Meta-learning for students: The ultimate skill to becoming independent lifelong learners in the era of technology and AI. An application in Mathematics

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Abstract

In this article, the way students learn and the meta-learning skills and techniques needed for them to become independent lifelong learners in 2025 are being studied. Some of these meta-learning techniques are priming, mind maps and effective note-taking. It is important to understand that, from the one side, the way our brains like or, in other words, tend to learn has been thoroughly studied and understood during the past years and different meta-learning mental models have gradually emerged. On the other side, the new framework of today's life due to the rise of technology and artificial intelligence (AI), with several chatbots such as ChatGPT, has inevitably inserted more perplexity in the aforementioned issue. In this new setting, according to the scientific community in the specific education field, meta-learning techniques are the ultimate key to enabling students to take the initiative of their learning, to pursue learning experiences that transform their lives and finally to acquire more conscious, self-directed as well as self-motivated learning. Lastly, an application of the aforementioned meta-learning techniques in Mathematics is presented, regarding the resolution of first-degree linear equations, in order to implement these techniques in real learning circumstances. The specific mathematics application was used by a first-year student of Greek upper secondary school (A Lyceum), under the researcher's guidance, in order to resolve a specific first-degree linear equation. Our case study indicated that the procedure proposed in the application had positive results to the student's level of understanding and self-motivation.

Keywords: meta-learning, priming, mind maps, effective note-taking, AI, ChatGPT

Introduction

Aristotle had said that the desire of human beings to learn constitutes a natural tendency. However, it is quite often that students complain that the way they are called to learn in school does not motivate them, or even causes difficulties, obstacles and finally problems to their learning. This fact, in turn, makes students feel that they cannot sufficiently take the control of their learning process, something that ends in students' loss of desire to study, to learn and to get accustomed to constantly expanding their learning horizons while simultaneously feeling pleased and joyful within the learning process (Drigas et al., 2023).

In order students to become independent lifelong learners in their adult lives after school, it is essential for them to understand the way their minds like or tend to learn and how the learning process itself takes place indeed. This is the so-called "meta-learning skill", i.e. the skill of metacognition of learning (Biggs, 1985; Jackson 2004). It is essential to state that there is much debate regarding the term of meta-learning, among the researchers nowadays (Lemke et al., 2015). The definition that is the most cited in literature and encompasses all the following definitions is the one of Biggs (1985), where meta-learning is described as the state where someone is aware of and takes control of their own learning (Biggs, 1985).

In fact, meta-learning techniques enable students not only to become more aware of the learning process itself but also to learn effectively to choose the appropriate and effective study techniques that foster the mind's functioning during the learning process (Biggs, 1985;

Jackson 2004). In other words, meta-learning refers to "*a set of mental meta-processes by which learners consciously create and manage personal models of learning*" (Drigas et al., 2023) and is also known as "learning to learn" (Wang, 2021).

It is essential to recognize that the terms metacognition, meta-learning, and meta-learning strategies are often used interchangeably, leading to potential conceptual ambiguity. Metacognition refers to the awareness and regulation of one's own cognitive processes, encompassing both knowledge about cognition and the ability to control learning activities (Flavell, 1979). Meta-learning, while related, specifically denotes the process through which learners become aware of and manage their learning strategies, adapting them as needed across different contexts (Pintrich, 2002). Meta-learning strategies, in turn, are the concrete methods or techniques employed by learners to regulate their cognitive processes effectively and optimize learning outcomes (Pintrich, 2002). Thus, metacognition provides the overarching framework of self-awareness in cognition, meta-learning focuses on the adaptive regulation of learning itself and meta-learning strategies represent the actionable tools applied within this regulation (Flavell, 1979; Pintrich, 2002).

