Metacognition Approaches to Enhance Student Learning in Mechanical Engineering Classroom

Quamrul H. Mazumder

Abstract— **It is conceivable that over the next decade, all students will have access to some form of internet-based device while attending classes. The work presented in this paper investigated how web-based metacognition tools influence student capacity to self-assess their understanding (learning), student regulation of their learning (confidence level), class dynamics (reaction) and instructor methods. Student self-assessment associated with specific lecture slides were collected and compared with content-specific questions later in the examination. A set of online questions were used to evaluate student understanding on specific materials presented in the slides. Students were also asked to self-assess their confidence level in their answers. A web-based metacognition tool "LectureTools" was used to collect student responses. Correlation of correct answers with the self-assessment is presented to reflect on what the student thought they understood versus the outcome of their exam scores. The study evaluates how students may regulate their own learning and improve their ability to self-assess their understanding more critically. The ultimate goal is to empower students to become a better learner by self-assessment and evaluation of their own knowledge.**

Index Terms—**Engineering Education, motivation, metacognition, classroom engagement, assessment**

I. INTRODUCTION

The objective of this two-phase, sequential mixed methods study is to explore participant views toward learning to develop and test an online metacognition instrument. The first phase will be an investigation of metacognitive strategies through an online tool "LectureTools," used by engineering students. This will compare pre and post-test questionnaires to exam scores in an introductory engineering course. Results from the above investigation will be used to determine whether using meta-cognitive approaches improve learning, confidence levels of the students' knowledge and performance in the tests and quizzes. During the second phase, the study will also investigate how a computer-based, interactive metacognition tool can be used to improve student learning, and a set of strategies will be developed along with a set of tools to evaluate metacognition improvement over the course.

This study focuses on four areas of students self-assessment or evaluation using web-based metacognition tools: (1) learning (which meta-cognitive strategies are employed by students while learning), (2) confidence level (measures the relationship between students meta-cognitive strategies and their performance), (3) reaction (differences in meta-cognitive strategies between the more accomplished students verses less competent students), (4) instructional methods (how students engage meta-cognitive strategies when the methods and materials being presented are already familiar to the students). A preliminary analysis of the level of understanding of the course material is presented in this paper, by comparing pre-test and post-test scores to academic performance using examination scores. The analysis may provide understanding of the effect of metacognition on student learning and academic performance.

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II. BACKGROUND

The term "metacognition" was first introduced by Favwell as a problem solving technique in 1976 [1]. Metacognition was also described as second-order cognitions such as thoughts about thoughts, knowledge about knowledge or reflection about actions [2]. Taylor defined metacognition as "an appreciation of what one already knows, together with a correct apprehension of the learning task and what knowledge and skills it requires, combined with the ability to make correct inferences about how to apply one's strategic knowledge to a particular situation, and to do so efficiently and reliably" [3]. The most effective learners are self-regulating [4] and by promoting metacognitive processes during instruction, more durable and transferrable learning can be achieved. Two fundamental and major components of metacognition are self-reflection and self-regulation, as learning is both cognitive and affective processes. Self-reflection includes learners reflection about their knowledge, abilities, motivation and characteristics by answering questions about "what you know, how you think, when and why to apply knowledge or strategies [5]. The second component, self-regulation or self-management, refers to a mental process that helps to orchestrate aspects of problem solving.

One of the important aspects of learning is to possess a clear understanding of metacognition [6]; pivotal to success, the learner should be aware of how one learns and possess the ability to control the learning process. An important characteristic of successful students is that they are capable of assessing and regulating their own learning behavior. They strive for deep understanding and assess how well they know the material in addition to what they learned.

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They demonstrate higher levels of confidence in their knowledge that can only be achieved by deep learning, rather than the surface learning by some of their peer students. One of the greatest barriers to learning is the lack of students' ability to apply their knowledge in problem solving [7]. By evaluating their own learning, students can identify their deficiencies and improve their knowledge to a higher level, enabling them to apply their knowledge in solving complex problems. A person's level of understanding of a topic can be measured by his or her problem solving abilities to apply the topic. Self-regulation involving interaction of cognitive, metacognitive, and affecting learning reduces the number of mistakes and setbacks during problem solving process [8]. A three-prong approach can be used in developing a problem solving tactic: initiate cognitive operations, understand the desired product of the operations and posses beliefs about the conditions under which a product can be seen as useful to the learner [9]. One of the negative impacts of self-regulation is academic procrastination, which consists of the motivational attributes of anxiety, self-esteem and depression related to students' fear of failure [10].

