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Metacognitive Self-Regulation and Problem-Solving: Expanding the Theory Base Through Factor Analysis

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Abstract

This instrument development study had two goals. First, we had the pragmatic goal of developing a measurement tool that would be valid for research and useful for assessment and intervention in classrooms. Second, we sought to develop theory in the area of self-regulated learning. To accomplish these goals, we began with theory-driven ideas and existing instruments, and combined these with constructs that emerged from exploratory factor analysis. Our results indicate that metacognitive awareness and regulatory skills in a problem-solving context are comprised of five independent factors: Knowledge of Cognition, Objectivity, Problem Representation, Subtask Monitoring, and Evaluation.

This research had two phases. In the first phase, we reviewed current techniques for measuring variables related to metacognition and self-regulation and decided on a self-report measure— mainly for pragmatic reasons. Next, data was collected using two existing inventories related to metacognition and problem solving. After eliminating items based on reliability analyses, remaining items were factor-analyzed resulting in five factors. In the second phase, a new inventory was developed focusing on these five factors. Again, reliability analyses were conducted, and the remaining items were factor-analyzed.

Our results have important implications for education. They indicate that there are five particular metacognitive and self-regulatory constructs relevant to problem solving. Being able to identify and delineate these constructs further should allow our educational research and teacher professional development teams to begin providing teachers with a set of tools and training resources to help them promote student self-regulation in their classrooms. These resources would be important to teachers who are concerned not only about what students learn but also about how they learn it.

Further, our analyses indicate that the constructs measured by the IMSR are independent, and therefore a student may show preferences or "styles" of metacognitive strengths and weaknesses that depend upon his or her unique combination of constructs. If these "styles" can be further understood and delineated, it might be possible to train students to habitually use particular regulatory behaviors.

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Background

Self-Regulated Learning, Metacognition, and Problem Solving

Various definitions and models of self-regulated learning abound in the research literature (Bruning, Schraw and Ronning, 1995). Zimmerman (1989) captured the sweeping purview of self-regulated learning when he said, “Students can be described as self-regulated to the degree that they are metacognitively, motivationally, and behaviorally active participants in their own learning process” (p.4).

For this study, we concentrated on measuring what it means to be a “metacognitively active participant” in the process of problem solving. Metacognition has been referred to as knowledge and regulation of one’s own cognitive system (Brown, 1978; Palincsar & Brown, 1987). Metacognition enables students to coordinate the use of current knowledge and a repertoire of reflective strategies to accomplish a single goal. Metacognitive awareness, therefore, serves a regulatory function and is essential to effective learning because it allows students to regulate numerous cognitive skills. Investigation of metacognition in academic settings has traditionally focused on two major components: knowledge of cognition, or how much learners understand about their own memory organization and the way they learn, and regulation of cognition, or how well learners can regulate their own memory and learning (Brown 1980; 1987).

Schraw and Dennison developed a 52-item Likert scale self-report inventory for adults (the MAI, or Metacognitive Awareness Inventory), which measured both knowledge of cognition and regulation of cognition (Schraw & Dennison, 1994). Although Schraw and Dennison set out to confirm the existence of eight factors (three related to knowledge of cognition and five related to regulation of cognition), the final factor structure was best represented by two factors (accounting for 65% of the sample variance). Post-hoc content analyses confirmed that these factors were indeed knowledge of cognition and regulation of cognition.

These two factors were found again in a second instrument development study. Dennison, Howard, Krawchuk, and Hill used the results from the MAI study to develop two inventories for use with younger learners, the Jr MAI, versions A & B, (Dennison, Howard, Krawchuk & Hill, 1996). Their results indicated that both versions A & B revealed two distinct factors, accounting for 64% and 56% of the sample variance respectively.

Method

We began with the pragmatic goal of developing an instrument that would further our research and could also be used extensively in classrooms across the country to help teachers identify students’ self-regulatory strengths and weaknesses. It was not our intention to replicate the work of our predecessors in this area. Instead, we wanted to develop an easy-to-use self-report inventory for use with 12–18-year-olds that focused more specifically on metacognitive awareness and regulatory skills for solving mathematical and scientific problems.