Finally, it is undeniable that contemporary student learning paradigms have undergone a profound transformation, largely driven by advancements in technology and the emergence of Artificial Intelligence (AI). Indeed, not only the way students learn has changed but also the skills needed during the learning process have also changed in comparison to the ones that were needed in the past years. Currently, smart technologies and AI have altered the learning's conditions and have given students the opportunity to pursue transformative learning experiences which are more conscious, self-directed and self-motivated (Drigas et al., 2023).

Meta-learning techniques for students

Priming

Priming is the technique through which the student's prior knowledge on a subject is linked to the new knowledge that is going to be acquired by them on the same subject. It is also known as pre-conditioning and it constitutes the core meta-learning technique which focuses on the learner's existing knowledge and also how to trigger their attention mechanism (Qin et al., 2021).

Indeed, it is a fact that priming has been used, in terms of meta-learning techniques, for catching the learner's attention. Indeed, prior knowledge gives the student the opportunity to perform in higher level of representations using their attention mechanism, to reduce their cognition burden and finally to successfully focus on the elements that are essential for deep understanding of the new knowledge (Qin et al., 2021). Apart from fostering knowledge acquisition and attention, it has been found that priming also can be a predictor of the learner's performance. Specifically, the prior knowledge on a field is positively correlated to the knowledge gains on the same field (Simonsmeier et al., 2021).

The use of priming in learning has been studied in various fields such as the linguistics field. More precisely, the syntactic priming is a methodology where students learn grammar and specifically syntax by using prior knowledge on the same. The procedure of recognizing the presence of syntactic knowledge fosters learning new grammar phenomena. It is important to state that, according to Kumarage et al. (2024), who conducted a meta-analysis of syntactic priming studies in children, it has been found that there was a medium-to-large syntactic priming effect (Kumarage et al., 2024).

Not only in linguistics, but also in mathematics, the learner's prior knowledge on a mathematical topic is of utmost importance. It has been known that effective teaching of any mathematical concept has to take the learner's prior knowledge in consideration and build up from there (Foster, 2021).

However, it is important to understand that priming has to be used appropriately as it can become an obstacle to the learning process, under some circumstances. For instance, in cases when the learner has misunderstood or learned something in the wrong way in the past, then this wrong or misunderstood part of "knowledge" can inhibit the learning process (Foster, 2021; Kumarage et al., 2024).

Also, in case the learner has prior knowledge to a mathematical problem, this can cause difficulties in problem solving, as the learner no longer perceives the problem as new and they just apply the solving techniques they already know, even when these are incorrect or inappropriate (Foster, 2021; Kumarage et al., 2024).

In order to overcome the latter problem, the teacher can either discuss the misunderstood linguistics concept or ask the students whether they remember an approach for solving the specific mathematical problem giving emphasis on the assumptions of the approach and whether these are fulfilled, rather than focusing on a specific solving method. By this, the students approach the new knowledge in a correct way and they use their prior knowledge on their advantage (Foster, 2021; Kumarage et al., 2024).

Mind maps

Mind maps are a meta-learning technique which enables learners to construct conceptual understandings of the knowledge. Specifically, a mind map is a dynamic visual tool that gives the learner the opportunity to organize the ideas or the learning material and to create dynamic links between and among ideas or concepts in a non-linear way. This representation, in turn, enables the learner to use their personal connections, as well as their experiences, and creativity, in a way that the learning process becomes meaningful for them (Abi-El-Mona & Adb-El-Khalick, 2008; Jones et al., 2012).

The way the mind maps are organized is hierarchical, which in turn means that the main concepts are placed in the main branches of the mind map structure and the other concepts are grouped in the next levels of the "tree" as being the details of the main concepts (Hidayati et al., 2023). Moreover, these representations not only link different ideas and concepts, but they also build hierarchical relationships among concepts, as mentioned above, all of which are of great importance in learning (Abi-El-Mona & Adb-El-Khalick, 2008).

The way that mind maps work is through taking information from several sources and integrate them into a dynamic visual representation by using keywords in a bright, colorful, vivid and creative manner that keeps the mind interested and active (Edwards & Cooper, 2010; Hariyadi et al., 2023).

