the five categorized EEG channels was generated by the Emotiv™ software. In Stevens et al.'s (2007) study, a wireless EEG sensor headset was used to record 12 participants' electrical signals generated from their brains during scientific problem-solving. Data sampling speed was at 256 samples per second, based on which the engagement index, ranging from 0.1 to 1.0, was calculated for each 1-second epoch for each student via the B-Alert software.

The advantages of using EEG to measure engagement include the ability to monitor levels of engagement continuously, unobtrusiveness, and being a fine-grained measure. However, several challenges remain in this area of measurement. For a practical one, EEG-based research can be labor-intensive and expensive for both researchers and participants. Another important consideration is that EEG devices and software operation can usually be very complicated, requiring researchers to accumulate sufficient skills and experiences. Besides, the engagement-related indices generated from EEG systems are not always accurate, especially considering individual differences and contextual factors (Stevens et al., 2007).

Log files

Researchers who conceptualized cognitive engagement from the depth of processing and self-regulation theories are increasingly using log files to assess cognitive engagement, since log files provide a wealth of information about the timing, occurrence, frequency, and pattern of learning activities as students engage in computer-based learning environments (CBLEs) for learning and problem-solving (Greene, 2015; Bernacki et al., 2012). Log files can be comprehensive if researchers pinpoint the types of learning events meaningfully associated with students' cognitive engagement. Moreover, log files provide new opportunities for understanding the dynamic nature of cognitive engagement since students' digital footprints during the interaction with CBLEs are recorded automatically and unremittingly. In general, cognitive engagement is assessed by extracting students' cognitive and metacognitive strategies from logs of learners' behaviours (Bernacki et al., 2012; Chen & Pedersen, 2012). Meanwhile, log files have also been used in other ways to infer levels of cognitive engagement. For example, many studies have operationalized the construct of cognitive engagement in terms of time-on-task (Helme & Clarke, 2001; Järvelä et al., 2008). In a recent study, Li, Zheng, Poitras, and Lajoie (2018) analyzed log file data to identify patterns in the allocation of cognitive resources of 62 medical students in solving patient cases. Findings from their research demonstrated that students' cognitive engagement, which was assessed by students' on-task time, varied across and within problem-solving phases (i.e., forethought, performance, and reflection).

Language and content analyses

Cognitive engagement is inherently unobservable and hard to measure. Thus researchers have explored another method, language and content analysis, to detect this construct from students' use of verbal languages or written materials, since language is the most reliable way for individuals to translate their internal thoughts into a form that others can understand (Tausczik & Pennebaker, 2010; Ireland & Henderson, 2014). At its simplest, word count reflects how engaged students are in a conversation or activity (Tausczik & Pennebaker, 2010). Researchers have also made a few attempts to extract language features from verbal or written materials to infer levels of cognitive engagement using a variety of text mining techniques. For example, a computerized text analysis program of Linguistic Inquiry and Word Count (LIWC) has been used in a wide range of experimental settings to study various forms of engagement by comparing students' written samples with its psychologically meaningful categories (Pennebaker, Boyd, Jordan, & Blackburn, 2015; Tausczik & Pennebaker, 2010).

Rather than using systematic, strict textual analysis, researchers have also used content analysis in a more qualitative, interpretive way to make inferences about students' cognitive engagement. For example, Zhu (2006) developed the Analytical Framework for Cognitive Engagement in Discussion to code students' levels of cognitive engagement based on collected discussion messages as students participated in asynchronous online discussions. While this qualitative approach of content analysis can address some of the issues that existed in textual analysis, the biggest challenge is that considerable effort should be made to reach objectivity in rating levels of cognitive engagement and solve discrepancies among raters.

All in all, there are various promising instruments and methods to measure cognitive engagement, and each type of measure has strengths and weaknesses. Based on the literature reviewed previously, we have identified some guidelines for future research and practice to measure cognitive engagement.

4. Conclusion, Discussion and Recommendations

To improve the measurement of cognitive engagement, one of the first steps for researchers is to describe the construct of cognitive engagement more clearly, given the variations in its definitions (Fredricks et al., 2011; Miller, 2015; Samuelsen, 2012). On the one hand, the many conceptualizations of cognitive engagement make it into a broad umbrella term covering a wide range of concepts and ideas. Researchers need to be aware of their preferences of a particular definition of cognitive engagement and the theories underlying that definition, otherwise constructs other than cognitive engagement would be included to mess up the measurement (Greene, 2015). For example, Sinatra et al. (2015) pointed out that the operational definition of cognitive engagement sometimes has much in common with existing motivation constructs. On the other hand, cognitive engagement has been conceptualized at different levels, such as an individual's cognitive engagement in tasks and a group of students' cognitive engagement in school. Thus, it is recommended that the nature of the research context (e.g., school, classroom or a specific task) and one's research goals (e.g., basic research or school policy) should be kept in mind (Azevedo, 2015), since they determine the grain-size of measurement of cognitive engagement and corresponding instruments.