Phase One

In Phase One the objectives were: (1) to confirm the existence of factors related to knowledge of cognition and regulation of cognition in the context of problem solving, and (2) to extend our understanding of regulatory skills related to planning, monitoring, and evaluating. To this end, we began with two existing public domain inventories, the Jr.MAI, version B (discussed previously) to examine constructs related to knowledge of cognition and regulation of cognition, and the How I Solve Problems inventory (HISP) to examine constructs related to regulatory skills of planning, monitoring, and evaluating. The HISP (Fortunato, Hecht, Tittle & Alvarez,1991) is discussed in detail below.

Procedure and Participants

We had three groups of participants: 134 students enrolled in two summer computer camps near Pittsburgh, 85 students from California, and 120 students from Michigan. Together these totaled 339 students aged 10-19 (53.3% male, 45.7% female). Ethnic breakdown included 70.3% Caucasian, 8.2% Asian American, 7.7% Hispanic, and 2.1% African American.

Materials

Jr.MAI form 2 (Version B)

The Junior Metacognitive Awareness Inventory was developed by Dennison, Murphy, Howard, & Hill (1996). In version B, for grades 7-9, students are instructed to read 18 items, and for each item circle the answer that best described the way they are when doing schoolwork or homework (1=never, 2=seldom/rarely, 3=sometimes, 4=often/frequently, 5=always).

How I Solve Problems

The HISP was developed by Fortunato, Hecht, Tittle, & Alvarez (1991) and originally used 21 items, with a 3-point scale (yes, maybe, no). In addition, the inventory was subdivided into four sections: three sections about working the problem before, during, and after, and one section about particular strategies a student might use. For our use the HISP was adapted to be similar in style and form to the Jr.MAI— with a five-point scale instead (1=never, 2=seldom/rarely, 3=sometimes, 4=often/frequently, 5=always) and some minor wording changes. Students were instructed to read 21 items and for each item circle the answer that best described the way they are when trying to solve a problem they might see in a math or science class.

Results

Item Analysis

Both instruments were treated as a single inventory for our purposes. Item means ranged from 2.3 to 4.5, and standard deviations ranged from .71 to 1.1. The standardized coefficient alpha was .8569. Upon eliminating items 11, 17, 18, and 20 from the HISP, the reliability rose to alpha = .8911.

Factor Analysis

We conducted an exploratory factor analysis with the expectation that we would see four factors: a knowledge of cognition factor from particular Jr.MAI items, and three regulation of cognition factors (planning, monitoring and evaluation) from both Jr.MAI items and the remaining HISP items (36 total items). For the purposes of extracting the most independent constructs, we utilized a principle components extraction method using varimax factor rotation.

Initial results revealed an eight-factor solution with eigenvalues 1.043 and above, which accounted for 55.2% of the sample variance. Visual inspection showed that factors 6, 7, and 8 were comprised of only a total of four items that loaded .35 and above. A content analysis of these four items showed that they measured particular learning strategies (e.g., “I draw pictures or diagrams to help me understand while learning"; "I write down important information"). These items were dropped, and the factor analyses were conducted again. The resulting solution revealed five factors accounting for 42.7% of the sample variance.

Our next procedure was to establish face validity for the five factors and the items that comprised them. Face validity was an important goal since we wanted an inventory that could be widely used by classroom teachers. We conducted a content analysis of the remaining 32 items. We wrote definitions for the five factors based upon the three or four items that loaded the most heavily on a factor (.5 and above), and used a team of five raters to determine which items they thought "hung with" the factor definitions. Each rater categorized all the items into the five categories, and we worked towards consensus on the items we thought best represented the five factors. We thus eliminated another nine items, resulting in a final set of 23 items to use for Phase Two. The final 23 items were again factor analyzed, and again five factors were found accounting for 56.3% of the sample variance.

