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Assessment of Metacognition in Mathematics Learning Across Educational Levels: A Narrative Literature Review

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ABSTRACT

Metacognition plays a crucial role in the development of self-regulated learning skills; however, its assessment remains challenging due to its complex and largely unobservable nature. Prior studies have consistently shown that students with higher metacognitive skills tend to perform better in mathematics than those with lower levels of metacognitive awareness. In this context, a variety of tools have been employed to assess metacognition and its components in mathematics education. This study adopts a narrative literature review approach to examine existing methods for assessing metacognition in mathematics across different educational levels and to find out about the gaps in current assessing methods. The review reveals that most studies focus on primary and secondary education, indicating a notable gap in assessment practices at the undergraduate level. While some studies employ specially designed digital tools, others rely on established methods such as questionnaires, think-aloud protocols, and systematic observations. Emerging approaches, including log file analysis, eye-tracking, and learning analytics dashboards, show promise for digital learning environments. Nevertheless, compared to language and arts education, metacognitive assessment in mathematics remains underdeveloped, highlighting the need for reliable, scalable tools suitable for large classes, particularly in digital contexts.

KEYWORDS*:* *Metacognition, Mathematics Education, Metacognitive Assessment, Digital Learning Environments, Educational Levels*

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1 INTRODUCTION

In both physical and online learning environments, students who possess the capacity to control their own learning environment are considered as the most successful learners by researchers and educators (Wong *et al.*, 2019). This ability is named as 'Self-Regulated Learning (SRL)." This is more important in Digital Learning Environment (DLE) where low levels of teacher presence create high levels of learner autonomy (Wong *et al.*, 2019). Previous studies indicate that students face difficulties in learning as they do not know effective SRL strategies (Wong *et al.*, 2019). If the support is given to develop SRL, it leads a greater academic success (Wong *et al.*, 2019). Self-regulated learning strategies are skills that can be practiced by students in their real learning environment (Broadbent and Poon, 2015).

SRL is composed with three essential components; cognition, motivation and metacognition (Schuster *et al.*, 2020). Cognition is thinking strategies used in problem solving, critical thinking, text comprehension etc. Motivation is attitudes and beliefs that affect the cognition and metacognition (Schuster *et al.*, 2020). Metacognition is awareness of one's own thinking or thinking about thinking (Schuster *et al.*, 2020). According to the findings of Broadbent and Poon (2015) and Schuster (2020), metacognition plays a key role in developing self-regulated learning skills in all educational level. Hence, it is worth to investigate metacognition concept in detail.

1.1 Metacognition and Its Components

Metacognition covers all terms related to individual's thinking processes and information (Akturk & Sahin, 2011). Akturk and Sahin (2011) mentioned several definitions about metacognition by different researchers. According to John Flavel who was the pioneer of introducing the concept, metacognition is one's knowledge concerning one's own cognitive processes and products or anything related to them (cited in Akturk and Sahin, 2011). Brown (cited in Akturk and Sahin, 2011) defines metacognition as students' awareness and organization of thinking processes that they use in planned learning and problem solving situations. Wellman (cited in Akturk and Sahin, 2011) defined it as 'thinking about thinking or a person's cognition about cognition.' From the above definitions, it can be concluded that metacognition is awareness of one's own thinking process. Metacognition is categorized into two main components: Metacognitive knowledge and skills (Figure 1).

Metacognitive knowledge includes knowledge about oneself as a learner (declarative), strategies used by a learner (procedural) and why and when to use those strategies (conditional). Metacognitive knowledge is a collection of activities which are specific to the given task such as note taking, summarizing main ideas etc. (Schuster et al., 2020). Hence, metacognitive knowledge is considered as task specific.

