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Cognitive Offloading in Mathematics at School: The Role of External Representations and Digital Tools in Problem Solving and Thinking

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Abstract

The aim of this paper is to study the cognitive offloading in mathematics at school by following a critical narrative review method. External representations and digital tools used during solving mathematical problems are the major focuses of this paper. The Cognitive offloading is defined as the use of external actions, representations & tools to regulate the cognitive demands of a task. In maths, the cognitive load required in the processing of information can be shifted from the student's mind to the external media by writing down the various intermediate steps, creating diagrams and tables and using physical manipulatives, calculators, dynamic geometry software or application and various AI tools. This paper studies the evidence from cognitive science, mathematics education and educational technology to find out that when offloading supports learning and when it hinders the learning. Studies have clearly shown that working memory is strongly linked to math problems-solving and well-designed external tools can be helpful for students to organize the information, understand relationships and manage complex or lengthy tasks. Still, external assistance can be considered helpful. Its extent that how it affects things depends on the design, what the task needs, what the learner already knows & understands and the guidance they receive. Further concerns arise from digital externalization because such means can save, change, or produce mathematical data requiring little effort from the student. Therefore, this paper presents a strategic-offloading framework that uses external support to reduce unnecessary cognitive load, while maintaining learner responsibility for mathematical reasoning, explanation, verification, and reflection. At the end of the review, the implications for secondary mathematics (especially Class 9) are discussed and suggestions for further research are given.

Keywords: cognitive offloading; mathematics education; mathematical problem solving; external representations; digital tools; working memory; mathematical thinking; secondary education

Introduction

Learning math is not about just getting the right answers but students need to understand numbers and learn how they relate to one another. They must be able to use different models, think logically, explain their thoughts, and solve new and unheard-of problems. It is also necessary for students to justify why their answers are right and use modern tools correctly. At present, schools emphasize these advanced problem-solving skills in addition to fundamental mathematical procedures. India's most recent educational guidelines promote this perspective. Experiential learning, critical thinking and the integration

of smart technology are being strongly promoted by National Education Policy 2020 (NEP-2020). National Curriculum Framework for School Education 2023 (NCFSE-2023) also continues with the aims to help learners gain practical mathematical abilities for their everyday life.

These objectives bring up a critical question about brain function: how do students handle all the data needed for multi-step math problems? As a student works through a word problem, they need to remember numbers, read and grasp the text, figure out connections, pick a plan, do the math, keep track of their progress, and verify their answers. Because of this, working memory is very important while solving math problems (Ji & Guo, 2023). A major study analyzing 130 past studies on more than 43,000 people observed a clear and moderate link between working memory and a student's ability to solve math problems (Ji & Guo, 2023). From this viewpoint, any pedagogical approach or resource that assists in lowering needless cognitive load can simplify achieving success in math for students. Such helpful mental strategies are called cognitive offloading. It is defined as using physical actions or external tools to lighten our brain's workload during a task (Risko & Gilbert, 2016). This is done all the time like writing a quick note, checking a map or using a calculator. During math class, students naturally do this by writing out steps, sketching diagrams, using number lines, or writing down formulas. These habits are so common that we frequently overlook how much they support our thinking. Yet, cognitive offloading does not always results in better learning. Not only can external tools make the working memory free but they can also bring in the misleading information or unnecessary steps. In the same way, digital tools can not only help the students to identify the ideas but they can also perform the thinking for them and results in missing out true understanding of the mathematics by students. The major problem of education is not to decide whether offloading the workload on tools is good or bad but the main issue is studying what is being offloaded and why, how the tools are being used and whether the student is still performing the fundamental mathematical thinking or not.

For the indepth understanding, this paper combines the cognitive offloading research with studies in mathematics education related to memory, problem-solving and digital tools. The main focus of this paper is high school primarily class IX. The main point is that good cognitive offloading should reduce the mental burden without removing the math reasoning that students have to learn.