It is important to mention that the traditional mind maps are drawn by hand but they can also be digital, known as electronic mind maps (e-mind maps), due to the emergence of specialized software, something that makes students be more active in creating the visual representations of the concepts and take the initiative of their learning process (Hidayati et al., 2023; Mohaidat, 2018). According to the experts, the e-mind maps are more efficient in the field of education than the traditional mind maps, as the e-mind maps are more attractive to the learners and include graphics (Mohaidat, 2018). There exist nowadays a lot of applications on mind maps' creation by their user, such as the mindmup application (at https://app.mindmup.com).

It is worth noting that the visual representations, that are created in mind maps, are student-created and they foster the long-term retention of information, they increase the comprehension of text, and also the link between and among the different ideas and concepts (Hidayati et al., 2023). This meta-learning technique is effective in improving the students' cognitive processes as well as their long-term memory of facts (Mohaidat, 2018).

It is well known among the researchers that mind maps are effective meta-learning techniques for learning written material. The specific meta-learning technique can be used in a lot of ways. First, mind maps can be used as an effective note-taking method. Second, they can be used as a problem-solving technique as well as a prompt or even as a revision tool.

Finally, mind maps are an excellent tool for engaging students and making them involve in the learning process by enabling them to express their ideas and then encompass them on the mind map (Edwards & Cooper, 2010; Hariyadi et al., 2023). Mind maps have been shown to enhance students' motivation, engagement, imagination, and creativity (Hariyadi et al., 2023), while also contributing to improved academic performance, even among lower-achieving students (Jones et al., 2012; Mohaidat, 2018).

Apart from learning written material, the mind maps constitute a meta-learning technique that can be used effectively in the STEM (Science, Technology, Engineering, Mathematics) field, as it has been known among the researchers that it enables students to foster their critical thinking skills as well as their problem-solving skills and even improve their science literacy (Hariyadi et al., 2023).

Effective note-taking

It is a fact that note-taking is considered by educators to be a critical part of learning in formal classroom settings. The results from the previous research have shown that students who take more course notes during the lectures at school achieve higher grades. However, the way the notes must be taken or even their real effectiveness has been an open research topic, among the experts on the field. No one can deny that note-taking is totally personalized as a task. The latter means that note-taking inevitably depends on the individual differences of every student which makes its study more complicated (Stacy & Cain, 2015).

However, there is always the challenge, for students, to keep effective notes from the lecture. More precisely, it is very demanding for the students to record all the vital information and concepts in an accurate way. In order for students to keep accurate notes that represent all essentials points of the lecture, they need a lot of skills· cognitive skills, information processing skills, information encoding into notes format, sufficient working memory, critical thinking skills, active listening and writing skills (Salame & Thompson, 2020; Stacy & Cain, 2015). It is a fact that training students on how they can take systematic and effective notes can become very helpful for them in encoding and thus studying large amounts of learning content (Stacy & Cain, 2015).

Especially for encoding, it is important to mention that it refers to the procedure during which the information is translated, organized and stored for future use, in the form of notes. The encoding process is a process that has been studied thoroughly by the experts on the field. One point that many researchers have reached to is that students who used note-taking while attending a lecture and then studied their own notes had a better performance than students who did not use the note-taking technique during their attending the lecture, even when they were provided with the educator's notes of the lecture (Beck, 2014). So, it becomes clear that note-taking is a meta-learning technique which is beneficial for students and also fosters their performance (Beck, 2014; Salame & Thompson, 2020).

Technology, Artificial Intelligence (AI) and ChatGPT

The researchers, nowadays, have pointed out that the way students learn, as well as what they learn and, also, the skills required for them during the learning process, have changed dramatically and are even to be transformed radically in the years to come. More precisely, the technology is changing all the conditions of the learning process for students, as it has already come into the specific field. It is important to mention that, according to the experts, technology is able to provide students with new opportunities in order for them to enjoy transformative learning experiences, as well as more conscious, self-directed and self-motivated learning, as also mentioned in the introductory section of this article and in fact revolutionize the whole field of education (Drigas et al., 2023; Singh, 2023).