Metacognitive skills include planning (selecting suitable strategies for the task), monitoring (one's knowledge of his/her own

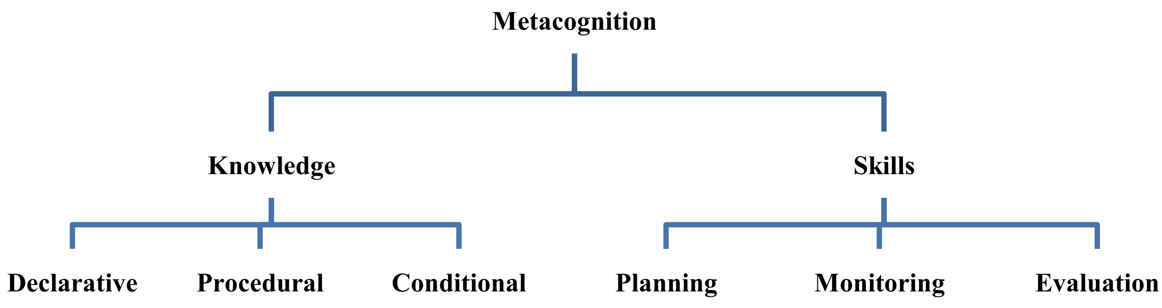

Figure 1. Components of Metacognition (Ozturk, 2017; Schuster *et al.*, 2020)

performance) and evaluation (reviewing the whole process) (Ozturk, 2017; Schuster *et al.*, 2020). Cognitive strategies are specific for the given learning task. As an example, text highlighting while reading a non-fiction text is not suitable for variable control strategy in laboratory experiments (Schuster et al., 2020). At the same time, motivation is also task specific since they address specific motivational problems. If the learning task is too heavy for the student, dividing it into smaller tasks and completing them is more suitable than self-rewarding strategy. Hence cognition and motivation are also task specific. For each task, different strategies should be introduced and developed, which is overwhelming.

But metacognitive skills are task-general (Schuster et al., 2020). Once developed, they can be applied in different types of tasks. Hence, developing metacognitive skills in students is like an investment. For example, planning, monitoring and evaluation are effective for both reading a text and conducting a laboratory experiment (Schuster et al., 2020). Since metacognitive skills are task-general, learners can get a wide range of benefits from practicing them in different types of domains. It has found that metacognitive skillfulness accounts for about 40% variance in learning outcomes in different subjects including Mathematics (Veenman, Kok and Blöte, 2005). In the next section, the researcher focuses on exploring the relationship between metacognition and Mathematics, which is a core module in any educational level.

1.2 Metacognition and Mathematics

From primary education to undergraduate education, Mathematics is included as an important subject. At the same time, Mathematics is utilizing most of the student's time (Özcan, 2014). There are studies which have revealed that students with high metacognitive skills perform better in Mathematics lessons than students with low metacognitive skills (Özcan, 2014). Various countries including US (National Council of Teachers of Mathematics) and Turkey (Ministry of National Education) have declared metacognitive skills as an essential component in Mathematics Education (Güner and Erbay, 2021).

Well-developed metacognitive skills help students cope with different areas in Mathematics such as Mathematical problem solving, Arithmetic, Mathematical Modelling, Linear Algebra etc. For any kind of solution, students must plan the process, monitor the process while solving it and must evaluate the process at the end (Chimuna and Johnson, 2016). In addition, Polya's four step problem solving model is known as a guide for successful problem solving in Mathematics and often cited as a process which fosters metacognitive skills. It includes the following steps.

a. Understand the problem
b. Devise a plan
c. Implement the plan
d. Reflect on the reasonableness of the solution
(Chimuna and Johnson, 2016, p.23, Güner and Erbay, 2021, p.718)

These steps are matched with planning, monitoring and evaluation in metacognitive skills. From these findings it confirms that there is a direct relationship between metacognition and mathematics. Hence, it is beneficial for mathematics educators to learn about methods available for assessing metacognition of their students in the classroom as it supports the teachers to provide effective feedback for them.

The aim of this narrative literature review is to study and analyze the current methods or tools used for assessing metacognition in the domain of mathematics. Hence, the objectives of this study are,

1. To study the methods available for assessing metacognition in the mathematics domain across educational levels.
2. To identify the gaps available in the current methods and tools.