Objectives

Objectives of this study are

1. To examine the concept of cognitive offloading and its relevance in mathematics learning at school.
2. To analyse the role of external representations in supporting problem solving and thinking in mathematics.
3. To examine how digital tools can function as cognitive offloading resources in learning mathematics.
4. To identify conditions under which cognitive offloading may support or interfere with learning mathematics.
5. To propose pedagogical principles for the strategic use of cognitive offloading in mathematics in secondary classrooms.

Method and Procedure

This paper uses a critical narrative review approach. It neither analyzes primary classroom data nor constitutes a systematic review or meta-analysis. Rather, data for the research was collected from academic databases and official online archives focusing on key terms such as "cognitive offloading," "mathematics

problem solving," "working memory," "external representation," "digital tools," and "AI in education." This study is primarily based on peer-reviewed research, expert reviews, fundamental principles, and official Indian education policy papers and documents.

To understand this research, the findings have been organized around five key questions: why mental workload is essential in solving math problems, how students utilize external resources, what digital tools contribute to this process, the potential risks of over-reliance on such tools, and the implications for classroom teaching. Rather than relying on statistical data, this analysis is interpretive. The ultimate goal is to combine the findings of cognitive science with mathematics education to prepare an evident conceptual framework that can guide the research of the future on high school students.

Understanding Cognitive Offloading in Mathematics

The Cognitive offloading is defined as the shifting of the burden of any mental tasks on the external things. It might be through paper notes or the digital tools. In a study, Risko & Gilbert (2016) found that we decide to offload tasks based on the difficulty of the work and whether we trust in our own abilities or the tools available related to that. Because of this, it is a mindful decision that students wisely choose whether to solve any problem solely in their own minds or to use any external assistance. This cognitive offloading occurs at various levels in mathematics. At a very basic level, the student simply writes down the numbers rather than trying to memorize it. While at a very advanced level, they may make diagrams or make tables to organize and solve the complex problem. When it comes to technology, students can use calculators for simple math, software to make & view graphs or AI tools for clues. These various ways impact our brains in various ways so they should not all be viewed equally the same. For the proper understanding of this offloading it can be divided into two parts: supportive offloading and replacement offloading. The Supportive offloading takes place when a tool improves the extra pressure of memory but the students keep doing the thinking, planning and testing by themselves. The Replacement offloading occurs when a tool itself executes all the primary mathematical tasks for students and leaves nothing to perform real mathematical logic & thinking by students. So, the same tool can be beneficial in one situation and harmful in another situation depending on how it is being used.

Working Memory, Cognitive Load and Mathematical Problem Solving

While solving any mathematical problems, it is necessary to retain multiple pieces of information together. Cognitive Load Theory shows that retaining multiple pieces of information together can create a massive burden on the brain, especially on beginners who have not yet formulated the strong cognitive schemas or patterns (Sweller, 1988). It is important in the school mathematics because students often have to think wisely about the steps that can be done by experts automatically.

Previous studies confirm the link involved in the working memory. A thorough review of 130 papers that includes the data from over 43,000 participants, showed a strong relationship between working memory and problem-solving in mathematics (Ji & Guo, 2023). Still it doesn't indicates that a score in math is dictated by memory but it suggests that processing of information is important for doing math. So, Cognitive offloading is a very useful step to handle the mental pressure. If a student writes down the intermediate steps of any problem then there is no need to keep every steps locked in his mind. Verbal problems easily transform into visual relationships on drawing pictures which are directly related to them. Similarly, they can easily compare numbers between rows just by making tables rather than panicking to memorize them. When we take help from outside it changes the way the brain works. But just by lowering

the cognitive load it does not guarantee the improvement in learning automatically. A student might fail in developing the true mathematical skill if an outside tool removes the exact mental challenge a student requires for growth. Thus, to eliminate unnecessary mental complexities while dealing with the challenges that can truly help students to understand the mathematics is the main purpose of teaching.

