

AN INVESTIGATION OF THREE METACOGNITIVE MEASURES

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Metacognition, or the awareness and ability to control one's cognitions, is hypothesized to play a central role in productive problem solving (Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995) and self-regulated learning (Zepeda, Richey, Ronevich, & Nokes-Malach, 2015). To assess metacognitive skills, different measures have been developed including questionnaires, verbal protocols, and metacognitive judgments. However, there is little research on whether these measures assess the same metacognitive processes (e.g., monitoring, debugging, and evaluation) or are related to the same learning outcomes (e.g., transfer and preparation for future learning). To address these issues we investigated whether these three measures captured the same metacognitive processes during a learning task and test. The results showed that evaluation skills as measured by verbal protocols were positively related to debugging and evaluation as measured by the task-based questionnaire. There were also unexpected negative associations between monitoring skills as measured by verbal protocols and the questionnaire and metacognitive judgments. There was no association between the monitoring questionnaire and metacognitive judgments. All three measures were related to learning, but the type of metacognitive skill, the direction of the effect, and the type of learning differed among the measures. Implications for future research and applications are discussed.

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1.0 INTRODUCTION

Metacognition is a multi-faceted phenomena that involves thinking about and controlling one's cognitions (Flavell, 1979). Past research has shown that metacognition is positively related to effective problem-solving (Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995) as well as transfer (Lin & Lehman, 1999) and self-regulated learning (Zepeda, Richey, Ronevich, & Nokes-Malach, 2015). However, prior work has used different metacognitive measures and the relations among the measures are not well understood, resulting in concern about each measure's validity and accuracy (Veenman, 2005; Veenman, Prins, & Verheij, 2003). Further research is required to help determine what types of metacognitive processes are being assessed by each measure. In particular, we seek to evaluate three metacognitive measures: verbal protocols, a task-based questionnaire, and metacognitive judgments.

1.1 THEORY AND MEASUREMENT

One source of the variation in measurement may be due to the variation in theories of metacognition (e.g., Brown, 1987; Brown, Bransford, Ferrara, & Campione, 1983; Flavell, 1979; Jacobs & Paris, 1987; Nelson & Narens, 1990; Schraw & Moshman, 1995). Although most theories hypothesize that metacognition involves the ability to assess and regulate one's thoughts, they differ in how they operationalize those constructs (Pintrich, Wolters, & Baxter,

2000; e.g., Nelson & Narens, 1990 and Schraw & Dennison, 1994). Two common differences are the type and grain size of the skill. For example, Nelson and Narens' (1990) model consists of a monitoring process that assesses the current state of working memory and uses that information to regulate and guide subsequent action. In contrast, Schraw and Dennison's (1994) model consists of more fine-grained skills including: planning, information management, monitoring, debugging, and evaluation (see Figure 1). Each of these skills is hypothesized to have a distinct process that interacts with the other skills. Zimmerman's (2001) self-regulated learning model also views metacognition as a set of fine-grain skills including planning, monitoring, and evaluation.

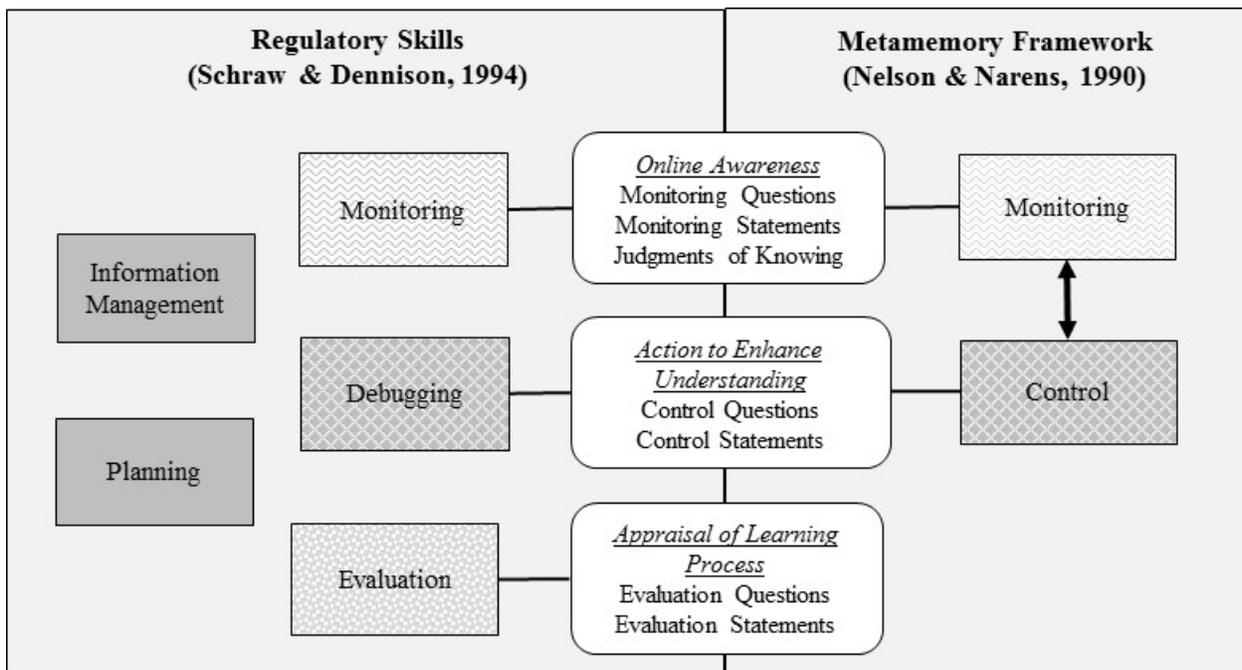


Figure 1. Comparison of theoretical frameworks and the measures related to them. We aim to measure the metacognitive constructs common between the models represented by the white rectangles.

Although some researchers initially sought to capture these finer-grained skills vis-à-vis a questionnaire they often ended up combining them into a single factor due to challenges in establishing each as a separate construct (e.g., regulation, Schraw & Dennison, 1994). Similarly, Pressley and Afflerbach (1995) had difficulty in differentiating monitoring from control processes in verbal protocols and found that they tend to occur at the same time. The challenges in differentiating between metacognitive skills could be why other researchers have proposed fewer, interactive skills (Howard-Rose & Winne, 1993; Pintrich, Wolters, & Baxter, 2000).

We aim to further examine the relation between theory and measurement with respect to monitoring, control/debugging, and evaluating. We define *monitoring* as one's awareness of his or her thinking and knowledge during the task, conceptual *debugging* as goal-directed activities to increase one's understanding, and *evaluation* as an assessment of one's understanding, accuracy, and/or strategy-use once the task is completed. For example, if a student identifies what he or she does not understand (monitoring) while attempting to solve a problem he or she has an opportunity to fill the gap in knowledge by seeking new information, rereading, summarizing the instructions, trying out new ideas, and so forth (debugging). Then, once the activity is completed, he or she can reflect on their accuracy as well as which strategies or knowledge they found most beneficial in order to prepare them for future tasks (evaluation).

1.2 RELATION AMONG MEASURES

Two factors that differ across the measures concern *when* (e.g., concurrent vs. retrospective) and *how* (e.g., think aloud vs. questionnaire vs. judgment) metacognition is assessed. Concurrent or “online” measures such as verbal protocols (e.g., Chi, Bassok, Lewis, Reimann, & Glaser, 1989)

attempt to examine people’s metacognition *as it is occurring* whereas retrospective or “offline” measures such as questionnaires (e.g., Schraw & Dennison, 1994) or retrospective metacognitive judgments (see Dunlosky & Metcalfe, 2009 for an overview) evaluate metacognition *after* the activity has occurred. Unlike the retrospective measures, concurrent verbal protocols allow access to the contents of working memory without having to rely on one’s long-term memory (Ericsson & Simon, 1980). For a visual representation see Figure 2.

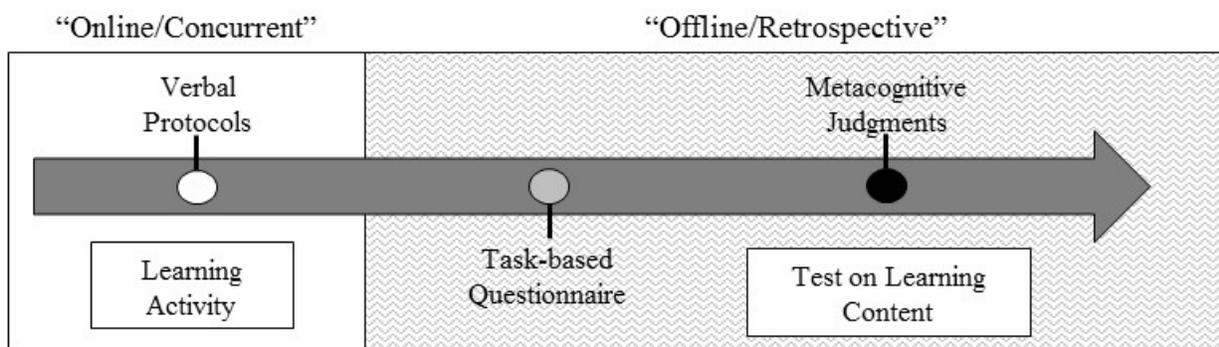


Figure 2. Visual representation of the across-methods-and-time design. The gray arrow indicates time from the learning task and the circles demonstrate the location of each metacognitive measure in relation to the target learning measure.