Next section describes the methodology applied in this study.

2 RESEARCH METHODOLOGY

This study adopts a narrative literature review approach to examine existing methods used to assess metacognition in mathematics education. Relevant studies were identified from scholarly sources focusing on metacognitive assessment tools used at elementary, secondary, and tertiary educational levels. The selected literature was analyzed and synthesized to identify commonly used instruments, assessment approaches, and trends in the domain of mathematics.

The next section includes a detailed review of available tools/methods for assessing metacognition in mathematics.

2.1 Review On Available Methods/Tools on Assessing Metacognition

Various types of mechanisms have been used to measure metacognition in Mathematics, such as questionnaires, interviews, observations, think aloud protocol, eye movement registration, note taking and stimulated recall (Veenman & van Cleef, 2019). The following sections discuss the assessing tools of metacognition in detail.

2.1.1 Assessing Metacognition in Primary Students

De Clercq, Desoete and Royers (2000) developed a computerized program to measure metacognition skills and performance offline in arithmetical problem solving in primary school children with disabilities in Mathematics learning. EPA2000 was developed as a result of series of metacognitive interviews with children in second and third grade (De Clercq, Desoete & Roeyers, 2000). The first version of EPA2000 was a paper-based test which measured offline metacognition with a color rating scale consisting of 230 items. Children were instructed to predict how successful they would be in the task without solving the problem (De Clercq, Desoete & Roeyers, 2000). Using 584 children, this was evaluated and found that the number of items in the questionnaire can be reduced to eighty. Then students were comfortable with updated version.

The program was built using Visual basic 6. The user interface of the program was designed using cartoon figures and colorful items to get the attraction of the children easily. In this first part, questions, possible answers and color ratings were displayed as in Figure 2. In this part, students can only rate their ability to solve the given problem. After all questions were rated, then every question was displayed without the rating scale, but with answers. The child must solve the process here. After all answers were submitted, rating scale appeared again to be re-evaluated the answering process.

EPA2000 was tested with 104 children and reliability of the application was high related with mathematical score, metacognitive prediction and metacognitive evaluation (De Clercq, Desoete and Roeyers, 2000). In another study done with 80 children, EPA2000 was able to differentiate students with or without mathematical learning disabilities in third graders.

One of the major problems of this paper-based version was the difficulty in clearly separating solving process and metacognitive process. Therefore, computer version (EPA2000) was designed with the same items as the EPA where the time for prediction and evaluation was measured separately and made it possible to hide the given answer during the evaluation.

In another study, Desoete (2001) and his colleagues studied the relationship between Mathematical Problem Solving and Metacognition of Grade 3 students. There, they used Metacognitive Skills and Knowledge Assessment (MSA) to measure metacognition. Figure 3 shows sample items from metacognitive skills and knowledge assessment used in this study.