First of all, the access to information comes without limits for students nowadays, something that in turn comes with both advantages and disadvantages. From one side, the limitless access to information provides students with the opportunity to adjust their learning

to their personal pace of learning, their personal learning style and to align the learning material with their individual needs and specific learning goals. From the other side, the information that is available through technology can become overwhelming for students. It takes skills and concise strategies for students in order to harvest the opportunities of technology used in learning (Daniela, 2018; Drigas et al., 2023).

Moreover, the rise of AI has affected meta-learning techniques radically and vice versa. More analytically, neuroscience, through its mental models regarding the meta-learning techniques, offers unique insights to the AI community, while AI algorithms in turn offer neuroscience new tools to foster students' meta-learning skills (Wang, 2021). Also, large language models (LLMs) such as ChatGPT have given new perspectives in the students' learning process. Especially in mathematics, ChatGPT has been used for tasks involving logical and arithmetic reasoning, but not to a great extent so far (Taani & Alabidi, 2024).

No one can deny that mathematical problems are of crucial importance and also, they consist essential educational tools for the evaluation of the students' logical and problem-solving abilities. However, ChatGPT can assist students in automatically generating pre-university math questions and it is important to acknowledge that the model's performance depends greatly on both the instructional prompts given by its user and the mathematics' topic (Pham et al., 2024; Wardat et al., 2023). However, ChatGPT's performance has surpassed 80% accuracy in all primary fields of mathematics education (Taani & Alabidi, 2024).

It is also interesting that researchers during the past two years have pointed out that ChatGPT demonstrates potential for improving how students engage and understand material. Apart from that, it is important to highlight that chatbots, such as ChatGPT, are regarded as tools for fostering interactive e-learning environments, delivering immediate answers to common questions, and reducing teachers' burden of answering repetitive queries, as well as personalizing the learning material. In mathematics, ChatGPT could be used effectively in the flipped classroom setting of teaching (Taani & Alabidi, 2024).

Apart from the benefits that AI can bring to a lot of domains in the education field, it is important to state that there exist also concerns about its potential for misuse, particularly in relation to providing inappropriate or harmful safety-related information (Fugate et al., 2023). The ethical and regulatory challenges of chatbots, such as ChatGPT, especially regarding the dissemination of disinformation, are also highlighted by Glorin & Shaliet (2024). The integration of AI tools such as ChatGPT into educational contexts raises significant concerns regarding misinformation and ethics. One key issue is the generation of inaccurate or misleading information, often referred to as AI "hallucinations", which can negatively affect students' understanding and academic integrity (Yang et al., 2024). Additionally, ethical challenges related to data privacy, algorithmic bias, and the responsible use of student data highlight the need for carefully developed regulatory frameworks (Reiss, 2021).

Case study: Application in Mathematics. Resolution of the linear equation "2(3x–1) –2(2x–1) = 4"

In this section, we apply all the meta-learning techniques discussed in this paper as well as the AI's capabilities in crafting an application in mathematics and using it for a case study. More precisely, a first-year student of Greek upper secondary school (A Lyceum) was called to resolve a specific first-degree linear equation following specific steps in order for the meta-learning techniques to be implemented. The researcher and the student were present in the same physical location, using a personal computer with an internet connection. Under the guidance of the researcher, the student solved the equation in Microsoft Word, utilizing both the mindmup application and ChatGPT as supplementary tools. The entire procedure lasted approximately thirty minutes.