External Representations as Cognitive Offloading

In mathematics, external representations play a very important role. Elements like symbols, diagrams, graphs, tables, number lines and written notes do not reflect only the mathematical ideas of students but they actually reflect what they can see, think & analyse. According to Ainsworth (2006), using multiple representations helps in learning but its achievement is directly related to the design of representation and expectations of students.

Visual aids and diagrams are more effective when students learn to make and use them according to their own need rather than just observing the readymade ones and it has been claimed by various studies related to word problems. When dealing with the complex problems, appropriate diagrams help students in visualizing the relation of one number to others by reducing the cognitive load (Jitendra & Woodward, 2019). So, the best way to reduce the mental burden is to make the diagrams and bringing clues in front of the student's eyes instead of directly telling them. But diagrams only don't make things easier always. It has been observed that extra visuals don't automatically help in making the math problems easy but sometimes they may create confusion or increase the mental workload (Van Lieshout & Xenidou-Dervou, 2018). Thus, it is very clear that external tools are helpful only when they are directly related to the mathematical task. Also, a recent review highlights the extent of research into the use of images and physical manipulatives in learning mathematics (Schoenherr & Schukajlow, 2024). Therefore, diagrams and sketches should not be viewed merely as decorative elements, they are powerful mental tools, and their design and the way they are taught truly matter.

Digital Tools and the Expansion of Cognitive Offloading

Digital devices provide multiple ways to offload our cognitive burden by storing, computing, altering, and animating mathematical data. For example, a calculator manages basic math, graphing software generates charts immediately, dynamic geometry tools let us sketch and experiment with shapes, spreadsheets structure data and search utilities and find answers within seconds. Still, a 2023 study by Skulmowski found that digital offloading helps with problem-solving but relying on it too heavily might harm the memory and deep learning. The main difference is whether technology is used to explore and understand mathematical concepts or to avoid them entirely.

Digital apps can offer students multiple ways to view a single mathematical problem. Previous research indicates that combining different methods or modes of representation can facilitate learning provided they are used judiciously (Ainsworth, 2006). A systematic review and meta-analysis titled "The More the Better?" claims that simply adding more technology or visuals does not automatically improve mathematics learning (2024). The quality of the tools and the guidance provided to students are far more important than the sheer number of tools used.

Generative AI as a New Form of Cognitive Offloading

Generative AI presents an entirely new alternative for lowering cognitive load. While traditional tools such as paper and calculators merely save notes or perform basic arithmetic, generative AI can actually

write out comprehensive explanations, steps, examples, and complete solutions. Consequently, it is more important to recognize the distinction between using AI for support and permitting it to completely substitute your own thought process.

During math class, students can use AI for a variety of tasks like getting a quick hint, identifying errors, requesting a basic explanation or copying the complete answer. Yet, these uses are not all equal. Seeking a hint enables the student to keep engaging in challenging thinking whereas copying the entire AI solution implies the machine does all the reasoning instead. Recent research on artificial intelligence (AI) and cognitive offloading highlights both the benefits and risks of its excessive use. Although their study focuses specifically on students with learning difficulties, their warning is universal that AI should support students rather than replace their effort (Seung & Basham, 2026). For this reason, students in modern mathematics classes should be taught how to use artificial intelligence (AI) sensibly. They need to learn how to utilize AI for constructive purposes such as seeking hints, checking their work or solving extra practice problems while retaining the core mathematical reasoning themselves. Effective classroom activities should always require students to explain, prove and verify their answers independently.

When Is Cognitive Offloading Beneficial and When Can It Become Harmful?

When is offloading beneficial and when is it harmful? Research indicates that there is no simple yes or no answer to this. Rather, offloading exists on context and its value depends entirely on the task, the student, the tools used and the ultimate learning objective.