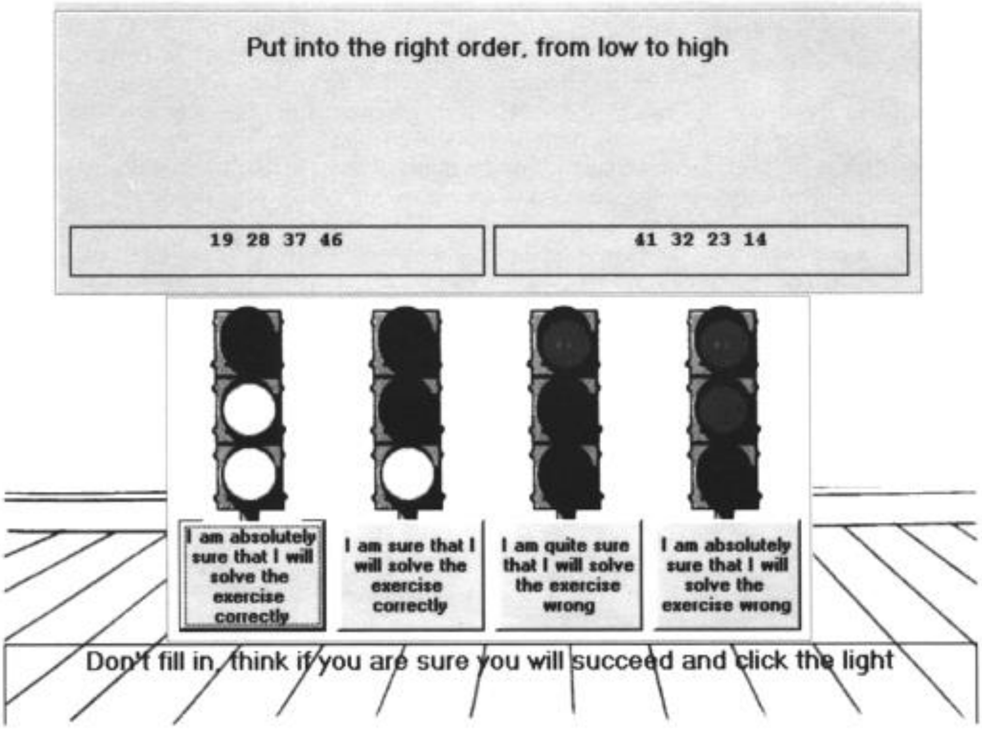

Figure 2.The User Interface with color rating scale (De Clercq, Desoete and Roeyers, 2000,p.307)

Desoete (2009) completed a two-year study with 66 students in Grade 3 to find out whether there was an improvement in problem solving in Mathematics after providing a training on metacognitive skills. To have a detailed idea on arithmetic abilities, they used two standard tests: test on arithmetical achievement and test on numerical ability. Arithmetic related metacognitive skills were measured using EPA2000. The Cognitive Developmental aRithmetics (CDR) test was used to measure metacognitive experience. CDR was developed for assessing arithmetic and metacognitive experience, and this test contains 90 items. Number of correct answers were called as performance score. After giving the solutions, students predicted the correctness of the given answers. It is called macro evaluation score. The difference between performance score and macro evaluation score is called as calibration score which interprets the metacognitive experience (Desoete, 2009). Another measure used here is child assessment (CA) which contains 12- item rating scale for children on metacognitive knowledge. Children had to answer questions on this questionnaire which revealed their behavior during Mathematical problem solving (Desoete, 2009). Think aloud protocol was used while solving three word-problems, to measure online metacognitive skills. Teacher ratings were also used as a measure to ensure the results obtained from above measures.

APPENDIX B

Sample Items From the Metacognitive Skill and Knowledge Assessment (MSA)

Look at these additions (without solving them).

45 + 28 =
45 + 23 =
43 + 8 =
23 + 6 =
9 + 23 =

- Which addition is the most difficult one? (*declarative metacognitive knowledge*)
- Why? (*conditional metacognitive knowledge*)
- How will you proceed? (*procedural metacognitive knowledge*)

Look at this exercise (without solving the exercise).
25 is 1 more than ?

Can you solve this exercise correctly? (*metacognitive prediction skill*)

☐ I am absolutely sure I can solve the exercise correctly.
☐ I am sure I can solve the exercise correctly.
☐ I am sure I cannot solve the exercise correctly.
☐ I am absolutely sure I cannot solve the exercise correctly.

How will you proceed to solve this exercise? Put the sentences in the correct order.
25 is 1 more than ?
(*metacognitive planning skill*)

☐ Choose the appropriate strategy.
☐ I read the assignment well.
☐ I extract the information necessary for the solution.

You have answered. Are you sure that your answer is the correct answer? (*metacognitive evaluation skill*)

☐ I am absolutely sure I have solved the exercise correctly.
☐ I am sure I have solved the exercise correctly.
☐ I am sure I have not solved the exercise correctly.
☐ I am absolutely sure I have not solved the exercise correctly.