Little prior work has directly compared these measures to one another. However, there are a few studies showing that student responses to questionnaires rarely correspond to concurrent measures (Cromley & Azevedo, 2006; Van Hout-Wolters, 2009; Veenman, 2005; Veenman et al., 2003; Winne, Jamieson-Noel, & Muis, 2002). For example, Veenman et al. (2003) found weak associations (r 's ranged from $-.18$ to $= .29$) between verbal protocols and a questionnaire assessing student’s metacognitive study habits. Van Hout-Wolters’ (2009) work revealed similar findings in which correlations between verbal protocols and dispositional

questionnaires were weak (r 's = -.07 to .22). In addition, Zepeda et al. (2015) found that students who received metacognitive training differed from a comparison condition in the accuracy of their metacognitive judgments, but *not in* their questionnaire responses. Schraw and Dennison (1994) and Sperling, Howard, Staley, and DuBoius (2004) found similar findings in which student accuracy on metacognitive judgments were not related to their responses on the Metacognitive Awareness Inventory's (MAI) regulation dimension. The lack of associations among the different metacognitive measures may be due to the measurements assessing different processes, an imprecise measurement, or a combination of the two. Veenman, Van Hout-Wolters, and Afflerbach (2006) suggest that to evaluate the relations of these measurements a multi-method design should explicitly compare different methodologies to one another.

1.3 RELATION TO ROBUST LEARNING

To what degree do these different measures predict learning? Prior research provides some evidence that metacognition is related to school achievement (e.g., grades or GPA) and performance on tests (e.g., quizzes, standardized assessments). However, no work has examined whether all three measures predict the same type of learning outcomes.

We define robust learning as the acquisition of new knowledge or skills, which can be applied to new contexts (transfer), or prepares students for future learning (PFL) (Bransford & Schwartz, 1999; Koedinger, Perfetti, & Corbett, 2012; Schwartz, Bransford, & Sears, 2005; Richey & Nokes-Malach, 2015). We define transfer as the ability to use and apply prior knowledge to solve new problems, and PFL, as the ability use prior knowledge to *learn* new material (reference Figure 3 for a comparison). To our knowledge, there is no work examining

the relation between metacognition and PFL using these different metacognitive measures. To gain an understanding of how these measures have been related to different learning outcomes we surveyed the literature.

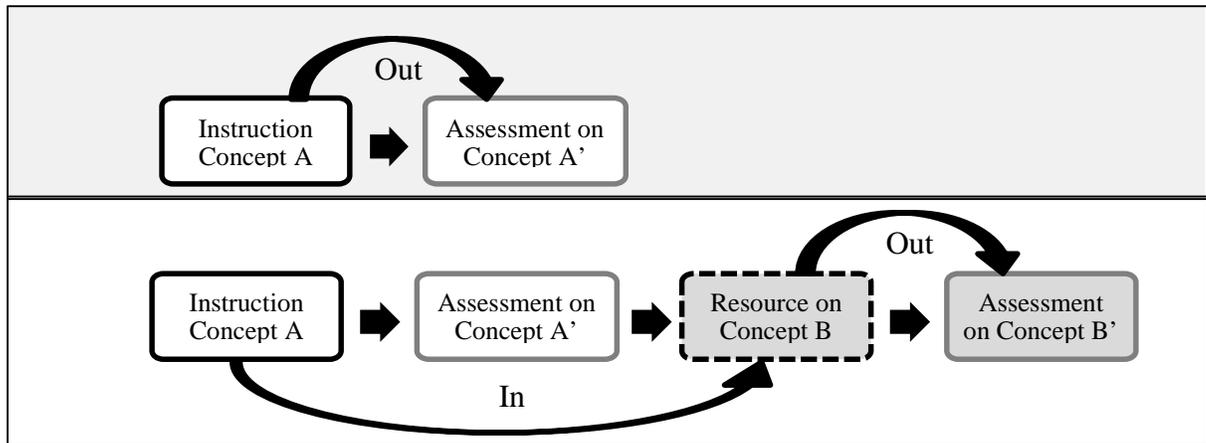


Figure 3. Comparison of transfer and PFL.

1.3.1 Questionnaires

Prior work using metacognitive questionnaires typically measure student achievement as assessed by class grades, GPA, or standardized tests (Pintrich & DeGroot, 1990 and Pintrich, Smith, Garcia, & McKeachie, 1993; Sperling et al., 2004). Using these measures makes it difficult to identify how much and what type of knowledge a student learned since these measures are coarse-grained and often do not take into account prior knowledge. For example, class grades (which determine GPA) typically include other factors in addition to individual learning assessments such as participation and group work. These measures also do not differentiate between different types of learning outcomes such as transfer or PFL.

1.3.2 Verbal protocols

In contrast to questionnaires, some past work using verbal protocol methods has examined different types of learning. For example, Van der Stel and Veenman (2010) found that increased use of metacognitive skills (e.g., planning, monitoring and evaluating) was associated with better near transfer (e.g., performance on isomorphic problems with different values). In other work, Renkl (1997) found that the frequency of positive monitoring statements (e.g., “That makes sense”) was unrelated to transfer performance, but the frequency of negative monitoring statements (e.g., “I do not understand this”) was negatively related to transfer. This result shows that different types of metacognitive phenomena are differentially related to transfer. In this case, monitoring behaviors can be useful in identifying when a learner does not understand something.

1.3.3 Metacognitive judgments

Metacognitive judgments such as judgments of knowing (JOKs) have typically been used in vocabulary paradigms (e.g., Jacob & Nelson, 1990). There is some work that has examined JOKs and their relation to test performance and GPA (Nietfeld, Cao, & Osborne, 2005; 2006). Nietfeld, Cao, and Osborne (2005) found that students’ JOKs across different tests (that included transfer items) within a course were associated with learning even when controlling for GPA.

From this brief survey of the prior literature, we see that different metacognitive measures have been related to different types of learning outcomes. Questionnaires have primarily been related to achievement outcomes whereas verbal protocols and metacognitive judgments have been related to multiple learning outcomes including achievement and transfer. This variation makes it difficult to determine whether these measures predict the same types of

learning. To gain a better understanding of how metacognition is related to learning, we examine the relations among all three measures to transfer and PFL. These empirical and theoretical challenges have direct implications for determining measurement validity.

1.4 MEASUREMENT VALIDITY

We use Messik's (1989) validity framework to structure our review. We focus on six aspects of validity: structural, external, content, temporal occurrence, generality, and utility. Structural validity concerns whether the measure produces the predicted structure of the theoretical constructs (e.g., type and number of metacognitive skills). External validity concerns the predictive or convergent relations to variables that theory predicts (e.g., similar types of learning outcomes and alignment of metacognitive measures). Given the "Relation among Measures" above, there are some issues in the convergent aspect of external validity. Content validity concerns whether the measure is tailored to a specific activity or material. Temporal occurrence concerns the measures relation to what is being assessed in terms of time elapsed as represented in Figure 2. Generality of the meaning concerns the applicability of the measure to different populations and utility examines the ease of implementation. Below we describe each metacognitive measure and their alignment with each of the six aspects of validity. See Table 1 for a summary.

Table 1. *Comparison of three measures.*

Measurement	Substantive Validity	External Validity	Structural Validity	Content Validity	Temporal Occurrence	Generality	Utility
Questionnaires	Weak	Moderate	Weak	Weak – General or specific	Retrospective	Yes	Strong
Verbal Protocols	Moderate	Moderate	Strong	Moderate – Domain general	Concurrent	Yes	Weak
JOK	Weak	Moderate	Strong	Weak – domain general and specific	Retrospective	Yes	Moderate

1.4.1 Questionnaires

Questionnaires are used to determine the degree to which students use various metacognitive skills. The majority of questionnaires ask students to report on their dispositional use of the skills although a few are specific to a task or context. The similarity between the structure of the measurement and theory is not aligned well. Many questionnaires attempt to assess fine-grain distinctions between metacognitive skills, but are unable to do so. For example, Schraw and Dennison (1994) originally sought to capture five distinct metacognitive skills within the MAI; however, the results revealed only a single factor.

In contrast, there is moderate evidence for the external validation of questionnaires. Prior work has shown that questionnaires relate to other variables predicted by metacognitive theory such as achievement (Pintrich & DeGroot, 1990; Pintrich & Garcia, 1991) as well as convergence with similar questionnaires assessing similar processes (Sperling et al., 2004; Muis, Winne, & Jamieson-Noel, 2007). For example, Sperling and colleagues (2004) found that MAI's Regulation of Cognition dimension was related to the MSLQ's Metacognitive self-regulation scale ($r = .46$).

The content validity of a questionnaire depends on its intended scope. Some questionnaires are designed to capture the general use of metacognitive skills such as the MAI or MSLQ. Other questionnaires assess metacognitive skills for a particular task. For example, work by Van Hout-Wolters (2009) demonstrated that task-based measures have a stronger positive relation to verbal protocols than dispositional questionnaires. It is difficult to assess the success of these different types of questionnaires because dispositional questionnaires typically focus on a generalization of the skills over a longer time period than task-based questionnaires.

