Scientific Electronic Archives
Issue ID: Sci. Elec. Arch. Vol. 14 (10)
October 2021
DOI: http://dx.doi.org/10.36560/141020211442
Article link: https://sea.ufr.edu.br/SEA/article/view/1442

ISSN 2316-9281

STEAM education- Metacognition – Specific Learning Disabilities

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Abstract. Students with Specific Learning Disabilities, tend to have low academic performance because of the cognitive disorders and deficits of their working memory, as well as executing fuctions like these of processing - organizing and recalling information. Development of the Metacognitive skills, like those that presented by Drigas & Mitsea (2020), as 8 pillars of Metacognition, such as self-Awareness, self-Monitoring and Self-Regulation, helping these students recognize their weaknesses and introduce strategies and tactics will assist them to compensate their cognitive deficits, by becoming more flexible and adapt to any changes coming up, better. STEAM (Science, Technology, Engineering, Art, and Mathematics) education involves students in the education process, via a multifaceted and multi-sensory approach of to develop Meta-cognitive Skills, control the way they learn while building up the necessary knowledge, in order to secure equal academic and career opportunities. As a result, their independence and self-esteem being boosted preparing them to come up against 21st century challenges.
Keywords: STEM education, Problem-based learning, Science education, Specific learning disabilities, Metacognition, 21st century skills, Problem solving

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Introduction

By metacognition we mean the knowledge that a person possesses in regard to his cognitive abilities, as well as, self-regulation of his behaviors, in an aim to deal with difficulties (Pappas, Drigas, & Polychroni, 2018). Metacognition contains consciousness and self-awareness, abilities that help individuals to perceive both their inner and outside world (Drigas & Karyotaki, 2019). According to Sternberg (2003), awareness of cognitive abilities, likewise the self-regulation of a person's cognitive processes, help them function autonomously in terms of time and the way being activated. This way, somebody can control the way one learns, improve the progress and evaluate the level of understanding, via adapting and applying the gained knowledge to new arising problems.

Students with specific learning disabilities despite of their normal intelligence, facing basic cognitive deficits due to mainly dysfunction of working memory. This causes difficulty in the organization of information received, such as remembering and using them. As a result, impairment in thought, memory, perception and learning occurs (Flynn, 2014). Such students performing lower academically, whereas facing difficulties in dealing effectively with everyday problems (Rogers, Hodge, & Counts, 2020). However, students with developed metacognition and self-awareness can develop memorization mechanisms and strategies, helping them to overcome their deficits (Trainin & Swanson, 2005; Pappas, Drigas, & Polychroni, 2018; Socratous & Ioannou, 2020).

There has lately been emphasis on teaching methods and learning tools that help students develop metacognitive skills, in order to achieve higher level of skills, as for example critical thinking and complex problem solving, required in the 21st century. One of the teaching methods, based on real problem solving, while involving them in the learning progress via an experiential way, is this of STEM or STEAM learning. Via the integration of science, technology, engineering, mathematics and art, this method manages to develop student's problem-solving skills, using activities inspired by everyday

life, at the same time proving motivation, flexibility, and ways of expression, will develop creativity.

The purpose of this literature review is to explore the importance of developing metacognition skills, according to the 8 pillars of metacognition, through STEAM learning. This will result to students with specific learning disabilities, developing 21st century skills, which will help them to compensate their cognitive deficits and eventually solve the problems effectively.

Development

STEAM Education

STEM acronym, consists an abbreviation of the words Science, Technology, Engineering and Mathematics, whereas Art is often added to the fields involved, so that STEAM is formed. The method conformed of an interdisciplinary learning approach that bridges education with sciences, in an aim to solve real everyday life problems (Kefalis & Drigas, 2019). According to Bruner's Discovery Learning theory, student's active role being emphasized (Roblyer, 2006). In addition, they are challenged to face new conditions and problems, by acquiring adaptation skills (Mutakinati, Anwari, & Kumano, 2018).

STEM learning challenges students, so that they develop this knowledge and skills, as for example critical and creating thinking or collaboration qualifications, vital for their real life (Cem Kagar, 2019). Importance of STEM learning emphasized from a Global perspective, as student's expert in this method, being prepared to become Leaders of the Global Economy. Furthermore, and from a personal perspective, this can be a valuable tool, which improves the quality of student's daily life, especially those with learning disabilities, as it consists of real situations and daily life problems, giving students more opportunities in the job market (Hwang & Taylor, 2016).