- According to you, what kind of mistakes do children make in such exercises? (*metacognitive monitoring skill*)
- What is important, according to you, to succeed in subtraction? (*metacognitive monitoring skill*)

☐ to put the numbers in the right place
☐ to know the multiplication tables well
☐ to pay attention to tens and units
☐ to finish as soon as possible

Write in ☐: 4 the most important reason
3
2
1 not important at all

- How can you help young children with these kinds of exercises? (*metacognitive monitoring skill*)

Figure 3. A Sample Item from Metacognitive Skill and Knowledge Assessment (Desoete, Roeyers and Buysse, 2001,pp.448-449)

Jacobse and Harskamp (2012) did a study with 39 grade 5 students in Netherland to evaluate a new measure on measuring metacognition in word-problem solving. Students were given two word-problems to solve while they were thinking aloud. Both problems had a metacognitive approach to the solution while having multiple possible solution paths. When students were thinking aloud, they were videotaped. Each video tape was assessed using a scoring scheme.

Then the new instrument called VisA (Visualization and Accuracy) instrument was used for measuring metacognitive monitoring and regulation during word problem solving. Students were given four word-problems to solve. They had to perform four steps while they were solving each word problem.

1)Read the problem and rate the confidence to find the correct answer (before calculating the answer)

2) Make a sketch of the solution

3) Solve the problem and record the answer

4) Study the student's actual confidence in finding the answer

(Jacobse and Harskamp, 2012)

Figure 4 shows the first two steps of VisA instrument

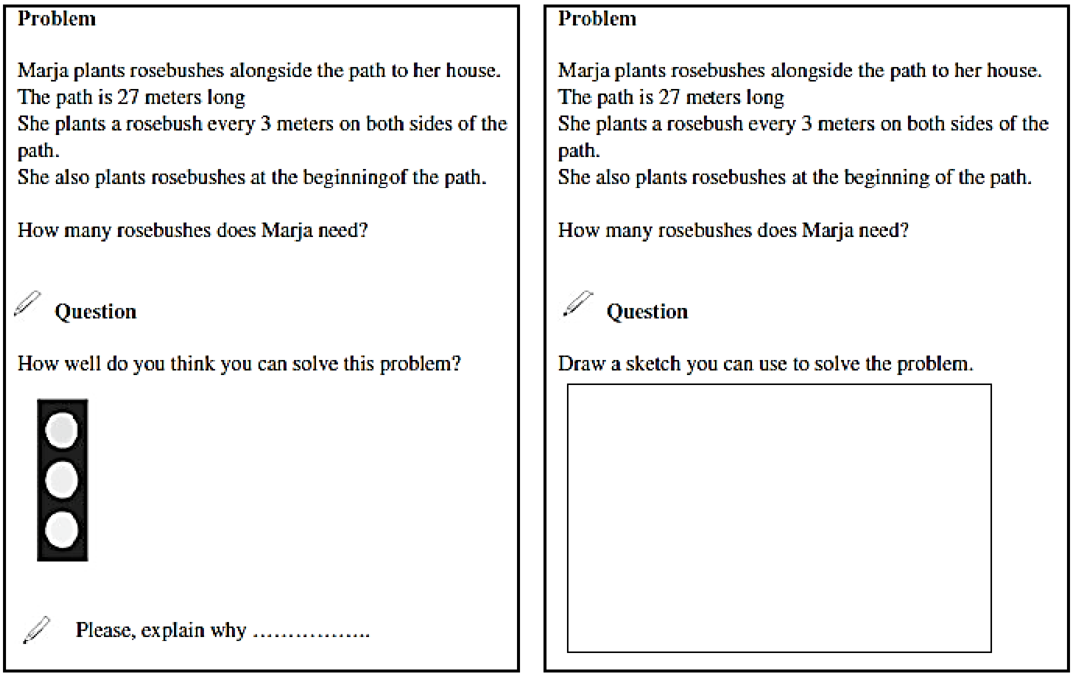

Figure 4. Step 1 and Step 2 of VisA Instrument (Jacobse and Harskamp, 2012,p.141)

A scoring scheme was used to evaluate the performance of the students. The maximum score was 12 marks. The scoring scheme used was straightforward and it was usable.