Additionally, metacognitive questionnaires have been reliably adapted to serve a variety of ages (e.g., Sperling Howard, Miller, & Murphy 2002). Of particular interest to educators and researchers is the ease of administering and scoring the instrument. Researchers have sought to develop easy-to-use retrospective questionnaires that take just a few minutes to complete. Perhaps the ease of this measure is why there are many questionnaires aimed at capturing different types of content, making it difficult to assess the validity of such measures.

Informed by this research and Schellings and Van Hout-Wolters' (2011) in-depth analysis of the use of questionnaires and their emphasis on selecting an appropriate questionnaire given the nature of the to-be-assessed activity, we created a task-based questionnaire and adapted items from the MAI, MSLQ, Awareness of Independent Learning Inventory (AILI, Meijer et al., 2013), a problem-solving based questionnaire (Howard, Mcgee, Shia, & Hong, 2000; How do I solve problems?), and a state-based questionnaire (O'Neil & Abeli, 1996; State Metacognitive Inventory [SMI]). We chose to develop and validate a task-based metacognitive questionnaire for three reasons. First, there is mixed evidence about the generality of metacognitive skills (Van der Stel & Veenman, 2014). Second, there are no task-based metacognitive measures for a

problem-solving activity. Third, to our knowledge there is no questionnaire that reliably distinguishes between the metacognitive skills of monitoring, debugging, and evaluation.

1.4.2 Verbal protocols

Verbal protocols provide fine-grain verbal data to test hypotheses about what and how metacognition is used when a participant is engaged in some learning or problem-solving activity. They tend to range in their specificity of metacognition in which the grain size of metacognition differs. For example, Renkl (1997) only examined negative versus positive monitoring whereas other verbal protocol analyses have attempted to create a detailed taxonomy for evaluating the metacognitive activity of a learner (Meijer, Veenman, & van Hout-Wolters, 2006). Although Meijer, Veenman, and van Hout-Wolters (2006) originally sought to develop a fine-grain taxonomy, due to difficulties in obtaining interrater reliability, they condensed their codes into fewer, more generalized aspects of metacognition. Given this ability to capture distinct metacognitive skills as predicted by theory, verbal protocols have structural validity.

Verbal protocols also have moderate external validity as they have been shown to correlate with learning outcomes in some studies (e.g., Van der Stel & Veenman, 2010), but not others (Meijer, Veenman, & van Hout-Wolters, 2012; Renkl, 1997). However, this might be attributed to the way in which the verbal protocols were coded. Some coding rubrics differ in whether they code for the quality of metacognition versus the frequency of a specific metacognitive activity (Meijer, Veenman, & van Hout-Wolters, 2012).

Within a specific coding rubric, there is evidence showing that verbal protocols have content validity, as it is domain general. Veenman, Elshout, and Meijer (1997) found that the same coding rubric could be applied across three domains and were each predictive of learning

outcomes within that domain. Verbal protocols have also been successfully employed with a variety of populations (e.g., Veenman et al. 2004) and can be applied to a variety of contexts and tasks. They have been used in physics (Chi et al., 1989), biology (Gadgil, Nokes-Malach, & Chi, 2012), probability (Renkl, 1997), and reading (Pressley & Afflerbach, 1995), among others.

Unlike questionnaires, verbal protocols take a substantial amount of time to administer and evaluate. Instead of administering the measurement to groups of students, researchers typically run one student at a time because of the challenges of recording multiple speakers and potential verbal interference across speakers in the same room. It also requires more time to transcribe and code, making it a time-consuming task for researchers and practically challenging to use in the classroom. Although think-aloud protocols are more difficult to employ in classrooms, they provide benefits to researchers as it provides a fine-grained source of trace data (Ericsson & Simon, 1980).

1.4.3 Metacognitive judgments

Metacognitive judgments are used to assess students' accuracy in their monitoring. Metacognitive judgments ask students to rate their confidence in their understanding, learning, or an answer to a question (see Alexander, 2013 for an overview). Different types of calibrations have been applied to determine the accuracy and consistency of student judgments (see Schraw, 2009 and Schraw, Kuch, & Gutierrez, 2013). A common form of metacognitive judgment is called a JOK in which a student is asked to rate how confident he or she about an answer (Schraw, 2009). It has structural validity in that it is designed to capture one metacognitive skill referred to as monitoring or awareness of one's understanding. However, this structure may differ dependent on the calibrations used to assess different types of accuracy (for a review see

Schraw, 2009). JOKs have some external validity as Neitfeld, Cao, and Osborne (2005; 2006) showed that student judgments were related to learning performance and GPA. The content validity of JOKs is unclear. Some work has demonstrated it is domain general (Schraw, 1996; Schraw, Dunkle, Bendixen, & Roedel, 1995) and other work has shown it is domain specific (Kelemen, Frost, & Weaver, 2000). For example, as Schraw (1996) showed that when controlling for test difficulty, confidence ratings from three unrelated tests (math, reading comprehension, and syllogism) were moderately related to each other (average $r = .42$). Regardless of these limitations, JOKs are also applied to multiple domains (e.g., physics, general facts) and are used for multiple age groups (Dunlosky & Metcalfe, 2009). Although JOKs are moderately easy to implement, it takes more time to determine calibrations of metacognitive judgments than it does to evaluate questionnaire responses, but it is not as time intensive as verbal protocols.

Drawing from Zepeda et al. (2015), we focus on the relation between three types of JOK calibrations: absolute accuracy, gamma, and discrimination. In our prior work, we found differences in an experimental manipulation for one form of calibration (discrimination) but not others (absolute accuracy and gamma), suggesting that they captured different metacognitive processes. Therefore, in this study we employ three different types of calibration: relative accuracy as measured by gamma, absolute accuracy, and discrimination. Gamma evaluates confidence judgment accuracy on one item relative to another (Nelson, 1996) whereas absolute accuracy compares judgments to performance. Schraw (1995) suggested that since there is not a one-to-one relation between gamma and absolute accuracy, research should report both. Discrimination examines the degree to which students can distinguish their confidence for incorrect and correct performance (Schraw, 2009). Positive discrimination indicates that a

learner gave higher confidence ratings for correct trials compared to incorrect trials, a negative value indicates higher confidence ratings for incorrect trials compared to correct trials, and a zero indicates no relation between the two. It can be interpreted that those with positive discrimination are aware of their correct performance. In addition to these calibrations, we also examined average JOK ratings given that students are typically poor at calibrating their understanding when the task is difficult (Howie & Roebbers, 2007).

1.5 CURRENT WORK

In this work, we assess the relations among a retrospective task-based questionnaire, concurrent verbal protocols recorded during a learning activity, and metacognitive judgments of knowing elicited during a posttest (outlined in Table 2). The overall goal of this study is to investigate whether these measures capture the same metacognitive skills and to determine the degree to which they predict similar learning outcomes. We hypothesize that:

H1: The metacognitive measurements will assess similar processes. Monitoring assessed by JOKs will have a small positive association with the monitoring assessed by the verbal protocols and the task-based questionnaire (r 's between .20 and .30) since all assess some type of monitoring. We also predict a moderate relation between the verbal protocols and the task-based questionnaire for monitoring, evaluating, and debugging (r 's between .30 and .50), which would be consistent with past work examining the relations between questionnaire and verbal protocols by Schellings and colleagues (2011, 2013).

H2: All measures will predict learning, transfer, and PFL.

Table 2. *Overview of the metacognitive measurements.*

Metacognitive Measurement	Metacognitive Skill	Timing	Framing of the Assessment	Analytical Measures	Predicted Learning Outcome
Questionnaires	Monitoring, Control, and Evaluation	Retrospective	Task-based	CFA, EFA, Cronbach's alpha	Learning, transfer, and PFL
Verbal Protocols	Monitoring, Control, and Evaluation	Concurrent	Task-based	Inter-rater reliability, Cronbach's alpha	Learning, transfer, and PFL
Metacognitive Judgments	Monitoring, and Monitoring Accuracy	Retrospective	Test items	Cronbach's alpha, Average, Mean Absolute accuracy, Gamma, and Discrimination measures	Learning, transfer, and PFL

Prior studies examining metacognition tend to utilize tell-and-practice activities in which students receive direct instruction on the topic (e.g., Meijer, Veenman, & Van Hout-Wolters, 2006). However, we chose a structured-inquiry learning activity as it might provide more opportunities for students to engage in metacognition (Schwartz & Bransford, 1998; Schwartz & Martin, 2004). A core feature of structured inquiry activities is that students try to invent new ways to think about, explain, and predict various patterns observed in the data. In the task we chose, students attempt to solve a challenging statistics problem in which they have an opportunity to monitor their progress and understanding, try out different strategies, and evaluate their performance. Although there is controversy in the learning sciences about the benefits of inquiry-based instruction (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011), several research groups have started to accumulate evidence for the benefits of these types of structured inquiry activities in math and science domains (e.g., Belenky & Nokes-Malach, 2012; Kapur, 2008; Roll, Alevan, & Koedinger, 2009; Schwartz & Martin, 2004). For example, these activities have been shown to engage students in more constructive cognitive processes (Roll et al., 2009), and to facilitate learning and transfer (Kapur & Bielaczyc, 2012; Kapur, 2008, 2012; Roll et al., 2009).