Metacognitive strategies are beyond the cognitive strategies which help learners regulate their own cognition and focus, plan, and evaluate their progress as they move toward communicative competence [11]. Cognitive approaches to achievement motivation suggest that low self-perceived ability inhibits achievement and that high ability estimates foster and encourage achievement. Metacognitive strategies are management techniques by which learners control their learning process via planning, monitoring, evaluating and modifying their learning approaches [12].

Metacognition has been widely used in science education research as knowledge, awareness and control of one's learning that includes knowledge about the nature of learning, learning strategies and individual learning characteristics [13]. Improving metacognition skills consists of helping learners to be aware of their own learning and how the learners engage with the learning process, by asking evaluative questions and thus control their level of understanding. The Reflective research model is grounded on metacognition and refers to "shift away from standard teaching method of directed transmission to actively engaging students in their learning from rote memorization to open thinking via questioning and reflection of ideas"[14]. Effective use of metacognition requires teaching concepts of metacognition to the students, then motivating them about how it can improve their learning behavior and end results. Most of the engineering students and even professors lack knowledge and understanding of such a learning technique and how this can be effective. In a recent introduction to an engineering class, only one out of thirty- three students had heard the term "metacognition," the student who had changed his major from psychology to engineering. It is perceived as a specialized area of psychology with little or no understanding of how it can be broadly used to improve student learning.

The purpose of this study is to determine if students who use metacognition strategies are more likely to improve their ability to acquire knowledge compared to those who do not use these strategies. However, the question remains: are students aware of these strategies or do they need to be taught the techniques to recognize their true potential? Are they able to facilitate this process on their own or should they be aided through the use of technology such as LectureTools? This study explores the learning process, metacognition and whether an interactive metacognition tool can facilitate self reflective learning.

III. Teaching about Metacognition

As most engineering students and instructors are not even familiar with the term "metacognition," it is unlikely that they will effectively use the strategies during the learning process. The first step in evaluating metacognition is to gain a better understanding of the conceptual framework and perceived benefit students can gain from using metacognition techniques. Enhanced metacognition itself is a learning outcome, as well as the critical impact it can have on the content-based learning outcome [15]. Enhanced and appropriate metacognition abilities will only be achieved by means of an integrative perspective and bund between content and context [16].

Metacognitive strategies such as concept-mapping, peer discussion and an emphasis on qualitative reasoning were implemented in a large physics lecture class [17]. Students demonstrated more sophisticated conceptions to deep approaches to learning as well as positive views towards the content of the course. Effective use of metacognition strategy also requires course contents to include cognitive learning with content that should be neither already understood nor totally unfamiliar. To promote metacognition in classroom the rate of coverage should also be slower than in traditional classroom [18]. Students' learning is nonlinear with slower progress at the beginning followed by rapid learning during later stages. A positive atmosphere of trust between the instructor and student is another critical parameter for success in implementation of metacognition strategies.

The metacognition strategies were taught in the introductory engineering class using a web based tool, LectureTools. Each student in the class was provided with a laptop computer through which they can register and access LectureTools.

IV. LectureTools

LectureTools (http://www.lecturetools.org) was originally developed by Professor Perry Samson of University of Michigan using PHP scripting with MySQL, and later improved in 2007 using Symphony web application framework [19]. The driving reason for the development of LectureTools was the desire increase options for student response to instructor questions, beyond what is available in traditional clicker systems such as free response questions, image-based questions and association questions. Some of the currently available features of LectureTools include: (1) typing notes synchronized with the lecture slides (2) self-assess students' confidence in understanding the materials being discussed (3) pose questions for the instructor and/or

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teaching assistant during the lecture (4) view answers to questions (with answerers' names removed) as posed by the teaching assistant/ instructor during or after the class (5) pop-up the slide, draw on it and save the drawing (6) respond to instructors questions (7) view podcasts (if any) that are that are uploaded by instructor (8) print lecture slides and notes for off-line review.

To allow real-time feedback from students about their self-assessment of level of understanding of the materials being presented, students were asked to assess their confidence level in the level of their understanding. Student's pre-test and post-test scores during each class will be compared to evaluate their ability to answer questions in the subsequent examinations.