1. If the student's judgement was correct (predicted that he can solve the problem and solve it correctly or predicted that he cannot solve the problem and solve it incorrectly) score of 1 was given. If the student's prediction was uncertain or wrong (predicted that he can solve the problem, but answer was wrong or predicted that he cannot solve the problem, but answer was correct) a score of 0 was given.
2. Students got 0 points if their sketches did not represent any important facts of the problem, 0.5 was given if the sketch was partially containing important facts related to the problem, and 1 mark was given for correct visualization.
3. The post diction judgements were scored as step 1. Students got 1 point when the post diction was correct and 0 point when the post diction was incorrect.

(Jacobse and Harskamp, 2012)

They have used Self Report Questionnaire as the third measure. It was 'metacognitive self-regulation sub scale of MSLQ' (Motivated Strategies for Learning Questionnaire) which contains 12 items. A test of 13 word-problems was used as the performance measure.

Both the think-aloud and the VisA instrument were correlated with word problem solving. But self-report questionnaire was not well related to the mathematics test. Further, self-report questionnaire did not show any relation with online measurements (Jacobse and Harskamp, 2012). This showed that what students say and what students actually do is not the same. (Jacobse and Harskamp, 2012).

Even though think-aloud protocol can provide more information about problem solving process, it was found that VisA instrument also had a potential as a measure of metacognition. This instrument had easy data collection and scoring methods. It was a good sign that instruments have a convergence with think aloud measure. But it overlaps partially with think-aloud. More work is required to complete this puzzle (Jacobse and Harskamp, 2012).

2.1.2 Assessing Metacognition in Secondary Level Students

Veenman, Kok and Blote (2005) did a study to explore to what extent metacognition skills are related to intelligence and whether the metacognitive hints affect the execution of metacognitive skills. Experimental group was 41 first year secondary school students. They first completed a standard intelligence test. Next, these students performed 6 mathematical word problems, with (3 problems) and without (3 problems) metacognitive hints.

In this study, metacognitive skillfulness was measured using think aloud data while solving six mathematical problems. Systematical observation was used as a scoring scheme. For each problem, experimenters observed whether the solving process contains 15 metacognitive activities listed in the scoring scheme. Those activities reflected planning, monitoring and evaluation. When the student correctly executed an activity, a score of 2 was given. An activity was initiated but not completed, 1 mark was given. A zero mark was given when the activity was not present (Veenman, Kok and Blöte, 2005).

Ozcan (2014) did another study using teacher evaluation form and student evaluation form to find which one is the better predictor for assessing metacognition. In this research, he used three forms/questionnaires; Young Pupils' Metacognitive Abilities in Mathematics which developed with the support of Jr Metacognitive Awareness Inventory (Jr MAI) for measuring metacognitive abilities in young pupils in Mathematics, Teacher evaluation form of Student's Metacognitive Abilities in Mathematics which is an instrument developed specifically for Mathematics and Personal Information Form which is filled by teachers (students' class level, final mathematics scores, scores from a standard mathematics test) (Özcan, 2014). He conducted two studies. First one for 408 primary students participated in the first study. And second one for only sixth grade students who sat for a standard Mathematics examination in Turkey (Özcan, 2014).

In the first study, Ozcan (2014) investigated the relationship between student's self-evaluation and teacher evaluation and Mathematics achievement which was student's Mathematics score from their grade report. In the second study, metacognitive scores were studied against scores from a standard test.

It has been found that teacher evaluation alone explained about 51% of the variance in Mathematics achievement. At the same time, students' self-report of metacognitive skills did not show any relationship to the mathematics scores. Author is suggesting that Teacher Evaluation form for measuring metacognition is a better predictor than using an online measure which is impractical to use in large classes.