First of all, in accordance with the principles of priming, it was deemed essential to activate the student's prior knowledge before introducing the concept of first-degree linear equations and their solution methods. Specifically, the student first:

1) discussed simpler numeric balancing problems, such as “5 + x = 12, x a real number”, where the student was guided to recall the fundamental idea that an equation remains balanced when the same inverse operations are applied to both sides,
2) solved every day contextual problems, such as: "A number is doubled, and then 3 is added. The result is 11. What is the number?" which results in the formulation of a linear equation, in our example, 2x+3 = 11.
3) recalled the distributive property of multiplication over addition, for instance in case of 3(4x-2).

Secondly, the use of mind maps was proposed to facilitate the visual deconstruction and conceptual linking of the key elements within the mathematics topic under study. After encouraging the student to create a personal mind map in the mindmup application for the specific first-degree linear equation, ChatGPT was employed as a supplementary tool to facilitate further understanding and problem-solving. More precisely, ChatGPT was effectively prompted to reconstruct a visual mind map focused on the specific first-degree linear equation.

Regarding the effective note-taking meta-learning technique, throughout the entire learning process, the student was actively encouraged to take effective notes independently, which was divided into consecutive steps: identifying the linear equation, rewriting the equation isolating the unknown parameter “x” on one side of the equation (if applicable), performing all the necessary inverse operations which are applied to both sides in order to keep only “x” on the left side of the equation and, finally, solving and then checking the solution.

The entire step-by-step application described above was subsequently employed in the resolution of the linear equation “2(3x–1) –2(2x–1) = 4” and is presented below. In the following section, the application is presented in a general form, without reference to a specific equation, so that interested mathematics teachers may adapt and use it in their own real teaching contexts.

Resolution of the linear equation “2(3x–1) –2(2x–1) = 4”

Priming

Step 1: Solve the following equation: 5 + x = 12, x a real number.

x = 12 – 5

x = 7

Step 2: Solve the following problem, by identifying the correct first-degree linear equation:

“A number is doubled, and then 3 is added. The result is 11. What is the number?”

Let x be the requested number (variable).

2·x is the number when doubled.

2·x + 3 is the doubled number when 3 is added.

The result of 2·x + 3 is 11 which, in mathematics, means that it is equal to 11.

Thus, the first-degree linear equation which describes the given problem is:

2·x + 3 = 11 or simply 2x + 3 = 11.

Step 3: Use the distributive property of multiplication over addition for 3(4x-2).

3(4x – 2) = 3 · 4x – 3·2 = 12x – 6

Mind maps

Construct a mind map illustrating the resolution of the linear equation 2(3x–1) –2(2x–1) = 4, using the mindmup application (at https://app.mindmup.com).

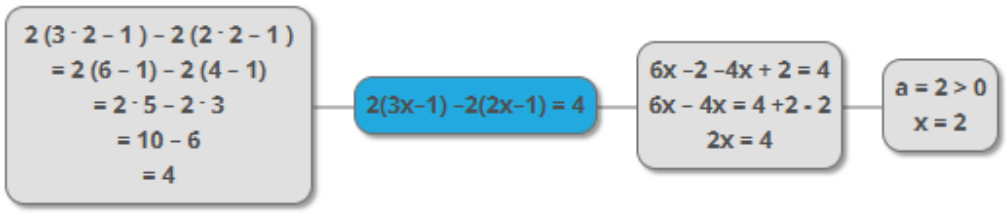

Figure 1: Mind map on the resolution of the linear equation 2(3x-1)-2(2x-1) = 4, using the mindmup application (at https://app.mindmup.com).