V. Methodology

A. *Experimental Design:*

The study was based on a repeated measure design (pre-tests core, post1 score, post2 scores, pre-test confidence, post1 confidence, post2 confidence). Students' scores and confidence levels were measured for six consecutive weeks to determine a correlation among them. Pre-test and pre-test confidences were measured at the beginning of the class prior to lecture, Post1 test was conducted immediately after presentation and discussion of the course materials; post2 test was after group discussion among peer students in the class. The objective was to evaluate whether students self-assessment of their knowledge, understanding and confidence level of their knowledge changes during the class and changes over the course. The second analysis was to evaluate whether there is any correlation between a student's score and confidence level during class and their academic performance measured during an examination, such as quiz.

Students were taught how to self-assess their level of understanding by preparing their own test questions and answers before the exam to regulate their own learning. The questions asked by students during the class discussions, along with the answers, were provided to all students which may also enhance their level of understanding.

B. *Participants:*

Participants were 29 male students and 4 female students with age group between 20-30 years. All students were enrolled in EGR102: Introduction to Engineering, a first-year course required by mechanical engineering students at University of Michigan-Flint. Out of 33 participants, 26 were engineering majors, with 7 students who have not yet decided their major field of study.

C. *Experimental material and procedure:*

Before conducting the study and during the first class, a lecture on metacognition was presented, to provide fundamental concepts, strategies, and benefits one can gain by using it. Instructions were provided on the online metacognition tool, LectureTools, and how to use its different features using laptop computers. The class used a laptop cart that contains 30 laptop computers that students can check out for use during the class. The remaining 3 students brought their own laptop for use in the class.

Prior to the lecture or classroom discussion of a topic, participants were asked to complete a pre-test questionnaire, designed to measure their level of perceived ability and confidence in the subject matter. Next, the instructor presented the material where students participated through discussion and by submitting questions using LectureTools. Following the lecture and discussion, they were asked to complete a post-test questionnaire (post1), designed to assess the level of accuracy of their knowledge about the subject matter and their confidence level. After the post-lecture test, students gathered in groups of 3-4 and discussed each question and their individual answers, providing rational explanation of why he or she had higher or lower level of confidence of their answers. The group members then answered the questions individually and indicated their level of confidence. It was observed that overall accuracy and confidence level had changed through these processes.

The data was analyzed using Pearson correlation with six different variables: pre-test score, pre-test confidence, post1score, post1 confidence, post2 score, and post2 confidence. The results of the six variables were compared to each other to determine any correlation among them. The analysis results will be used to determine any correlation between scores and confidence levels to evaluate how accurately students are able to self-assess their level of understanding. The results will also be used to observe the changes in level of understanding and confidence levels between pre-test, post1 test and post2 tests.

A second analysis was performed to determine the correlation between weekly pre, post scores and confidence levels with examination scores of quiz one. The results of the pre-test, post1 test, post2 tests were compared to exam scores to determine how well they did perform in the examination compared to their self-assessment during the classroom session. The next phase of this study will involve an experiment with a control group, using learning instruments to determine if metacognitive strategies improve learning amongst students at the University of Michigan-Flint campus.

VI. Results

Our model's assumption is low perceived ability impedes performance and that high-level absorption advances achievement to areas of their strengths and students improve their metacognitive abilities in the classroom by increased confidence level after the post2 test. The results of pre-test and post test score data for a week with students' self-assessment of their confidence level of the correctness of their answers are presented in Fig. 1. The expected outcome line shown in the figure is a perfect agreement line between students' scores and their self-assessment of confidence level of correctness of their answers. The mean scores and confidence levels of 33 students for 6 weeks of study is presented with 95% confidence level error bars in Fig. 2. The mean score and confidence levels increased from approximately 6 to 9 demonstrating a 50% improvement during the class. This overall observation demonstrates the level of improvements using metacognition strategies in the