Idhi Amin and Sukestiyarno (2015) did an analysis on Metacognitive Skills on Learning Mathematics in High Schools. They studied what the relationship is between cognitive skills and metacognitive skills with metacognitive awareness (Amin and Sukestiyarno, 2015). There, they have used Metacognitive Awareness Inventory to measure metacognition.

Guner and Erbay (2021) did a study to explore metacognitive skills used by students in Mathematical problem solving. Thirty-seven (37) middle school students from 8^{th} grade participated as the experimental group. Students solved one non-route question and answers were collected. Students were asked to fill in a self-monitoring questionnaire on metacognitive strategies which were used while solving the problem. They have used a model of measuring metacognitive monitoring and evaluation Table 1) developed by Goos (as cited in Güner and Erbay, 2021)

Table 1. The Model used while problem solving (Güner and Erbay, 2021,p.719)

Problem Solving Behaviors	Metacognitive Skills (Monitoring/Regulation)
Before solving the problem: Reading the problem more than once, trying to understand the problem, trying to restate the problem, checking the familiarity with a similar problem before, identifying the given information in the problem and considering which ways should be used to solve the problem.	Assess knowledge, understanding of problems and strategy appropriateness
As solving the problem: Checking the solution step by step, returning the beginning if a mistake was made, rereading the problem to control whether the solution steps were still true, determining whether they got closer to the solution, reviewing the solution and trying a different approach.	"Red Flag": Error detection • Assess strategy execution • Correct errors "Red Flag": Lack of progress • Assess progress towards goal • Assess understanding of problem and strategy appropriateness • Change strategy
After solving the problem: Checking the correctness of the calculations, looking back over the solution to control the consistency between what the problem asked and what was done, examining whether the answer was sensible and thinking on different solution ways.	"Red Flag": Anomalous result • Assess strategy appropriateness and execution • Assess result for accuracy and sense

Here the evaluation was done in three stages. Those stages were before solving the problem, while solving the problem and after solving the problem. In each stage, the model identifies where the mechanisms are missing.

2.1.3 Assessing Metacognition in Tertiary Level Students

Later, Chimuna and Johnson (2016) investigated the use of metacognitive skills in mathematical problem solving among undergraduates before and after metacognitive training. While performing problem solving, student's self-talk and while performing group activity, student's group talks were recorded using a smart pen and evaluated using a rubric. Student's metacognition was measured using Metacognitive Awareness Inventory (MAI). It is a standard questionnaire developed by Schraw G. and Dennison R.S (as cited in Chimuna and Johnson, 2016). MAI assesses both metacognitive knowledge and skills in the same questionnaire. For a 'true' answer, a point of 1 was given and for a 'false' answer a point of '0' was given. MAI score was based on the total marks on each section. High scores implied high level of metacognition (Chimuna and Johnson, 2016).

Another assessing method used in computerized environments is log file analysis. In log file, frequencies of certain button presses, mouse clicks, link and screen selections, scrolling and menu clicks are registered along with the time (Veenman, 2013). In log file analysis, there are two steps to follow. First one is to select which cognitive activity is consequential to metacognitive skills. Hence, the second step is to validate these selected activities with concurrent online assessment such as think aloud or systematical observations (Veenman, 2013). This is also a trending measure which can be used in the digital learning environment.

The next section includes a comprehensive discussion about the tools identified in the literature review.

3 RESULTS AND DISCUSSION

Questionnaires, Interviews, think aloud protocol, systematic observations are most frequently used tools for assessing metacognition. In addition to these, error detection paradigms, self-report judgement and log file analysis are also some of the trending tools. These tools can be categorized based on method of implementation, behavior of the participant or the applied environment.