Beneficial offloading occurs when it reduces unnecessary mental strain while keeping genuine thinking alive, helps students organize unorganized numbers using tables, diagrams or written steps and makes it easier to visualize hidden mathematical relationships. It also promotes the exploration and testing of various problem-solving methods, provides useful support to students struggling with memory or reading details, and frees up mental capacity to focus on understanding and explaining mathematics. On the other hand, harmful offloading occurs when it solves math problems for students depriving them of necessary practice, students blindly accept the answer without verifying it and it prevents them from practicing the fundamental facts and steps they need to memorize. This also includes using misleading images or poor tools that makes the problem harder, creates an unhealthy dependence on digital tools for student-led tasks and gives students false confidence in answers they do not actually comprehend.

This difference is easy to see in the chapter algebra of IX class. Writing every step of an equation on paper is a great example of helpful offloading because it keeps track of your progress while you handle the algebra logic yourself and it is also fine to use a calculator to recheck the final number. Conversely, having an AI tool to solve a whole algebra problem and copying it without knowing the underlying process is replacement offloading. After all, a tool is only as good as the role we assign to it.

A Strategic Cognitive-Offloading Framework for School Mathematics

Based on all this research, this paper introduces a brand-new guide called the Strategic Cognitive-Offloading Framework for school math. This framework is laid out in six simple steps to help teachers and students use external tools wisely:

Stage	Framework Step	Description & Classroom Action
1	Identify the Mathematical	Determine whether the learning target focuses on conceptual

	Goal	understanding, procedural fluency, problem solving, reasoning, representation, or tool use.
2	Identify the Cognitive Demand	Figure out what information must be managed and whether the struggle comes from the actual math or from unnecessary memory, organization, or layout issues.
3	Select Minimum Effective External Support	Choose a tool—such as a diagram, table, manipulative, calculator, or digital aid—only when it serves a clear, purposeful mathematical function.
4	Preserve Core Mathematical Thinking	Ensure the student remains fully responsible for reading the problem, picking strategies, explaining connections, and making final math decisions.
5	Require Verification & Explanation	Have students check results, catch mistakes, justify steps, and explain why an answer works instead of blindly trusting an external tool.
6	Gradually Reduce Support	Slowly remove aids as students build confidence, helping them internalize strategies and work independently over time.

The whole procedure extends from Mathematical goal → Cognitive demand → Appropriate external support → Learner reasoning → Verification and explanation → Gradual independence. The golden rule is simple that offloading should share the mental weight but it should never steal away the student's responsibility to actually learn the math.

Implications for Class IX Mathematics

Class IX provides a prime setting for classroom inquiry since learners start engaging with abstract, multi-step math and build independence in their logical thinking. This approach adapts smoothly to numerous IX class subjects including algebraic identities, linear equations, coordinate geometry, statistics and word problems. While studying algebra, students can write down intermediate steps on paper to keep track of changes. While in geometry, diagrams and dynamic software help students visualize shapes and test ideas before writing their proofs. In statistics, tables and spreadsheets handle complex calculations allowing students to focus on identifying patterns and drawing conclusions. During solving the word problems, students can create diagrams, charts or equations to outline the relationships involved before deciding on a method to solve them. During this process teachers play an important role. Teachers can establish clear, task-specific rules for allowing students to use them without any restrictions instead of banning all devices. For example, an examination could consist of two parts: the first without digital devices to assess fundamental independent thinking and the second allowing the use of devices provided students clearly explain how they utilized them and verified the accuracy of their answers.

Discussion

After analysing the related studies, we arrived at three main conclusions. First, the cognitive offloading or reducing the mental workload is considered to be very normal in problem-solving. It is not a sign of

weakness in thinking. Since, the capacity of the human brain is limited so using the external tools helps in managing the information in a more effective way. Studies have shown that even young children know the appropriate usage of external aids still sometimes they choose poor tools or become over dependent on them (Armitage and Gilbert, 2025).