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classroom

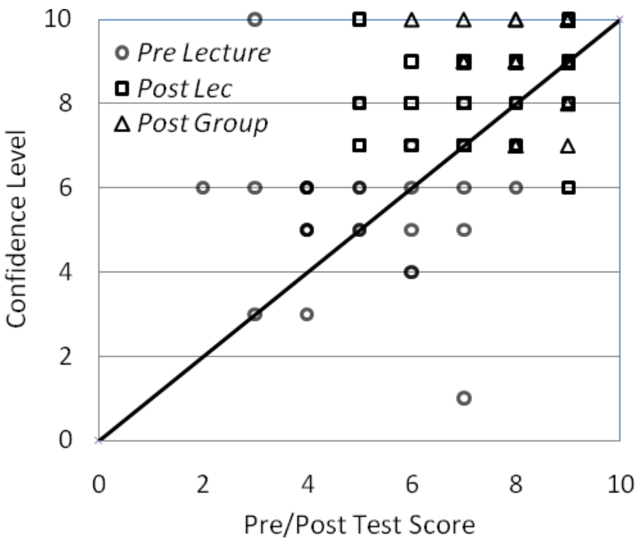

Figure 1 Students' Self-assessment of Confidence Level and Pre/Post Test Scores

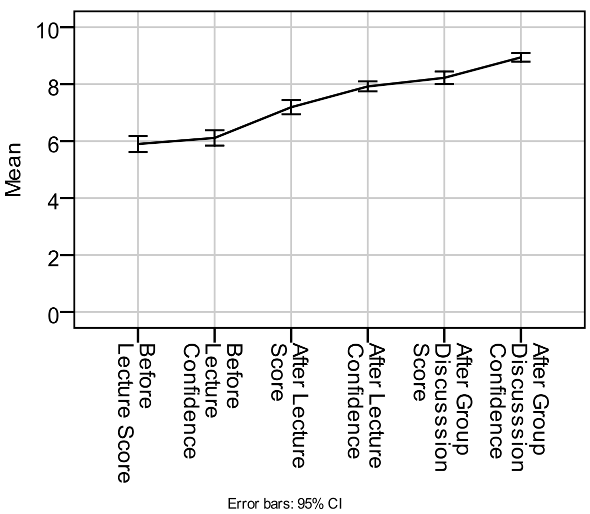

Figure 2: Mean scores and confidence levels of pre and post tests

The changes in scores and confidence levels for all 33 students in 6 weeks presented with 95% confidence level error bars in Fig. 3. It appears that there is a consistent level of improvement between 2.5 and 4 points across a six week period, with higher scores and confidences in Week One compared to Week Six. One of the possible explanations for this difference in scores may be attributed to the fact that the students may be more familiar with the materials presented in Week One compared to Week Six. Although a downward trend is observed, the incremental changes in scores and confidence levels are highest during week four. The mean scores and mean confidence levels are presented separately for each week in Fig. 4 and 5 showing consistent improvement in both students' scores and their confidence levels of their level of understanding.