Moreover, it has been reminded by some researchers that large-scale engagement surveys should be used cautiously, since they are usually developed for non-academic purposes. The large-scale surveys present little evidence of their validity (Veiga et al., 2014). For example, the High School Survey of Student Engagement (HSSSE) is administered every year to collect information about students' views of school learning environment, schoolwork, and interactions with the school community, with an attempt to assist schools in recognizing areas for improvement (Fredricks & Mccolskey, 2012). The National Survey of Students Engagement (NSSE), another large-scale instrument initiated every two years, has elicited considerable criticism from the engagement research community for lacking validity (Veiga et al., 2014; Fredricks et al., 2011). Consequently, researchers who use subscales or sets of items adapted from a larger instrument need to pay particular attention to the instruments' reliability and validity. Otherwise, the construct of cognitive engagement would be measured differently from what it is supposed to (Fredricks et al., 2011).

Another necessity in advancing the measurement of cognitive engagement is to distinguish indicators of cognitive engagement from its antecedents and facilitators (e.g., willingness, interest, self-efficacy) and its direct or indirect outcomes, such as procrastination, grade, and task performance (Veiga et al., 2014). Take the Student School Engagement Survey (SSES) as an example. Items like 'Most of my teachers know the subject matter well' and 'I get good grades in school' were included to capture students' cognitive engagement. However, the prior item relates to teachers' competency in teaching, and the latter one associates with students' academic performance, which are the antecedent and outcome of cognitive engagement, respectively.

In addition, more advanced statistical techniques are needed to differentiate the salient indicators of cognitive engagement from the trivial ones and to exclude the repetitive elements since a variety of indicators for measuring cognitive engagement have been proposed. For instance, to what extent do students' experiences of flow (i.e., an indicator of cognitive engagement in the SCEM) relate to the indicator of absorption as measured in UWES-S? The same with instrument items. Betts (2012) suggested that statistical modelling techniques, especially confirmatory factor analysis and item response theory, should be considered in constructing and evaluating cognitive engagement measures. Samuelsen (2012) also argued that statistical methods, such as differential item functioning, could address some of the measurement issues. Lastly, researchers are increasingly calling for the use of multiple methods to measure cognitive engagement rather than relying merely on a single method (Greene, 2015; Sinatra et al., 2015; Betts, 2012). First, researchers may overcome some limitations of using only one approach by adopting multiple methods (Azevedo, 2015). For example, using self-reports along with the experience sampling method (ESM), researchers may gain a more nuanced understanding of students' cognitive engagement since students would be more sensitive to survey questions as they are still in the proximity of time and space in the context of problem-solving (Xie et al., 2018; Zirkel et al., 2015). Moreover, multimethod might reveal more components or manifestations of cognitive engagement than a single method. For instance, Helme and Clarke (2001) used both observation and interview techniques to examine students' cognitive engagement levels, whereby twenty indicators of cognitive engagement were identified from observations, and four additional indicators were discovered from the interview records. Furthermore, the combination of different approaches to measuring cognitive engagement allows researchers to triangulate and therefore establish the validity of the data, which is a robust way to study how cognitive engagement changes over time (Greene, 2015). While keeping the strengths of multimethod for measuring cognitive engagement in mind, it is vital to notice that construct definition drives the choice of measures rather than the opposite, considering that different methodologies often imply different theoretical orientations of cognitive engagement (Sinatra et al., 2015). Thus, a clear definition of cognitive engagement should be provided before the selection of measurements.

Taken together, this paper adopts an analytical perspective to review contemporary measurement methods of cognitive engagement used in broader academic settings. In doing so, no prospective method is omitted, and many possibilities are offered to researchers when exploring how cognitive engagement unfolds within and across learning phases. In addition, this review is particularly useful to practitioners in exploiting the affordances and minimizing the constraints of different cognitive engagement measures. Moving forward, we propose that a multimethod approach to capturing cognitive engagement is a necessity for future empirical work. Analyzing multimodal data about cognitive engagement may open new scientific leads to come closer to the essence of this construct, and this study paved the way for fulfilling this goal.

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