Phase Two

In Phase Two, our goal was to create a new inventory specific to metacognitive awareness and regulatory skills in the context of problem solving. To this end, we examined the 23 remaining items from the original two inventories and revised or rewrote them to increase reliability, and wrote additional items to clearly demonstrate the existence of the five factors that had emerged in Phase One.

Procedures/ Participants

We recruited 829 students from schools across the country in grades 6-12 to complete the revised inventory (51% male, 49% female). The ethnic breakdown included 85.2% Caucasian, 7.5% Hispanic, 5% African American, 1.9% Asian American, and 0.8% Pacific Islander.

We titled the new instrument the Inventory of Metacognitive Self- Regulation (IMSR). The IMSR included 37 items with a five-point Likert scale. For each of the 37 items, students were instructed to circle the answer that best described the way they are when doing schoolwork or homework (1=never, 2=seldom/rarely, 3=sometimes, 4=often/frequently, 5=always). The items are shown in Table 1.

Results

The overall inventory demonstrated a reliability of alpha=.935. We conducted an exploratory principle components factor analysis using a varimax rotation. The resulting solution revealed five factors with eigenvalues over 1.12, which accounted for 51.6% of the variance. Reliability for each factor ranged from alpha=.720 to alpha= .867. Table 1 shows the factors, their descriptions, and the factor weights above .40. In addition, Table 1 shows three items (asterisked) that weighed only moderately across several factors, or weighed heavily on factors different than those hypothesized. For future research we would recommend removing or revising these three items.

Discussion

We found Knowledge of Cognition to be an important factor in this instrument as it was in the Jr.MAI and the adult MAI (Dennison et. al., 1996; Schraw & Dennison, 1994). The fact that Knowledge of Cognition stands out so clearly and independently indicates that more work should be done in understanding this construct. Prior research on metacognition and self-regulation has also discussed the importance of constructs similar to Monitoring and Evaluation, but very little research has connected the factors of Objectivity and Problem Representation to self-regulation.

Our results have important implications for education. They indicate that there are five particular metacognitive and self-regulatory constructs relevant to problem solving. Being able to identify and delineate these constructs further should allow our educational research and teacher professional development teams to begin providing teachers with a set of tools and training resources to help them promote student self-regulation in their classrooms. These resources would be important to teachers who are concerned not only about what students learn but also about how they learn it. Our analyses indicate that the constructs measured by the IMSR are independent, and therefore a student may show preferences or “styles” of metacognitive strengths and weaknesses depending upon his or her unique combination of constructs. If these “styles” can be further understood and delineated, it might be possible to train students to habitually use particular regulatory behaviors.

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Table 1

The Five Factors, Their Descriptions and Factor Weights Above .40

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Knowledge of Cognition: How much learners understand about the extent and utilization of their unique cognitive abilities and the ways they learn best					
I can make myself memorize something.					0.6952
I use different ways to memorize things.					0.6493
When it comes to learning, I can make myself learn when I need to.					0.6350
When it comes to learning, I know how I learn best.					0.6282
I use learning strategies without thinking.					0.5000
When it comes to learning, I know my strengths and weaknesses.					0.4060
Objectivity: Standing outside oneself and thinking about one's learning as it proceeds					
When I am done with my schoolwork, I ask myself if I learned what I wanted to learn			0.7006		
I think about how well I am learning when I work a difficult problem.			0.6793		
I ask myself if there are certain goals I want to accomplish.			0.6384		
I ask myself how well I am doing while I am learning something new.			0.6056		
I think of several ways to solve a problem and then choose the best one.			0.4938		
I try more than one way to learn something.			0.4842		
*I ask myself what is the easiest way to do things.	.0269	0.4926	0.2344	.1450	.2093
Problem Representation: Understanding the problem fully before proceeding					
I try to understand what the problem is asking me.				0.6406	
I read the problem more than once.				0.6322	
I read the problem over and over until I understand it.				0.5842	
I think to myself, do I understand what the problem is asking me?				0.5582	
I try to understand the problem so I know what to do.				0.4615	
*I make an extra effort to pay attention to what's important.	0.3496	0.3252	0.1658	0.2970	0.0668
Subtask Monitoring: Breaking the problem down into subtasks and monitoring the choice of learning strategies and completion of each subtask					
I use different learning strategies depending on the problem.		0.6595			
I use different ways of learning depending on the problem.		0.5746			
I try to break down the problem to just the necessary information.		0.5530			
I identify all the important parts of the problem.		0.5335			
I try to eliminate information in the problem that I don't need.		0.5025			
I pick out the steps I need to do this problem.		0.4650			
I think about what information I need to solve this problem.		0.4466			
*I think about all the steps as I work the problem.	0.3871	0.3868	0.3110	0.3566	0.1446
Evaluation: Double-checking throughout the entire problem-solving process to evaluate if it is being done correctly					
I go back and check my work.	0.7786				
I double-check to make sure I did it right.	0.7486				
I check to see if my calculations are correct.	0.6942				
I look back to see if I did the correct procedures.	0.6592				
I check my work all the way through the problem.	0.6346				
I look back at the problem to see if my answer makes sense.	0.5888				
I stop and rethink a step I have already done.	0.5776				
I make sure I complete each step.	0.4591				