STEAM is designed to enable students, acquire knowledge in a holistic way developing 21st century metacognitive skills, such as critical thinking, creativity, flexibility, adaptation, collaboration and problem solving ones, so that they gain a competitive advantage in the job market (Anwari, et al., 2015).This approach of learning, based on the methods of project planning, research and problem solving, which improve students motivation, interest and effectiveness, whereas actively involving them in the learning progress as well as the collaboration enhancement (Slekiene & Lamanauskas, 2020).

Teaching and learning STEAM fields, considered to be valuable for the improvement of the student's daily life quality, especially those with specific learning disabilities. This achieved, via the offer of flexible programs, do not require students to provide a standard answer, within a certain timeframe, helping them focus more on creativity, promoting at the same time, their self-expression. Along with the various arts integration, students manage to simplify abstract concepts, otherwise difficult to understand, due to their cognitive deficits (Zayyad, 2019; Hwang & Taylor, 2016).

According to Basham and Marino (2013), foundation of STEAM learning, lie in applied Engineering and should be implemented to the Universal Design for Learning (UDL) curriculum, using multiple tools of representation, expression and action, so that students with disabilities included. In a STEAM environment this can be done through graphic representations, simulations and audiovisual materials.

Problem -Solving

The application of STEAM learning requires the use of appropriate teaching methods, such as the discovery method, the project method and the problem solving (Erdogan & Stuessyb, 2015). All these teaching methodologies presuppose the existence of a problem, which should be solved in the most effective way.

According to Woolfolk (2005) problem solving is: "the development of new answers that go beyond the simple application of the rules we have learned before to achieve a goal". Problem solving involved in all kinds of activities of our daily, academic and professional life. It requires the search of a rule, plan or strategy, a goal to be achieved (Kafadar, 2012). In order problems to be solved, one must go through four phases, according to the model of Polya, 1957, including the a) recognition and understanding of it, b) connection of individual elements, c) implementation of a plan – strategy and the d) evaluation of the solution - discussion (Robertson, 2017).

According to Sternberg (2003) problem solving "consists of its ability to face and overcome obstacles, hindering the answer to a question or the achievement of a goal", while describing the stages of the problem-solving cycle according to the Figure 1.

This way, when a problem arises, we must go through various phases to make a decision, so that the given situation changes to the desired one. Decision making, refers to the choice of action course, one should follow in order solve the problem. If the choice is correct, we anticipate seeing the solution to the problem (Sternberg, 2003).

The benefits of problem-based learning, as cited by Slekiene & Lamanauskas (2020), consist of the cognitive flexibility, the development of effective problem-solving skills, collaborative, and lifelong learning skills, as well as the motivation enrichment.

According to Drigas & Karyotaki, (2019) there has been a two-way relationship, between executive functions and problem-solving skills, given the fact both based on self-control ability. Effective problem solving requires metacognitive skills, so that individuals can stay on top of their performance, evaluate the possible solution, while recalling personal experiences via similar situations (Pappas, Drigas, & Polychroni, 2018). Students with developed metacognitive skills, tend to be more

effective when it comes to problem solving. They possess the way for more effective learning better, applying at the same time strategies, aiming to help them overcome obstacles, via the regulation of their own knowledge. Metacognition education process, help students improve the mathematical problems solution (Socratous & Ioannou, 2020).

Figure 1. "The problem-solving cycle", (Sternberg, 2003).

Metacognition

Metacognition was originally defined by Flavell (1977) as "knowledge for knowledge" or "thought for thought" (Bogdanović, Obadović, & Cvjetićanin, 2015; Efklides, 2009). Since then, the concept of metacognition has been grated different meanings, although most researchers recognize that this refers to the monitoring and control of thought. Hennessey (1999) defined metacognition as "the awareness of thought and the consciousness of perceptions content, the active control and regulation of one's cognitive processes, in relation to the further learning. In addition, the application of knowledge and experiences, so that the methods used to solve various problems to be in order" (Bogdanović, Obadović, & Cvjetićanin, 2015).

Metacognition is the process of self-knowledge and self-evaluation. It allows people control the way they learn (Velasquez & Cababaro Bueno, 2019). It refers to the ability of self-observation and self-control of the individual's own perceptual and cognitive processes, skills playing a crucial role in learning process and memory (Coutinho, Redford, & Church, 2015). In addition, allows students to solve new problems, by recovering and developing strategies they have gained from past experiences (Bogdanović, Obadović, & Cvjetićanin, 2015).