ChatGPT

Provide ChatGPT with the prompt: "Can you give me a visual mind map on the resolution of the first-degree linear equation 2(3x–1) –2(2x–1) = 4*?" and then paste its response.*

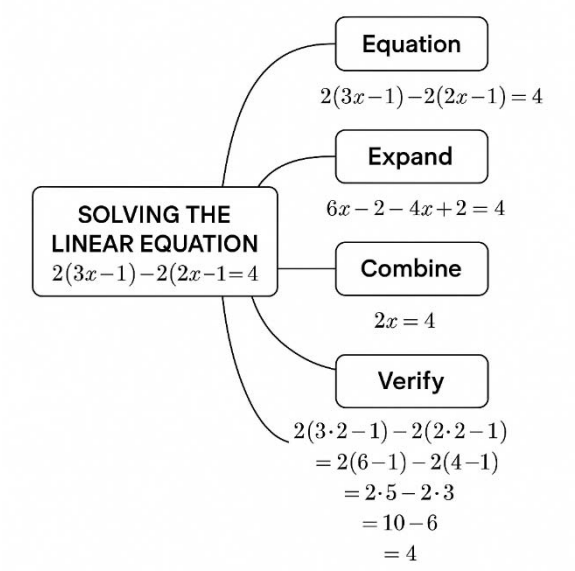

Figure 2: Mind map on the resolution of the linear equation 2(3x–1) –2(2x–1) = 4, using ChatGPT.

Effective note-taking

Step 1: Problem – Identify the equation:

2(3x–1)–2(2x–1) = 4

Step 2: Rewrite the equation (if applicable), with the goal to isolate "x" on one side of the equation.

2(3x–1)-2(2x–1) = 4

6x – 2 – 4x + 2 = 4

6x – 4x = 4 + 2 – 2

2x = 4

Step 3: Perform all the necessary inverse operations, which are applied to both sides of the equation, in order to keep only "x" on the left side of the equation.

$x = \frac{4}{2}$

Step 4: Solve the equation.

x = 2

Step 5: Check the solution.

2 (3 · 2 – 1) – 2 (2 · 2 – 1) = 2 (6 – 1) – 2 (4 – 1) = 2 · 5 – 2 · 3 = 10 – 6 = 4 ✓

The mathematics application on the resolution of first-degree equations

Priming

Step 1: Solve the following equation: ……, x a real number.

_____

_____

Step 2: Solve the following problem, by identifying the correct first-degree linear equation: .....

_____

_____

Mind maps

Construct a mind map on the resolution of the linear equation ……., using the mindmup application (at https://app.mindmup.com).

_____

_____

ChatGPT

Provide ChatGPT with the prompt: "*Can you give me a visual mind map on the resolution of the first-degree linear equation ……..?*" and then paste its response.

_____

_____

Effective notetaking

Step 1: Problem – Identify the equation:

_____

_____

Step 2: Rewrite the equation (if applicable), with the goal to isolate "x" on one side of the equation.

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Step 3: Perform all the necessary inverse operations, which are applied to both sides of the equation, in order to keep only "x" on the left side of the equation.

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_____

Step 4: Solve the equation.

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_____

Step 5: Check the solution.

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Conclusion

In this article, meta-learning techniques have been studied in terms of their significance on the way students learn and how they could foster their learning procedure enabling them to become self-directed lifelong learners. The processes by which the human mind acquires knowledge have been extensively studied in recent years and several mental models have been created based on neuroscience (Biggs, 1985; Jackson, 2004; Wang, 2021).

More precisely, in this article meta-learning techniques such as priming, mind maps and effective note-taking have been extensively studied. Priming is a meta-learning technique that links a student's existing knowledge of a subject to the new knowledge they are expected to gain in that domain. This is a technique which triggers the student's attention mechanism, catches the student's attention and enables the student to focus on the essential parts and achieve deep learning, while their cognition burden reduces. It is a fact that the student's prior knowledge on a subject is positively correlated to the knowledge gains on the same subject

and also to better learning performance. The priming meta-learning technique has been used in many areas, such as linguistics and mathematics, with important gains for the students, when used appropriately and on their advantage (Foster, 2021; Qin et al., 2021; Kumarage et al., 2024; Simonsmeier et al., 2021).