2.0 MIXED METHOD STUDY

The first set of analyses examined the structural validity and reliability of each method as outlined in Table 2. For the questionnaire, we evaluated the distinction between the different metacognitive components of monitoring, control, and evaluation. The second set of analyses examined whether the metacognitive skills represented by the task-based questionnaire, verbal protocols, and metacognitive judgments captured the same processes. The third set of analyses evaluated the degree to which the different measures related to learning, transfer, and PFL. This set of analyses would also provide external reliability for the measurements.

3.0 METHODS

3.1 PARTICIPANTS

Sixty-four undergraduates (51 = males) enrolled in an introductory psychology course at the University of Pittsburgh participated in the study. All students received credit hours for their participation. We excluded 19 students from the analyses, as they were able to correctly solve for mean deviation and/or standard deviation on the pretest. The remaining 45 students (36 = male) were included in the analyses as they still had an opportunity to learn the material. Within this sample, student GPAs included a broad range with students reporting below a 2.0 (4.4%), 2.0-2.5 (20%), 2.5-3.0 (28.9%), 3.0-3.5 (24.4%), and 3.5-4.0 (22.2%). The sample was comprised of 77.8% Caucasians, 6.7% African Americans, 6.7% Biracials, 4.4% Hispanics, 2.2% Asian Indians, and 2.2% did not specify.

3.2 DESIGN

Using an across-method-and-time design, we recorded student behaviors with video recording software during a learning activity, and collected student responses to a task-based questionnaire and retrospective judgments of knowing. See Figure 4 for an overview of the experimental design, materials, and procedure.

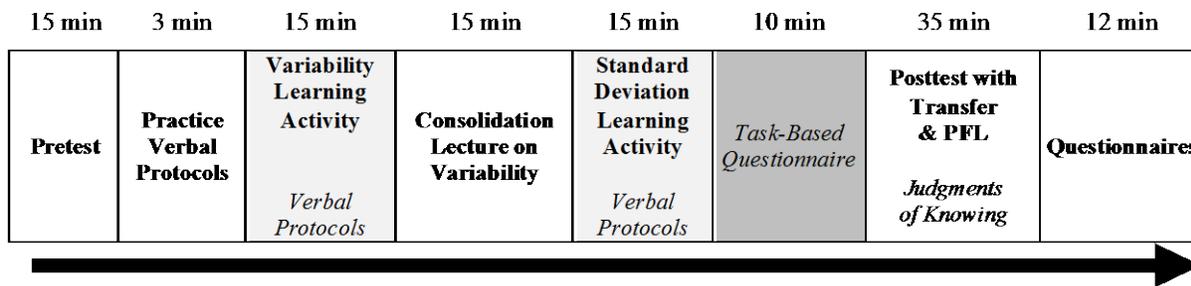


Figure 4. Design summary.

3.3 MATERIALS

The materials consisted of a pretest, learning phase, questionnaires, and a posttest. The learning phase was divided into three segments: an invention task on variability, a lecture on mean deviation, and a learning activity on standard deviation. The questionnaires assessed student metacognition, motivation, and cognitive processes; however, for this paper we focus only on the metacognitive components.

3.3.1 Learning pretest

All students completed a pretest with three types of items targeting procedural and conceptual knowledge. All items were scored as either correct (1) or incorrect (0). Two questions assessed basic procedural knowledge of mean and mean deviation, and one assessed a conceptual problem that is matched to a preparation for future learning problem in the posttest (PFL; Bransford & Schwartz, 1999). See Figure 5 for an example of the PFL item.

Driving Test

Susan and Robin are two teenagers who both just took their state driver's license road test. They are arguing about who got a better score on their test, which is scored out of 100 possible points. Susan got an 88 taking the driving test with Mr. Wheelie. The mean score Mr. Wheelie gave out that day was a 74, and the average deviation was 12 points. The average deviation indicates how close all the people taking the test were to the average. Robin earned an 82 on Mrs. Axel's driving test. On that day, the mean score Mrs. Axel gave out was a 76, and the average deviation was 4 points. Both Mr. Wheelie and Mrs. Axel tested one hundred teenagers that day.

Who do you think did better, Susan or Robin? Use math to help back up your opinion.

Figure 5. *Example PFL test item. Identical to Belenky & Nokes-Malach (2012, p. 11).*

3.3.2 Learning activities

The learning materials consisted of two activities and a lecture. The first learning activity was based on calculating variability. Students were asked to invent a mathematical procedure to determine which of four pitching machines was most reliable (Figure 6). The consolidation lecture provided a worked example that explained how to calculate variability using mean deviation and two practice problems with feedback on how to correctly solve the problems. The second activity asked students to invent a procedure to determine which of two track stars on two different events performed better (Bill on the high jump versus Joe on the long jump). Students received scratch paper and a calculator.

Your task is to invent a procedure for computing a quantity that expresses the variability for each of the pitching machines and decide which is most reliable. There is no single way to do this, but you have to use the same procedure for each machine, so it is a fair comparison.

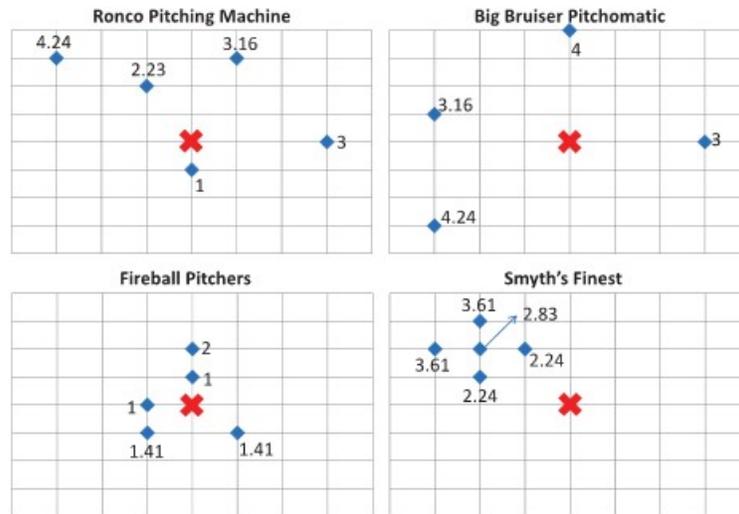


Figure 6. Data sets given in the variability activity. Identical to Belenky & Nokes-Malach (2012, p. 12)

3.3.2.1 Scoring of learning activities

Learning materials were evaluated based on the use of correct procedures and the selection of the correct response. Since students could determine the correct answer based on evaluating the means, we coded for every step students took and their interpretations of their final answers. For the variability activity, students could receive a total of 4 points. They received 1 point for calculating the mean, 1 for subtracting the numbers from the mean and taking the absolute value, 1 for taking the mean of those numbers, and 1 for stating that the Fireball Pitching Machine was most reliable. For the standardization activity, students could receive a total of 5 points. They received 1 point for calculating the mean, 1 for subtracting the numbers from the mean and squaring that value, 1 for taking the mean of those numbers, 1 for taking the square root of that value, and 1 for stating that Joe was more reliable.

3.3.3 Learning posttest

The posttest contained seven items that measured students' conceptual and procedural knowledge of the mean deviation. It also assessed students' abilities to visually represent and reason about data. These items assess a variety of different types of transfer such as near and immediate (Nokes-Malach, VanLehn, Belenky, Lichtenstein, & Cox, 2013). For the purposes of this work, we do not analyze these levels of transfer separately as there are not enough items for each transfer type to effectively examine outcomes.

Within the assessment, there was also a PFL problem that evaluated students' abilities to apply information from an embedded resource to this standard deviation problem (see below for more information and Figure 5 for an example problem). The PFL problem required students to determine which value from two different distributions was more impressive. During the posttest, students were also asked to respond to a judgment of knowing or JOK for each problem in which they rated how confident they were in their answer from 1 being *not at all confident* to 5 being *very confident*.

3.3.3.1 Embedded resource

The learning resource was presented as a worked example in the posttest and showed students how to calculate a standardized score with a simple data set. This resource also gave another simple problem involved using standardized scores. The transfer question appeared two problems after the worked example. The problem was presented later in the posttest so that the application of the information was not due to simple temporal proximity (i.e., the next problem), but instead it required that students to notice, recall, and apply the relevant information at a later time.

3.3.3.2 Scoring of posttest items

Each item was coded for accuracy. The posttest was comprised of two types of problems: 6 transfer items focused on solving the correct procedure and understanding the concepts of mean deviation ($\alpha = .39$), and 1 PFL problem. Two transfer problems involved the use of the correct procedure in which a correct response was coded as 1, and an incorrect response was coded as a 0. The other four transfer problems involved reasoning and were coded for the amount of detail within their reasoning. Each of these conceptual problems included different types of reasoning. One point was granted for a complete understanding of the concept and either a .67, .50, .33 for partial understanding (dependent on how many ideas were needed to represent a complete concept) or a 0. The PFL problem was scored as correct (1) or incorrect (0).