Metacognition therefore refers to a set of "self-regulating" functions and skills that allow the individual to improve many areas of his life (Drigas, Mitsea, & Mantas, 2021), while involving self-observation, self-regulation, reflection, self-evaluation and the ability to modify and adapt cognitive and emotional functions. For this reason, the executive functions consist of cognitive, metacognitive and emotional structures, amid the continuous or selective attention of individuals, the acquisition of inhibition control and the emotional regulation (Drigas & Karyotaki, 2019).

8 Pillars of Metacognition

Drigas & Mitsea (2020) presented the 8 pillars of metacognition, which are completely interdependent, while having a degree of autonomy. Any improvement or malfunction in each pillar, affects the metacognitive mechanism. The 8 pillars, as they mention, are the following:

1. Theoretical knowledge of cognitive functions. It refers to the knowledge that person has, regarding one's functions and abilities. It consists the first basic step for the development of metacognition through which, someone is able to monitor, regulate and adapt his/her cognitive mechanism.
2. Functionality limitations of cognitive processes. Human cognitive abilities, if not exercised systematically, are limited. A person must practically

know through the experience gained, the functionality of his/her cognitive abilities, in order to realize the limitations that exist.
3. Self-monitoring and Internal attention of cognitive functions through self-observation. Self-monitoring is an executive process, which allows conscious internal monitoring of human's thoughts and actions.
4. Self-regulation of our physical, cognitive and emotional functions through monitoring and control processes. It is a mechanism that allows us, to regulate our behaviors and emotions, achieving "peace of mind", as typically reported by Drigas & Mitsea (2020).
5. Adapting our physical, emotional and cognitive functions to perform each task. Adaptability is considered a necessary skill of the 21st century, whereas without it, there can be no metacognition. Someone who has developed adaptability, has emotional and behavioral flexibility and is able to become innovative and creative by adapting to new data, dealing with new complex problems that may arise.
6. Identification of the external and internal objects, their relationships, correlations, situations and functions. It is a metacognitive skill, through which a person is able to realize, perceive and understand the objects, internally and externally, as well as relationships and correlations. At this point acknowledgment of a person's own mistakes is possible.
7. Differences between what is functional or not. Discrimination helps information filtering, in an aim to make the right and effective choice. Recognition along with discriminationn, are the two aspects of remembrance due to the fact that they work together to conclude what is right and what is wrong.
8. Mnemosyne. Consists of the highest level, one able to remember the true holistic self and identity.

Every higher level is equally a state of self-awareness. It is reported that metacognitive development and intelligence, are proportional, whereas any negative or positive change, affect human's intelligence by degrading or developing it accordingly.

21st century skills

The 10 most important skills of the 21st century, necessary for the labor market, as mentioned in a report of the World Economic Forum 2016, according to Phang, Yusof, Abd Aziz & Nawi (2017) are:

- Complex Problem Solving
- Critical Thinking
- Creativity
- Cooperation
- Emotional Intelligence
- Decision Making
- Cognitive Flexibility

Drigas, Mitsea & Mantas (2021) presented the soft skills of the 21st century, required to develop the above skills, as per below:

- Self- Awareness
- Self- Monitoring
- Self- Regulation
- Regulation
- Recognition
- Discrimination
- Mnemosyne
- Consciousness

It seems that these soft skills are in line, with the 8 pillars of metacognition. By training student's metacognitive skills from early school age to early adolescence, students can improve their problem-solving strategies, self-regulation and overall math performance (Pappas, Drigas, & Polychroni, 2018).

Learning Difficulties and Metacognition

Students with learning disabilities, able to offset their deficits by developing metacognitive strategies, in order to consciously control their actions, which is difficult to be done automatically (Trainin & Swanson, 2005). Students with developed metacognitive skills, are more effective in problem solving. They know better the way for more efficient learning and can implement strategies to overcome obstacles by regulating their own knowledge (Pappas, Drigas, & Polychroni, 2018; Socratous & Ioannou, 2020). Thus, through the use of metacognitive strategies, students learn to regulate their learning behavior, thus improving their academic performance.