*asterisked items weighed only moderately across several factors, or weighed heavily on factors different than those hypothesized.

<u>How do You Solve Problems?</u>

Please read the following sentences and circle the answer that best describes the way you are when you are trying to solve a problem. Think about a problem that you might see in a science or math class.

- Think about when you have to solve a hard problem. What do you do <u>before</u> you start?
- What do you do <u>while</u> you work the problem?
- What do you do <u>after you finish</u> working the problem?

There are no right answers--please describe yourself as you are, not how you <u>want</u> to be or think you <u>ought</u> to be. Your teacher will not grade this.

Never	Seldom/ Rarely	Sometimes	Often/ Frequently	Always
A	**B**	**C**	**D**	**E**

1. I try to understand what the problem is asking me.	A B C D E
2. I think of several ways to solve a problem and then choose the best one.	A B C D E
3. I look back at the problem to see if my answer makes sense.	A B C D E
4. I use different ways to memorize things.	A B C D E
5. I think to myself, do I understand what the problem is asking me?	A B C D E
6. I read the problem more than once.	A B C D E
7. I think about what information I need to solve this problem.	A B C D E
8. I use different learning strategies depending on the problem.	A B C D E
9. I look back to see if I did the correct procedures.	A B C D E
10. I think about how well I am learning when I work a difficult problem.	A B C D E
11. I use different ways of learning depending on the problem.	A B C D E
12. I go back and check my work.	A B C D E
13. I read the problem over and over until I understand it..	A B C D E
14. For this question, please circle letter B.	A B C D E
15. I check to see if my calculations are correct.	A B C D E
16. When it comes to learning, I can make myself learn when I need to.	A B C D E

Never	Seldom/ Rarely	Sometimes	Often/ Frequently	Always
A	**B**	**C**	**D**	**E**

17. I ask myself how well I am doing while I am learning something new.	A B C D E
18. I check my work all the way through the problem.	A B C D E
19. I identify all the important parts of the problem.	A B C D E
20. I try to understand the problem so I know what to do.	A B C D E
21. I think about all the steps as I work the problem.	A B C D E
22. I can make myself memorize something.	A B C D E
23. When it comes to learning, I know my strengths and weaknesses.	A B C D E
24. I pick out the steps I need to do this problem.	A B C D E
25. When I am done with my schoolwork, I ask myself if I learned what I wanted to learn.	A B C D E
26. I double-check to make sure I did it right.	A B C D E
27. For this question, please circle letter A.	A B C D E
28. I try to break down the problem to just the necessary information.	A B C D E
29. I use learning strategies without thinking.	A B C D E
30. When it comes to learning, I know how I learn best.	A B C D E
31. I ask myself if there are certain goals I want to accomplish.	A B C D E
32. I try more than one way to learn something.	A B C D E

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