3.3.3.3 Calibration of JOKs

We also analyzed the JOKs ($\alpha = .86$) using different calibrations. As mentioned in the introduction, we calculated mean absolute accuracy, gamma, and discrimination (see Table 3 for formulas and Schraw, 2009 for further details). When calculating the calibrations gamma could not be computed for 9 participants (25% of the sample) since they responded with the same confidence rating for all seven items. Therefore, we did not examine gamma in our analyses. Absolute accuracy ranged from .06 to .57 with a lower score indicating better precision in their judgments whereas discrimination in this study ranged from -3.75 to 4.5 with more positive scores indicating that students were able to indicate when they knew something.

Table 3. Formulas used to calculate calibrations.

Type of Calibration	Formula
Mean Absolute Accuracy	$\frac{1}{N} \sum_{i=1}^N (c_i - p_i)^2$
Gamma	$\frac{N_S - N_D}{N_S + N_D}$ where N_S is the number of concordant pairs and N_D is the number of discordant pairs
Discrimination	$\frac{1}{N} \left[\sum_{i=1}^{N_c} (c_{i \text{ correct}}) - \sum_{i=1}^{N_i} (c_{\square \text{ incorrect}}) \right]$

3.3.4 Task-based metacognitive questionnaire

We adapted questionnaire items from previously validated questionnaires and verbal protocol coding rubrics (Chi et al., 1989; Gadgil et al., 2012; Renkl, 1997) as indicated in Table 4. In total, there were 24 metacognitive questions: 8 for monitoring, 9 for control, and 7 for evaluation. Students responded to each item using a Likert scale ranging from 1, *strongly disagree*, to 7, *strongly agree*. All items and their descriptive statistics are presented in Table 4.

Table 4. Descriptive statistics and factor loading.

Item	Original Construct	Min	Max	<i>M</i>	<i>SD</i>	Standardized Factor	Residual Estimate	Variance
Monitoring						0.90	0.94	
During the activity, I found myself pausing to regularly to check my comprehension.	MAI (Schraw & Dennison, 1994)	1	7	4.20	1.78	0.90	0.81	0.19
During the activity, I kept track of how much I understood the material, not just if I was getting the right answers.	MSLQ Adaptation (Wolters, 2004)	1	7	4.18	1.60	0.83	0.69	0.31
During the activity, I checked whether my understanding was sufficient to solve new problems.	Based on verbal protocols	1	7	4.47	1.59	0.77	0.59	0.41
During the activity, I tried to determine which concepts I didn't understand well.	MSLQ (Pintrich et al, 1991)	1	7	4.44	1.65	0.85	0.73	0.27
During the activity, I felt that I was gradually gaining insight into the concepts and procedures of the problems.	AILI (Meijer et al. 2013)	2	7	5.31	1.28	0.75	0.56	0.44
During the activity, I made sure I understood how to correctly solve the problems.	Based on verbal protocols	1	7	4.71	1.46	0.90	0.80	0.20
During the activity, I tried to understand why the procedure I was using worked.	Strategies (Belenky & Nokes-Malach, 2012)	1	7	4.40	1.74	0.78	0.62	0.39
During the activity, I was concerned with how well I understood the procedure I was using.	Strategies (Belenky & Nokes-Malach, 2012)	1	7	4.38	1.81	0.74	0.55	0.45
Control/Debugging						0.81	0.66	
During the activity, I reevaluated my assumptions when I got confused.	MAI (Schraw & Dennison, 1994)	2	7	5.09	1.58	0.94	0.89	0.11
During the activity, I stopped and went back over new information that was not clear.	MAI (Schraw & Dennison, 1994)	1	7	5.09	1.54	0.65	0.42	0.58
During the activity, I changed strategies when I failed to understand the problem.	MAI (Schraw & Dennison, 1994)	1	7	4.11	1.67	0.77	0.60	0.40
During the activity, I kept track of my progress and, if necessary, I changed my techniques or strategies.	SMI (O'Neil & Abeli, 1996)	1	7	4.51	1.52	0.89	0.79	0.21
During the activity, I corrected my errors when I realized I was solving problems incorrectly.	SMI (O'Neil & Abeli, 1996)	2	7	5.36	1.35	0.50	0.25	0.75

During the activity, I went back and tried to figure something out when I became confused about something.	MSLQ (Pintrich e.t al, 1991)	2	7	5.20	1.58	0.87	0.75	0.25
During the activity, I changed the way I was studying in order to make sure I understood the material.	MSLQ (Pintrich e.t al, 1991)	1	7	3.82	1.48	0.70	0.49	0.52
During the activity, I asked myself questions to make sure I understood the material.	MSLQ (Pintrich e.t al, 1991)	1	7	3.60	1.59	0.49	0.25	0.76
REVERSE During the activity, I did not think about how well I was understanding the material, instead I was trying to solve the problems as quickly as possible.	Based on verbal protocols	1	7	3.82	1.72	0.54	0.30	0.71
Evaluation						0.84	0.71	
During the activity, I found myself analyzing the usefulness of strategies I was using.	MAI (Schraw & Dennison, 1994)	1	7	5.02	1.55	0.48	0.23	0.77
During the activity, I reviewed what I had learned.	Based on verbal protocols	2	7	5.04	1.40	0.57	0.33	0.67
During the activity, I checked my work all the way through each problem.	How do I Solve Problems? (Howard et. al, 2000)	1	7	4.62	1.72	0.94	0.88	0.12
During the activity, I checked to see if my calculations were correct.	How do I Solve Problems? (Howard et. al, 2000)	1	7	4.73	1.97	0.95	0.91	0.09
During the activity, I double-checked my work to make sure I did it right.	How do I Solve Problems? (Howard et. al, 2000)	1	7	4.38	1.87	0.89	0.79	0.21
During the activity, I reviewed the material to make sure I understood the information.	MAI (Schraw & Dennison, 1994)	1	7	4.49	1.71	0.69	0.48	0.52
During the activity, I checked to make sure I understood how to correctly solve each problem.	Based on verbal protocols	1	7	4.64	1.57	0.86	0.75	0.26

3.3.5 Verbal protocol coding

All videos were transcribed and coded from the first learning activity on variability using prior rubrics for monitoring, debugging, and evaluation (Chi et al., 1989; Gadgil et al., 2012; Renkl, 1997; see Table 5). Critically, we coded for the frequency of each metacognitive process as it aligned well with how cognitive psychologists have measured it in the past. We hypothesized that the first learning activity would have representative instances of metacognition since it was an invention task. The second learning task also involved invention, but it came after direct instruction. This order of materials might have led students to directly apply the knowledge they learned in the instruction to the second activity, perhaps reducing the probability of observing metacognitive statements.

Table 5. *Verbal coding rubric.*

Code Type	Definition	Transcript Examples
Monitoring	Checking one’s understanding about what the task is asking them to do, making sure they understand what they are learning/doing.	“I’m gonna figure out a pretty much the range of them from vertically and horizontally? I’m not sure if these numbers work (inaudible)” “That doesn’t make sense”
Control/Debugging	An action to correct one’s understanding or to enhance one’s understanding/progress. Often involves using a different strategy or rereading.	“I’m re-reading the instructions a little bit” “So try a different thing”
Conceptual Error Correction	A statement that reflects an understanding that something is incorrect with their strategy or reflects noticing a misconception about the problem.	“I’m thinking of finding a better system because, most of these it works but not for Smythe’s finest because it’s accurate, it’s just drifting”
Calculation Error Correction	Noticing of a small error that is not explicitly conceptual. Small calculator errors would fall into this category.	.28 “4, whoops”
Evaluation	Reflects on their work to make sure they solved the problem accurately. Reviews for understanding of concepts as well as reflects on accurate problem-solving procedures such as strategies.	“Gotta make sure I added all that stuff together correctly” “Let’s see, that looks pretty good” “Let’s check the match on these.”

In our verbal protocols, we also coded for two distinct types of debugging – conceptual error correction and calculation error correction. These were coded separately as one might predict that these types of corrections are more likely to directly relate to better performance. Students who focus on their conceptual (conceptual error corrections) or procedural understanding (calculation error corrections) are aiming to increase a different type of understanding than those who are rereading or trying out other strategies. Those who reread and try out different strategies are still on the path of figuring out what the question is asking them to achieve whereas those who are focusing on conceptual and calculation errors are further in their problem-solving process.

3.4 PROCEDURE

The study took approximately 120 minutes to complete. During the first fifteen minutes, students completed a pretest (5 minutes per question) followed by think-aloud training (3 minutes). The remaining time involved learning activity and posttest materials, followed by a debriefing. Reference Figure 4 for the timing details.

At the beginning of the study, students were informed that they were going to be videotaped during the experiment. After completing the pretest, the experimenter instructed students to say their thoughts aloud. Then, the experimenter gave the students a sheet of paper with three multiplication problems. If students struggled to think aloud while solving problems (i.e., they did not say anything), the experimenter modeled how to think aloud. Once students completed all three problems and the experimenter was satisfied that they understood how to think aloud, the experimenter moved onto the learning activity. Students had 15 minutes to complete the variability learning activity. After the variability activity, students watched a consolidation video, and worked through a standard deviation activity. Then, they were asked to complete the task-based questionnaire. Once the questionnaire was completed, the students received 35 minutes to complete the posttest. Upon completion of the posttest, students completed several questionnaires, a demographic survey, and then students were debriefed.