Secondly, the effectiveness of externalizing information depends totally on the task and the tools being used. The hidden connections can be disclosed by drawing or writing and thus mental energy can also be conserved. But problems can become more confusing if the diagrams are poorly designed. This aligns with the idea that the design of a tool, the student's activity and the learning goals must always work in concert (Ainsworth, 2006; Jitendra & Woodward, 2019; Schoenherr & Schukajlow, 2024).

Thirdly, digital technology and generative AI have further complicated the situation. While modern tools make understanding mathematics easier, instead of merely assisting, they can provide the complete solution themselves, thereby stopping our thought process. Therefore, in today's mathematics classes, it is essential to teach how to use these tools wisely rather than simply clicking away.

Consequently, in a technical class, genuine critical thinking means identifying which tool is helpful, understanding what it is actually doing, verifying whether the answer is correct and ensuring that the student keeps control over their own mathematical reasoning.

Pedagogical Recommendations

Ten practical strategies are needed to incorporate these ideas into daily teaching, helping students use external tools wisely:

Sr. No.	Strategy	Core Classroom Action
1	Teach Tools as Strategies	Treat diagrams and aids as active problem-solving skills rather than mere decorations
2	Ask "Why?"	Have students explain their choice of tool (diagrams, tables, calculators) before starting
3	Match Tools to Goals	Adjust tool permissions based on whether the goal is building basic fluency or deep reasoning
4	Use Tech for Exploring	Let digital tools handle visualization and checking while students keep the core reasoning
5	Prompt AI for Hints	Train students to use AI for guidance, error checking, and hints instead of copying full solutions
6	Always Verify	Require students to double-check external or AI outputs to spot mistakes and false assumptions
7	Fade Support Over Time	Gradually remove learning aids as students build competence to prevent permanent dependence
8	Assess Reasoning	Design tests that grade explanations, justifications, and representations alongside final answers

9	Build Self-Awareness	Ask students to reflect on what they offloaded and evaluate if it genuinely helped them learn
10	Tailor Support	Provide targeted visual or external help for students who need it, avoiding a rigid, one-size-fits-all approach

Limitations and Directions for Future Research

All studies have limitations and this research is no different. Limitations of the review are given as follows:

1. As this is a narrative critical review, it presents a conceptual overview rather than a statistical or aggregated numerical impact on mathematics grades.
2. Current research employs diverse approaches to defining and measuring cognitive offloading.
3. A lot of current research on offloading happens outside of standard, daily school math classes.
4. Conclusions on digital devices and generative AI shift extremely fast, frequently moving ahead of conventional classroom studies.

Based on reviews' insights, there are several possibilities for future research given as follows:

1. Test cognitive offloading directly within an actual secondary school mathematics environment.
2. Use a class IX setting to compare how students perform using paper, drawings, calculators, geometry software, and AI.
3. Go beyond basic test accuracy to evaluate solution quality, explanation proficiency, long-term memory, and post-assistance autonomy.
4. Perform mixed-methods research to see how diverse learners react to different tools and how educators can best instruct students in using them prudently.

Conclusion

Cognitive offloading provides a helpful framework for comprehending how mathematics is learned within settings abundant in external and digital cognitive tools. Findings from the reviewed literature show that external representations may decrease extraneous cognitive strain and aid in mathematical problem-solving, assuming they match the task and feature adequate student involvement. Simultaneously, when external resources substitute for the mathematical reasoning, retrieval, explanation or verification students need to build, offloading can become counterproductive.

Consequently, the pedagogical issue is not whether learners should delegate their cognitive processing to external aids. A more practical inquiry is if, in which conditions and for which educational goal this ought to occur. When teaching school math, particularly in higher secondary class, strategic offloading serves as a method to decrease mental effort while keeping students mathematically active. Thus, the suggested framework focuses on the student's reasoning, justification, explanation and gradually emerging autonomy at the center of technology-supported mathematics learning. This approach aligns with the competency-oriented perspective of mathematics education in which students are expected not only to obtain answers but also to meaningfully understand, reason about, communicate and apply mathematics.

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