According to the method of implementation, tools can be categorized as offline and online. When the measurement is taken while the student is performing the task, that measurement is called an online measure. When the measurement is taken before (prospective) or after (retrospective) the task, it is called an offline measure. Popular online measures are thinking aloud protocol and systematical observations. Offline measures are interviews and questionnaires. Table 2 presents a comparison between offline and online measures. Easy administration and ability to conduct in larger classes tend to be the main reasons why questionnaires are more popular.

Table 2. Comparison of Online and Offline Measures

Online	Offline
1. Conducts while task is being done	1. Conducts after or before the task.
2. Can conduct in smaller classes. Not practical for larger classes.	2. Can conduct in larger classes.
3. Administration is not easy.	3. Administration is easy.
4. Time consuming.	4. Minimum time consumption
5. Data is more reliable.	5. Data distortions can occur due to memory failures.
6. High response rate.	6. Low response rate and poor responses due to comparisons with various reference points such as the top student in class.

When the tools are categorized based on the behavior, some tools are objective behavioral measurements, and some are self-assessing tools. Objective behavioral measurements in measuring metacognitive skills involve assessing observable behaviors or actions that reflect the individual's metacognitive processes. These measurements focus on what individuals do rather than relying solely on self-reporting (Ozturk, 2017). Examples for objective behavior measurements are thinking aloud protocol, systematical observations, eye tracking in digital learning environment, response time and error tracking. In contrast to that, self-reporting tools assess the metacognition directly asking questions from the participant. Interviews or self-reporting tools are under this category.

Some of the assessing tools can be applied in the physical classroom while others in digital environment. Interviews, questionnaires, think aloud protocol and systematic observations can be applied in physical classroom settings. Online self-report questionnaires, eye tracking, log data analytics or interactive learning analytics dashboards are some examples that can be applied in digital environment (Veenman, 2013; Veenman *et al.*, 2014; Ozturk, 2017). Comparatively, there is a shortage of tools which can be applied in the digital learning environments. Most of the tools can be applied in the physical classroom. The tools used in digital environments are under development or were merely oriented for specific research. Those tools are not developed as commercial or open-source software. This creates a gap for the metacognition assessing tools used in the digital environment.

Number of research on metacognition in the domain of language, arts and reading are exceeding the amount of research on metacognition in the domain of Mathematics.(Schneider and Artelt, 2010). It suggests that there is a need for increasing studies on assessing metacognition in Mathematics. In the domain of mathematics there are various topics that can be used for studying the nature of the metacognitive skills. But a very few number of areas such as arithmetic, mathematical modelling (Vorhölter, Krüger and Wendt, 2019), word problem solving are used. There are lots of subject areas in Mathematics that are not touched by researchers. Further, most of the time they have used one question or fewer number of questions for the analysis. It is debatable whether we can assess the whole construct using only one question.

Most of the studies discussed above are for primary and middle level students. Assessing metacognition in undergraduates is less. Hence more studies should be conducted to assess metacognition in undergraduate or adult education.

In the domain of Mathematics, measuring metacognition in students who learn in digital learning environment was not found in the literature. There were studies which used log file data for measuring metacognitive skills (Veenman, 2013; Veenman *et al.*, 2014) and using eye tracking for measuring metacognition process (van Gog and Jarodzka, 2013) in computer based environments, but those studies do not address the domain of Mathematics.

4 CONCLUSIONS & RECCOMMENDATIONS

Assessing metacognitive skills in mathematics learning is essential as it enables the provision of targeted feedback that supports learners' self-regulation and improvement. Because metacognitive skills are largely task-general, systematic investment in their assessment offers sustained benefits across learning contexts. This review indicates that existing research predominantly focuses on elementary and secondary education, with limited attention given to undergraduate learners, highlighting a need to strengthen metacognitive assessment in higher education. Moreover, current studies are concentrated on a narrow set of mathematical topics, such as linear algebra and word problem solving, suggesting the need to expand assessment efforts to a wider range of mathematical domains. Future research should therefore prioritize the development of scalable and easily administered metacognitive assessment tools suitable for large classes and digital learning environments, where commonly used approaches such as think-aloud methods are often impractical.

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