4.0 RESULTS

4.1 PRETEST

The pretest evaluated student familiarity of mean, mean deviation, and standard deviation. Students had adequate procedural knowledge of solving for the mean ($M = .95$, $SD = .21$), but had a more difficult time solving for mean deviation ($M = .08$, $SD = .27$), and standard deviation ($M = .21$, $SD = .40$). For all analyses, we removed the participants who correctly solved the mean and standard deviation problems. Therefore, the remaining participants had the opportunity to learn the concepts and procedures of mean deviation and standard deviation.

4.2 STRUCTURAL VALIDITY AND RELIABILITY

In the first set of analyses, we evaluated whether the three conceptualized constructs of metacognition (monitoring, debugging, evaluation) were distinguishable within the coding of the verbal protocols and whether the task-based questionnaire had structural validity.

4.2.1 Task-based questionnaire

For the questionnaire, we evaluated a second-order model consisting of three correlated factors (i.e., monitoring, control, and evaluation) and one superordinate factor (i.e., metacognition). The resulting second-order model had an adequate goodness-of-fit, CFI = .96 TLI = .96, RMSEA = .096, $X^2(276) = 2862.30$, $p < .001$ (Hu & Bentler, 1999). This finalized model also had a high internal reliability for each of the factors: superordinate, $\alpha = .95$, monitoring, $\alpha = .92$, debugging, $\alpha = .86$ and evaluation, $\alpha = .87$. For factor loadings and item descriptive statistics, see Table 4. On average students reported a moderate use of monitoring ($M = 4.51$), debugging ($M = 4.51$), and evaluation ($M = 4.7$).

4.2.2 Verbal protocols

The verbal protocols were transcribed into statements. Statement length was identified by clauses and natural breaks in the protocol. Two coders independently coded 20% of the data and reached an agreement as examined by an inter-coder reliability analysis ($k > .7$). The coders discussed and resolved their discrepancies. Then they independently coded the rest of the transcripts. The verbal protocol coding was based on prior rubrics and is represented with examples from the transcripts in Table 5. Due to an experimental error, one participant was not recorded and, therefore, was excluded from all analyses involving the verbal protocols. For each student, we counted the number of statements generated for each coding category and divided this number by their total number of statements. On average students generated 58.79 statements with much variation ($SD = 34.10$). Students engaged in monitoring the most ($M = 3.05$ statements per student) followed by evaluation ($M = 2.71$ statements per student). Students rarely employed

debugging, conceptual error correction, and calculation error correction ($M = .23, .05, \text{ and } .61$, respectively). Therefore, we combined these scores into one debugging verbal protocol code ($M = .88$ statements per student).

We also examined the relations between the total number of statements generated (i.e., verbosity) and the number of statements for each type of metacognitive category (Table 6). The amount students monitored, debugged, and evaluated their understanding was related to the total number of utterances. The descriptive statistics are represented in Table 7.

Table 6. *Associations between the number of utterances and the counts of each verbal protocol code*

	Monitoring	Debugging	Evaluation
Number of Utterances	.59**	.69**	.72**

Table 7. *Descriptive statistics for each measure*

Measure	Variable	<i>N</i>	Min	Max	<i>M</i>	<i>SE</i>	<i>SD</i>
Questionnaire	Monitoring	45	1.13	6.75	4.51	0.19	1.29
	Debugging	45	2.33	6.44	4.51	0.16	1.08
	Evaluation	45	2.14	7.00	4.70	0.19	1.28
Verbal Protocols	Monitoring	44	0.00	0.29	0.05	0.01	0.06
	Debugging	44	0.00	0.06	0.01	0.002	0.02
	Evaluation	44	0.00	0.16	0.04	0.01	0.04
JOK	Mean	45	2.00	5.00	4.31	0.09	0.60
	Mean Absolute Accuracy	45	0.06	0.57	0.22	0.02	0.13
	Discrimination	45	-3.75	4.5	1.43	0.33	2.21

4.3 RELATION WITHIN AND ACROSS METACOGNITIVE MEASURES

Second, we examined the correlations within and across each of the metacognitive measures to evaluate whether the different methodologies captured the same processes. Using Pearson

correlation analyses we found that there was a positive association between all of the metacognitive questionnaire factors, but there was not an association within the verbal protocol codes. For the JOKs, there was a negative association between mean absolute accuracy and discrimination, meaning that the more accurate they were at judging their confidence (a score closer to 0 for absolute accuracy), the more likely they were aware of their correct performance (positive discrimination score). There was also a positive association between the average ratings of the JOKs and discrimination, meaning those who were assigning higher values in their confidence were also more aware of their correct performance.

Across measures an interesting pattern emerged. Monitoring statements were negatively associated with the monitoring questionnaire and the average JOK ratings. However, there was no relationship between the monitoring questionnaire and the average JOK ratings. Debugging and evaluation questionnaires positively correlated with evaluation statements (see Table 8 for all correlations and Figure 7 for a visual of the significant relations across measures). Otherwise, there were no other associations.

Table 8. *Correlations between the task-based questionnaire, verbal protocols, and metacognitive judgments*

Variable	1	2	3	4	5	6	7	8	9	
Qs	1. Monitoring	-	0.73*	0.73*	-0.36*	0.12	0.29	0.26	0.06	0.02
	2. Debugging		-	0.65*	-0.1	-0.08	0.31*	0.02	-0.02	-0.03
	3. Evaluation			-	-0.16	0.14	0.37*	0.15	0.11	-0.09
VPs	4. Monitoring				-	0.1	0.01	-0.41*	-0.07	-0.14
	5. Debugging					-	0.16	-0.16	0.03	-0.08
	6. Evaluation						-	-0.1	0.02	0.01
JOK	7. Average							-	0.14	0.39*
	8. Mean Absolute Accuracy								-	-0.76*
	9. Discrimination									-

Note. Qs = Questionnaire, VPs = Verbal Protocols, * = $p < .05$

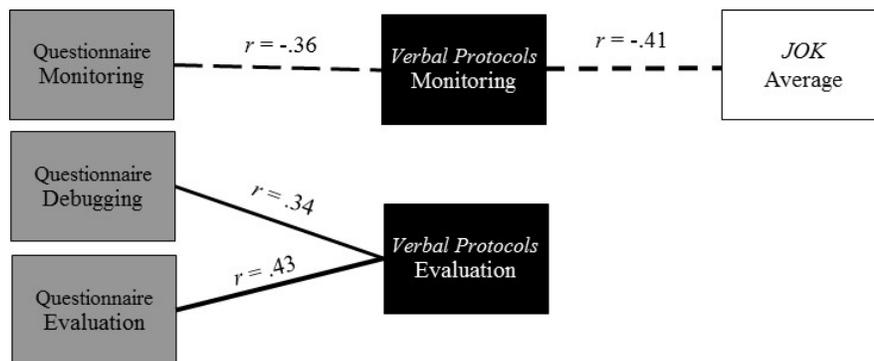


Figure 7. Associations among variables across measures.

4.4 RELATION BETWEEN METACOGNITIVE MEASURES AND LEARNING

4.4.1 Learning and test performance

The learning materials included the first and second learning activities, and a posttest that included transfer items and a PFL item. For the first learning activity, the scores ranged from 0 to 3 with students receiving an average 1.6 points ($SD = .72$). On the second learning activity, the scores ranged between 0 and 2 with the average score being 1.56 ($SD = .59$). Given the low performance on solving this activity and the observation that most students were applying mean deviation to the second activity, instead of inventing a new procedure, we did not analyze these results. The transfer scores ranged from 1 to 5.67 with an average score of 3.86 points ($SD = 1.26$). We did not include the PFL in the transfer score, as we were particularly interested in examining the relation between the metacognitive measures and PFL ($M = 0.52$, $SD = 0.49$). For ease in interpretation, we converted student scores for all learning measures into the proportion correct. See Table 9 for these proportions.

Table 9. *Descriptive statistics for each learning measure*

Measure	<i>N</i>	Min	Max	<i>M</i>	<i>SI</i>	<i>SD</i>
First Learning Activity	45	0.00	0.75	0.40	0.00	0.18
Transfer	45	0.17	0.94	0.64	0.00	0.21
PFL	45	0.00	1.00	0.49	0.00	0.51

To evaluate the relation between each metacognitive measure and the learning materials, we used a series of regressions. We used multiple linear regressions to test the amount of variance explained in the first learning activity and posttest performance by each measure. Then, to test the amount of variance explained by each metacognitive measure in PFL performance, we used multiple logistic regressions. All results are summarized in Figure 8. In addition to these models, we also regressed the learning outcomes on the most predictive variables from each of the measures and entered them into a competing model to evaluate whether and how much they uniquely contribute to the overall variance.