Mind maps is another meta-learning technique that has been studied in this article. The specific meta-learning technique gives students the opportunity to understand conceptually the new knowledge by creating a visual representation of the ideas and/or concepts as well as all the links between them, in a way that keeps them active, creative and engaged. Through a visual representation that resembles a tree, where the main concepts are placed in the main branches and then next levels as being the secondary branches, students understand the new learning material, build hierarchical relationships between its concepts, keep it in their long-term memory. In contemporary educational settings, students have access to a variety of digital tools and techniques to construct electronic mind maps· either by using chatbots e.g. ChatGPT or free online applications such as the mindmup application (at https://app.mindmup.com) [Abi-El-Mona & Adb-El-Khalick, 2008; Edwards & Cooper, 2010; Hariyadi et al., 2023; Jones et al., 2012; Mohaidat, 2018].

Effective note-taking is another effective meta-learning technique. Mind maps may also be considered a form of structured note-taking (Edwards & Cooper, 2010; Hariyadi et al., 2023). Note-taking constitutes a meta-learning technique that is considered crucial in formal educational environments, as it involves the real-time encoding of newly presented information by students. Empirical studies have found a positive correlation between effective note-taking and higher grades. However, the task of accurately capturing all critical information and conceptual content can be cognitively demanding for students. In order students to keep accurate notes that represent all essentials points of the lecture, they need a lot of skills· cognitive skills, information processing skills, information encoding into notes format, sufficient working memory, critical thinking skills, active listening and writing skills (Salame & Thompson, 2020; Stacy & Cain, 2015). Research findings indicate that students require explicit training to develop the skills necessary for effective note-taking during the learning process (Beck, 2014; Salame & Thompson, 2020).

Apart from the most essential meta-learning techniques that have been studied in this article, it is important to mention that technology and AI have transformed radically the students' whole learning process and revolutionized the whole field of education. The advent of advanced technologies and AI within the educational landscape has profoundly transformed pedagogical approaches, empowering students to engage in deep, transformative learning experiences. This paradigm shift supports the cultivation of heightened metacognitive awareness, fostering autonomous, self-regulated, and intrinsically motivated learners (Drigas et al., 2023; Singh, 2023). First of all, the access to information comes without limits for students nowadays, something that in turn simultaneously offers numerous opportunities and poses distinct challenges (Daniela, 2018; Drigas et al., 2023). Especially in mathematics, chatbots, such as ChatGPT, have been used for tasks involving logical and arithmetic reasoning, but not to a great extent so far. More precisely, ChatGPT can assist students by automatically generating pre-university math questions. However, it is important to note that the model's performance depends significantly on both the quality of the instructional prompts provided by the user and the specific mathematics topic. Nevertheless, its accuracy can exceed 80% under optimal conditions (Pham et al., 2024; Taani & Alabidi, 2024; Wardat et al., 2023). Lastly, chatbots such as ChatGPT, are regarded as tools for fostering interactive e-learning environments, delivering immediate answers to common questions, and reducing teachers' burden of answering repetitive queries, as well as personalizing the learning material. Within the context of mathematics education, ChatGPT has the potential to be employed as a supportive tool in flipped classroom settings, facilitating student-centered and self-paced learning (Taani & Alabidi, 2024).

Finally, the present study integrates the meta-learning techniques investigated, together with technological and AI tools, into an applied framework in mathematics education, specifically addressing the solution of first-degree equations. More precisely, the mathematics application was initially used for the case of the first-degree linear equation "2(3x–1) –2(2x–1) = 4". The specific application was employed in a case study involving a student from the Greek upper secondary education level (A Lyceum), who was tasked with solving the aforementioned first-degree linear equation. Throughout this application, all procedural steps were presented with conceptual clarity. Subsequently, the application has been made available in a generalized form, without restriction to a specific equation, allowing interested mathematics teachers to adapt and implement it within their own authentic teaching contexts. Although the mathematics topic addressed is relatively straightforward, the key objective is for interested mathematics teachers to grasp the application of meta-learning techniques and employ them in the instruction of more complex mathematical concepts.

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