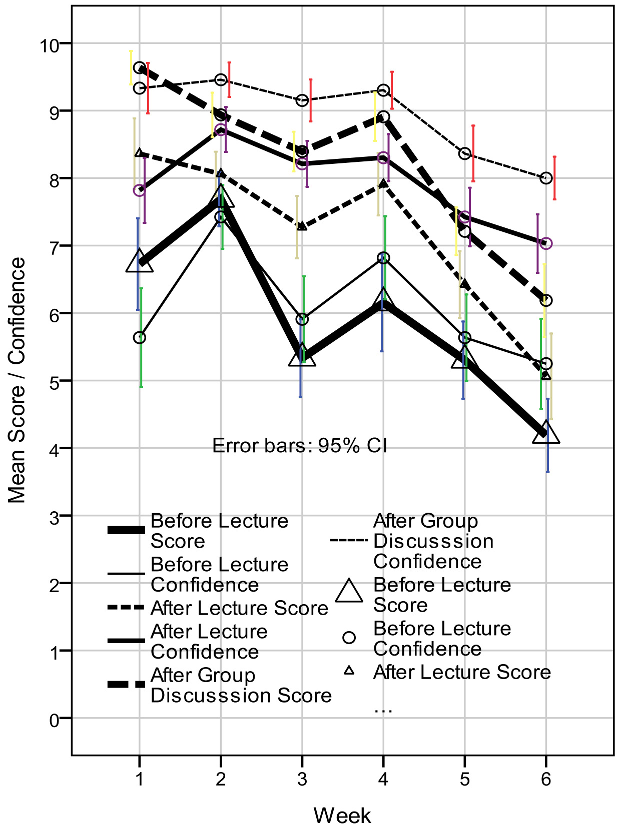

Figure 3: Weekly changes in mean scores and confidence Levels

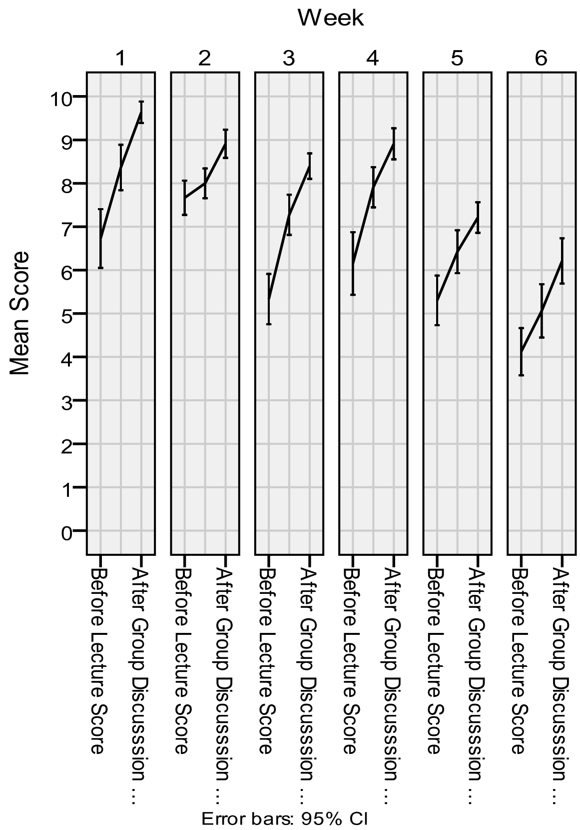

Figure 4: Weekly changes in Mean Scores between Pre and Post tests

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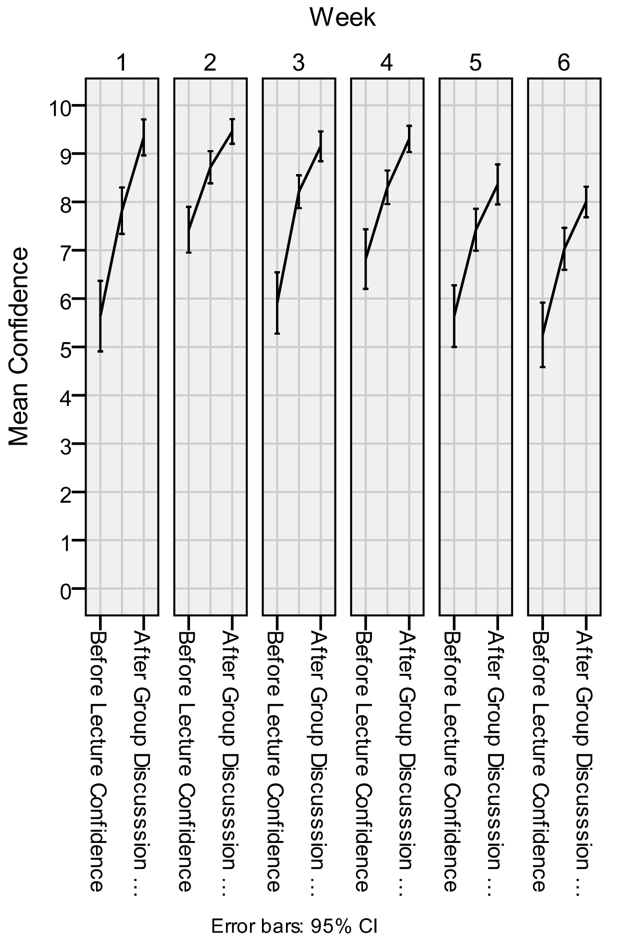

Figure 5: Weekly changes in Mean Confidence between Pre and Post Tests

The first of the two analysis performed on the preliminary results of the metacognition research was performed using SPSS software. The Pearson correlation analysis among six different variables shows significant correlation between pre-test score and pre-test confidence ($r = 0.425$, $p < 0.01$) , between post1 (after lecture) test score and post test confidence ($r = 0.480$, $p < 0.01$), between post2 (after group discussion) score and post2 confidence levels ($r = 0.374$, $p < 0.01$) The highly significant level of correlations can be interpreted as students ability to self-assess their knowledge and level of understanding of the materials discussed in the class. The analysis results are presented in Table 1.