4.4.2 Task-based questionnaire

For the task-based questionnaire we computed two types of models; one with all three metacognitive skills and the other with each metacognitive skill entered separately. Entering all three skills simultaneously led to no significant relations for the learning activity ($F(3, 41) = 1.46, p = .24$), transfer, ($F(3, 41) = .15, p = .93$), or PFL ($\chi^2(1, N = 45) = 2.97, p = .40$). However, since the three factors were highly correlated we entered each factor into three separate models (Kraha, Turner, Nimon, Zientek, & Henson, 2012).

Entering the skills into separate models revealed a marginal effect of self-reported monitoring, $\beta = .27$, $t = 1.87$, $p = .07$, and self-reported evaluation, $\beta = .29$, $t = 2.0$, $p = .05$ on the first learning activity. The model predicting performance on the first learning activity with self-reported monitoring explained 7.5% of the variance as indexed by the adjusted R^2 statistic, $F(1, 43) = 3.50$, $p = .07$, whereas the model predicting performance on the first learning activity with self-reported evaluation explained 8.5% of the variance as indexed by the adjusted R^2 statistic, $F(1, 43) = 4.01$, $p = .05$. Otherwise there were no significant relations. Self-reported monitoring and evaluation were not related to performance on transfer ($F(1, 43) = 0.1$, $p = .75$; $F(1, 43) = .02$, $p = .88$) or PFL scores ($\chi^2(1, N = 45) = 0.01$, $p = .91$; $\chi^2(1, N = 45) = 1.29$, $p = .26$), respectively, and self-reported debugging had no relation to any of the learning outcomes (learning activity: $F(1, 43) = 1.52$, $p = .22$), transfer: $F(1, 43) = 0.07$, $p = .79$, and PFL: $\chi^2(1, N = 45) = .69$, $p = .41$).

4.4.3 Verbal protocols

For verbal protocols we entered in each of the codes into the model. The model predicting performance on the first learning activity explained 14.2% of the variance as indexed by the adjusted R^2 statistic, $F(3, 40) = 2.21$, $p = .10$. Within the model, there was only an effect of monitoring, $\beta = -.37$, $t = -2.51$, $p = .02$, VIF = 1.00 (Table 10). The models predicting transfer ($F(3, 40) = .19$, $p = .90$) and PFL scores ($\chi^2(3, N = 44) = 5.05$, $p = .17$) were not significant.

Table 10. Multiple linear regression model predicting performance on the first activity with verbal protocols

Variable	β	t	p	VIF
Monitoring	-0.37	-2.51	0.02	1.01
Debugging	-0.05	-0.32	0.75	1.03
Evaluation	-0.03	-0.17	0.87	1.02
Constant		10.06	0	

4.4.4 JOKs

The JOKs were separately entered into three separate models for each learning outcome since they were highly correlated with each other.

4.4.4.1 Average ratings

The model predicting first activity explained 10.4% of the variance as indexed by the adjusted R^2 statistic, $F(1, 43) = 6.11, p < .05$, in which there was an effect of average JOK ratings, $\beta = .35, t = 2.47, p < .05$. The model predicting transfer explained 14.1% of the variance as indexed by the adjusted R^2 statistic, $F(1, 43) = 7.07, p < .05$, in which there was an effect of average JOK ratings, $\beta = .38, t = 2.66, p < .05$. The logistic model predicting PFL scores explained 15.6% of the variance as indexed by the adjusted Nagelkerke R^2 statistic, $\chi^2(1, N = 43) = 5.6, p < .05$. There was an effect of average JOK ratings, $B = 4.17, \text{Exp}(B) = 64.71, \text{Wald's } \chi^2(1, N = 44) = 4.21, p < .05$. Thus, higher average JOK ratings were associated with an increase in likelihood of solving the PFL problem.

4.4.4.2 Mean absolute accuracy

The model predicting first activity explained 4.2% of the variance as indexed by the adjusted R^2 statistic, $F(1, 42) = 1.85, p = .18$. The model predicting transfer explained 50.8% of the variance

as indexed by the adjusted R^2 statistic, $F(1, 42) = 43.42, p < .05$, in which there was an effect of mean absolute accuracy, $\beta = -.71, t = -6.59, p < .05$. The logistic model predicting PFL scores explained 8.9% of the variance as indexed by the adjusted Nagelkerke R^2 statistic, $\chi^2(1, N = 43) = 3.03, p = .08$, in which there was a marginal effect of mean absolute accuracy, $B = -4.26, \text{Exp}(B) = .01, \text{Wald's } \chi^2(1, N = 44) = 2.74, p = .098$. Thus, increasing mean absolute accuracy (i.e., worse accuracy) was associated with a reduction in likelihood of solving the PFL problem.

4.4.4.3 Discrimination

The model predicting performance on the first activity explained 0.1% of the variance as indexed by the adjusted R^2 statistic, $F(1, 42) = .047, p = .83$. The model predicting transfer explained 88.1% of the variance as indexed by the adjusted R^2 statistic, $F(1, 42) = 318.61, p < .05$, in which there was an effect of discrimination, $\beta = .94, t = 17.85, p < .05$. The logistic model predicting PFL scores explained 33.6% of the variance as indexed by the adjusted Nagelkerke R^2 statistic, $\chi^2(1, N = 43) = 12.80, p < .05$, in which there was an effect of discrimination, $B = .60, \text{Exp}(B) = 1.82, \text{Wald's } \chi^2(1, N = 44) = 8.88, p < .05$. Thus, increasing discrimination was associated with an increased likelihood of solving the PFL problem.

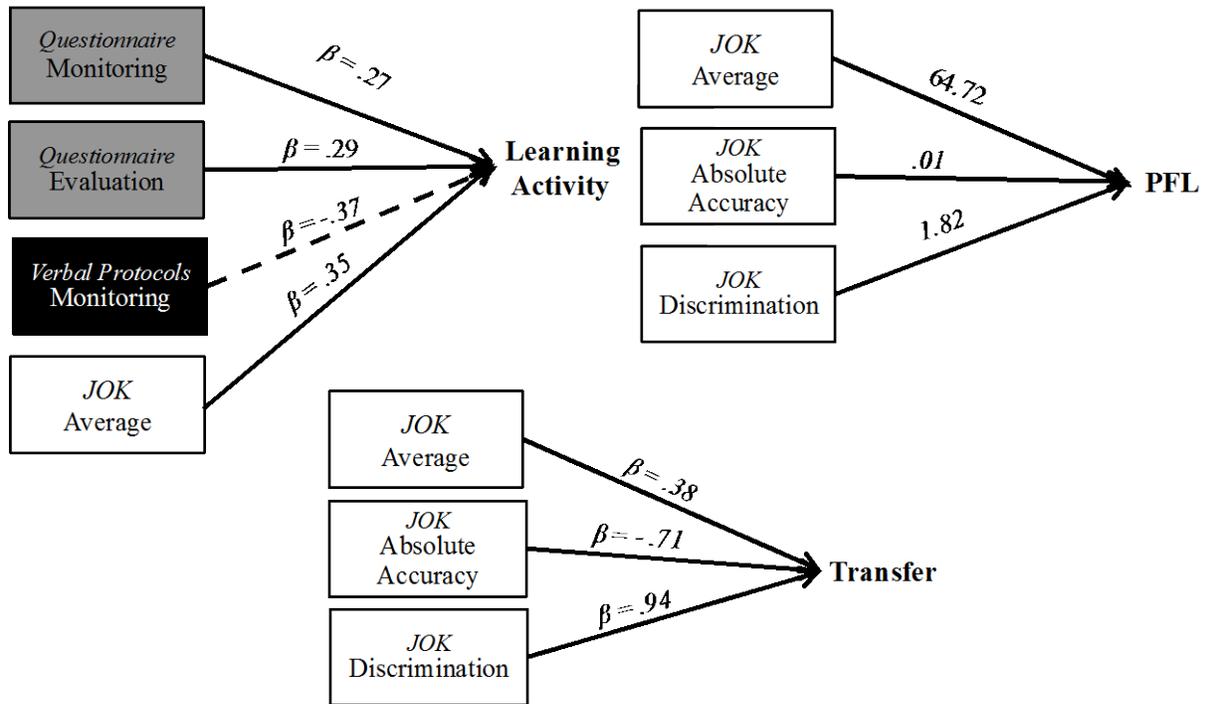


Figure 8. Summary figure of learning outcomes.

4.4.5 Competing models

We evaluated the competing models for the learning activity to determine whether constructs from different measurements were predictive of differential variances within these learning outcomes (Figure 9). The models predicting transfer and PFL were not computed, as only the JOKs were predictive. For the model predicting the first learning activity, we regressed it on self-reported evaluation, monitoring statements, and JOK average. The model explained 24.7% of the variance as indexed by the adjusted R^2 statistic, $F(3, 40) = 4.367, p < .01$. Within the model, there was a marginal effect of self-reported evaluation, $\beta = .24, t = 1.71, p = .095, VIF = 1.03$.

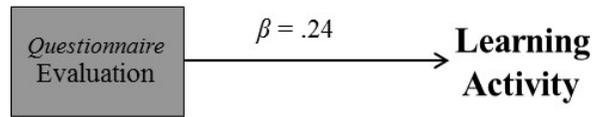


Figure 9. *Summary figure of competing models for learning outcomes.*

5.0 DISCUSSION

From these results, we raise some important questions about the measures. Not only do the measures show little relation to one another, but they also predict different learning outcomes. However, in the competing model for the learning activity the different types of measures did not result in a significant model suggesting that they captured some overlapping variance.