The second statistical analysis using SPPS was performed to determine any correlation between pre and post test scores and confidence levels to academic performance as measured by a quiz conducted during Week Five of the class. The results are presented in Table 2 below. The mean scores of pre and post test results for each student were compared with their quiz scores using Pearson correlation analysis showing no significant correlation ($r = 0.217$, $p = 0.225$, $r = 0.017$, $p=0.923$ and $r = 0.078$, $p= 0.666$) between academic performance and students self assessment during classroom

Table 1: Pearson Correlation among Pre/Post Test Scores for Six Weeks (n=198)

		Pre-test Score	Pre-test conf	Post1 Score	Post1 Conf	Post2 Score	Post 2 Conf
Pre-test Score	Corr	1					
	Sigm						
Pre-test Confid	Corr	.425**	1				
	Sigm	.000					
Post1 Score	Corr	.554**	.269**	1			
	Sigm	.000	.000				
Post1 Confidence	Pear	.341**	.621**	.480**	1		
	Sigm	.000	.000	.000			
Post2 Score	Pear	.392**	.156**	.693**	.295**	1	
	Sigm	.000	.009	.000	.000		
Post2 Confidence	Pear	.298**	.331**	.449**	.632**	.374**	1
	Sigm	.000	.000	.000	.000	.000	

***. Correlation is significant at the 0.01 level (2-tailed).*

Table 2: Pearson Correlation between Academic Performance and Pre/Post Test Results (n=33)

		Quiz	Pre-	Pre-	Post1	Post1	Post2	Post2
Quiz1	Pearson	1	.217	.001	.017	.324	.078	.256
	Sig. (2-		.225	.995	.923	.066	.666	.150
Pre-test Score	Pearson		1	.361*	.705**	.189	.369*	.061
	Sig. (2-			.039	.000	.293	.035	.735
Pre-test Confiden	Pearson			1	.238	.640**	-.103	.403*
	Sig. (2-				.182	.000	.568	.020
Post1 Score	Pearson				1	.323	.632**	.099
	Sig. (2-					.066	.000	.585
Post1 Confiden	Pearson					1	.053	.761**
	Sig. (2-						.769	.000
Post2 Score	Pearson						1	.073
	Sig. (2-							.687
Post2 Confiden	Pearson							1
	Sig. (2-							

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**. Correlation is significant at the 0.05 level (2-tailed).*

***. Correlation is significant at the 0.01 level (2-tailed).*

VII. Conclusion:

Introduced in the first phase was an experimental paradigm evaluating the study of metacognitive behavior? Overall performance was based on each participant's assessment of their knowledge of the subject matter. It was hypothesized that the students' confidence level would affect the actual score they received on their exams. It was compared to their actual performance based on exam scores. No significant main effect was revealed linking the pre- and post-test scores and student's self-assessment of their confidence levels of knowledge. Our argument that low perceived ability impedes performance and that high level absorption advances achievement was not supported. However, it is important to note that our sample size was very small, meaning that our results of the early phase of this study have very low statistical power. It is important to emphasize that students were chosen to participate from the Engineering 102 class; this is not representative of the entire population at UM-Flint. Further studies in this area will conduct more random assignments when selecting samples for these studies.

Additional studies need to be conducted to determine if students use of metacognitive strategies improve their knowledge and academic performance. Secondly, will they enhance their abilities if they were to use the online metacognitive instrument, LectureTools, to facilitate the learning process? These theories will be explored in phase 2 of this study. Since many of the metacognitive strategies can be taught to students, perhaps it would be plausible for educators to incorporate new methods and tools to facilitate the use of metacognitive strategies which can improve student achievement.

There are, however, some implications for teaching these strategies. First, students are not aware of the importance of utilizing metacognitive strategies; they do not realize the importance of the process unless it is reinforced by a teacher. Secondly, in order to properly incorporate these strategies into the classroom, teachers must teach a subject in-depth, to form a firm foundation of factual knowledge [20]. In order for this to be plausible, the teacher must bring with them a wealth of experience of in-depth study of the subject matter. They must be familiar with the "process of inquiry between information and the concepts that help to organize that information in the discipline" [20]. Thirdly, they must acknowledge that all students bring different experiences and backgrounds into the classroom, thereby making their understanding and ability to process these concepts different from one another. Teachers should be able to embrace the growth and development of the students' thinking and understanding of these ideas. Future studies are being conducted by the author on tracking the age at which students are taught to implement metacognitive strategies and a comparison of this to their academic achievement. The future phases of this research will compare students' organizational skills with their level of academic achievement, to see if there is any correlation with the way they organize their thoughts.

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