5.1 RELATION OF MEASURES

A central goal of this study was to examine to what degree these different measurements relate to each other. The results demonstrated that there is little association between the task-based metacognitive questionnaire and the corresponding verbal protocols, suggesting that these methods have either poor/inaccurate measures of metacognition or they measure different types of unrelated metacognitive phenomena. For example, self-reported monitoring was negatively related to the monitoring statements. This finding suggests that the more students monitored their understanding, the less likely they were to report doing so on a questionnaire. It also reflects a disconnect between what students do versus what they think they do. This misalignment might be particularly true for students struggling with the content who are making more monitoring statements. It also implies that students are unaware of the amount they are struggling or, worse, they are aware of it but when asked about it, they are biased to say the opposite, perhaps because

they do not want to appear incompetent. This speculation is also be related to the observational finding that when students monitored their understanding, they were more likely to have negative monitoring statements such as “I don’t understand this.” Therefore perhaps a more in-depth analysis of the monitoring statements might provide more clarity on the relation between these two measures. It could be that the self-reported monitoring is negatively aligned with negative monitoring statements but not positive monitoring statements. A similar pattern might also be true of the JOK average ratings and the monitoring statements as they were also negatively associated with each other.

The frequency of evaluation statements was associated with self-reported debugging, and evaluation, suggesting that the different self-reported constructs capture a similar aspect of metacognitive behavior. This misalignment of associations between the questionnaire and verbal protocols could also be attributed to students not being very accurate at knowing what they did and did not do during a learning task. This was also evident in work by Veenman and colleagues (2003) in which students’ self-reports had little relation to their actual behaviors. Instead, students might be self-reporting the gist of their actions and not their specific behaviors which are captured in the verbal protocols. It is also possible that there could have been more overlap between the two measures if we coded the verbal protocols for the entire set of learning activities that the students were self-reporting on. It is also unclear as to what students were referencing when answering the self-reports. They could have been referencing their behaviors on the most recent task (i.e., the standard deviation activity) in which we did not code for their metacognitive verbalizations.

Contrary to our hypothesis, there are no positive associations between the monitoring of the JOK calibrations and the monitoring statements or between the JOK calibrations and the self-

reported monitoring. As mentioned in our hypothesis, JOK calibrations capture the accuracy of one's monitoring, not just the act of monitoring or recounting their monitoring instances. One interpretation of this finding is that being able to identify when one knows or does not know something is different from gauging whether one is understanding information or self-reporting on whether one was engaged in checking one's understanding. Another interpretation is that the monitoring accuracy might benefit from the additional learning experiences that took place after the verbal protocols (i.e., the consolidation video) and after the questionnaire (i.e., the embedded resource). These additional resources may provide a more comprehensive picture of the learner's understanding and might have allowed them to resolve some of their misunderstandings.

The learning activity might have also played a role in the relationship across the different measures. As previously mentioned the structured inquiry task allows for more opportunities to engage in metacognition. This opportunity might also allow for instances in which the metacognitive skills are difficult to distinguish as they might co-occur or overlap with each other. Perhaps if the learning activity were designed to elicit a specific metacognitive behavior, different associations would emerge.

5.2 ROBUST LEARNING

In terms of the learning, we see that students' self-reported use of monitoring and evaluation has a marginal relation to their learning performance on the first activity, which provides some external validity for those two components. However, there was not a relation between the self-reports and the transfer or PFL performance. It could be that the monitoring and evaluation components of the questionnaire were able to predict performance specific to the task with which

they were based on but not the application of the knowledge beyond the task. This finding suggests that these questionnaire measures are limited in the types of learning outcomes they predict. It is also important to note the differences between this work and past; here, the questionnaire was task specific and involved a problem-solving activity whereas other work has looked at more domain-general content and related the questionnaires to achievement. In general, the majority of prior work examined dispositional metacognition or metacognition within a specific domain in which they related metacognitive questionnaires to performance measures (e.g., standardized tests or GPA); therefore, it is difficult to know whether the framing of the questionnaire limits its predictability.

The low internal reliability of the transfer posttest could have also posed difficulties in examining these analyses as students were responding very differently across the items. The lack of internal reliability might be attributed to the combination of different types of transfer items within the assessment that assess the varying degrees students can apply their knowledge. Future work could employ an assessment with multiple items per concept and per transfer type (e.g., near versus intermediate) to determine the extent to which the reliability of the test items impacted the results.

As predicted, there was an association between monitoring verbal protocols and the first learning activity. The negative association, as well as the observation that the majority of the metacognitive statements reflected a lack of understanding, aligns well with Renkl's (1997) findings in which negative monitoring was related to transfer outcomes. Although monitoring was not a positive predictor, we used a different verbal protocol rubric that differs from those who have found positive learning outcomes as we coded for the frequency of the metacognitive statements and not the quality (e.g., Van der Stel & Veenman, 2010). Perhaps the differentiation

in the learning task also contributed to the finding that the verbal protocols were unrelated to the transfer and PFL outcomes, which is in contrast to some prior research. Although there is no prior work evaluating PFL, other work evaluating transfer would have suggested that we would find some relation (e.g., Renkl, 1997). It would be productive for research to explore how different verbal protocol rubrics relate to one another and whether the types of verbal protocols elicited from different learning activities result in different relations to robust learning.

Students' average JOK ratings, absolute accuracy (knowing when they knew something) and discrimination (rating correct items with higher confidence than incorrect items), were strong predictors of performance on transfer and PFL. This could be partially due to the time-locked aspect of the JOKs as they were tied to the test whereas the verbal protocols and questionnaires were tied to the learning materials. Regardless, these findings suggest that being able to monitor one's understanding is important for learning outcomes. Given the stronger relationship between the JOK calibrations than that of the average JOK ratings and task-based questionnaire it also indicates that these measures might capture different aspects of metacognition. JOK calibrations might be assessing one's accuracy at identifying their understanding (i.e., monitoring accuracy) whereas the non-calibrated JOKs and the monitoring questionnaire might be assessing one's awareness of checking one's understanding. However, when comparing the average JOK ratings to the monitoring questionnaire on the first learning activity, it appears that the JOKs are more predictive, implying that after a learning experience and consolidation lecture students are more accurate at recognizing their understanding.

Although prior work has argued that JOKs are domain general (Schraw, 1996), we do not find JOK calibrations to be predictive of the learning activity but the average JOK ratings were predictive. That means that students who had higher ratings in their average JOKs performed

better on the learning activity, but it did not matter how accurate their JOKs were. However for transfer and PFL measures, their accuracy in their monitoring did matter. This finding suggests that students' ability to monitor their understanding might transfer across different learning measures, but their accuracy is more dependent on the actual learning measure. This assumption is consistent with prior work on monitoring calibrations in which students' monitoring accuracy varied as a function of the item difficulty (Pulford & Colman, 1997).

When generating competing models across the metacognitive measures, we were only able to examine one in which we predicted performance on the first activity with evaluation questionnaire, monitoring statements, and JOK average. The model was not significant. This suggests that they captured shared variances in their relation to learning, but that they are distinctly different in that they were not associated to each other.

5.3 THEORY

One goal of this study was to explore the relation between different skills and at what level of specificity to describe the constructs. We were able to establish a second-order factor in which the different skills were distinguishable. We were also able to distinguish between the different metacognitive skills in the verbal protocols with adequate inter-rater reliability between the two coders and the differential relations the codes had with each other and the learning and robust learning outcomes. The lack of correlation between the codes shows that they are not related to each other and suggests that they are capturing different skills. This finding is further supported when predicting learning outcomes the codes are related to different types of learning outcomes.

Future work should develop a metacognitive theory that incorporates these types of measures into a cohesive framework.

5.4 FUTURE RESEARCH

This work examines a subset of metacognitive measures, but there are many more in the literature that should be compared to evaluate the ways in which metacognitive regulation functions. Given the nature of the monitoring examined in the measures presented in this paper, it would be particularly interesting to examine how different metacognitive judgments such as judgments of learning relate to the monitoring assessed by the verbal protocols and questionnaire. Kelemen, Frost, and Weaver (2000) provide evidence that different metacognitive judgments assess different processes so we might expect to find different associations. For example, perhaps judgments of learning are more related to monitoring statements than JOKs. Judgments of learning have a closer temporal proximity to the monitoring statements and target same material as the verbal protocols. In contrast, JOKs occur at a delay and assess posttest materials that are not identical to the material presented in the learning activity. Therefore due to the timing of the measures and the material referenced we might see different relations emerge.

Future work could also explore the predictability the task-based questionnaire has over other validated self-report measures such as a domain-based adoption of the MAI or MSLQ. It would also be interesting to examine how these different measures relate to other external factors as predicted by theories of self-regulated learning. These factors include examining the degree to which the task-based questionnaire, JOKs, and verbal protocols relate to motivational aspects such as achievement goal orientations as well as more cognitive sense-making processes such as

analogical comparison and self-explanation. Perhaps this type of research would provide more support for some self-regulated learning theories over others given their hypothesized relationships.

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