Trainin & Swanson (2005), in an effort to draft the deficient cognitive processes in students with learning disabilities, which advanced metacognition can counterbalance, conducted a research and examined whether successful students with learning disabilities, relied on metacognitive strategies amid processing difficulties. The study involved 40 students (20 with a diagnosis of learning disabilities and 20 without) from 4 universities in South Carolina. Both groups underwent tests, to measure and compare verbal ability, working memory through information retrieval, information processing speed, visual recognition, semantic processing, spatial reasoning, as long as word recognition and comprehension. Results showed that students with learning disabilities characterized by deficits in reading, processing speed, semantic processing and working memory. The results of student's performance and achievements, underlined that those with learning disabilities and developed metacognitive strategies, had equally high average performance, to those without. Students' average grade and achievement seemed to be related to the increased metacognitive learning strategies they had developed.

Mogonea (2013) explored methods and tools, developing metacognitive skills in children with learning disabilities. These were based on the constructivist approaches, emphasizing to the importance that students construct themselves, the knowledge they gain. The research involved 1100 high school students with learning disabilities. Students asked to complete assignments based on experimentation and research. The results highlighted the importance of metacognition development, so that school performance improves.

Bogdanović, Obadović & Cvjetićanin (2015) conducted a research, in order to investigate the correlation between the level of metacognition and the performance of students in physics. The survey was conducted between 746 students of 15 years old, in the city of Novi Sad, in the Republic of Serbia. Analysis of the results showed that students with higher literacy, performed better in physics test, highlighting its importance on the support of a more efficient learning process. In addition, this can be a success predictor, in the scientific content learning process. This research emphasizes to the need that teachers, help students acquire the habit of checking the understanding and approach of their tasks, aiming to develop metacognitive knowledge and skills, while teaching them. Students with poor reading skills, get benefit from metacognitive education, improving their metacognitive and cognitive performance.

Developing Metacognition through STEAM

Through the application of STEAM education, students seem to develop 21st century skills by improving their metacognition. Various studies have proved the effectiveness of STEAM, in terms of developing metacognitive computational thinking skills, in students of all levels, with positive results in learning and in the development of skills of the 21st century.

Venville, Rennie, & Wallace (2004) during a study targeting high school students aged 13-14, which took place in Western Australia, explored the way they were using knowledge, to make key decisions, in regards to building a solar boat, via concepts and principles usage, which had been taught in previous courses, through the fields of STEM. Results showed that the academically talented students, focus of this study, used several sources of knowledge, from STEM files, such as scientific one, in contrast with other students and adults, resulting to key decisions that significantly influenced the outcome. In addition, students were helped, so that they identify the theoretical background, as a source of knowledge, in practice. Finally, students' decision-making ability, seemed to be enhanced.

Charyton & Merrill (2009) applied a design engineering course to 61 first-year engineering students, at University in the western United States, which included design activities with ultimate goal the designing a functional roller coaster. The learning outcomes, resulted to students acquiring design skills, necessary for engineering.

Pinto-Llorente, Casillas-Martín, Cabezas-Martin, & Garcia (2016) in a 52 students (9-10 years old) survey, conducted between 2015-16 in Salamanca, explored the seconds' perception of the Lego Education WeDo software use on the natural sciences, promoting computational thinking. Students designed and programmed a mechanical spinner, through STEM learning, using Lego WeDo. Students showed great enthusiasm about this project, considering it as the perfect way of learning, motivating them to desire learn more about science. Results demonstrated the capabilities of Lego Education WeDo software, as a useful tool in STEM learning, enhancing computational thinking that engages students in programming and problem solving.

Corlu & Aydin (2016) evaluated the results of implementing a STEM-based course, aimed at improving 21st century skills, involving engineering and mathematics to 125 first year scientific fields students, of an Istanbul. They examined the adequacy of students adapting to the knowledge of physics and mathematics, amid the investigation of predefined research questions, with the use of computer. Results showed that students strengthened their thinking skills, while understood better the relationships between concepts, to realize the importance of the laws of physics and mathematics, in the explanation of cause and effect.

Phang, Yusof, Abd Aziz, & Nawi (2017) conducted research that implemented collaborative problem-based learning, in STEM training schools. In the program participated 65 students, working in groups of 3-4. Research has shown that collaborative learning, based on STEM problem-solving, can successfully secure an active, complete and constructive learning process, via the development of 21st century skills.

Mutakinati, Anwari, & Kumano (2018) concluded to similar results in a 2017 Japanese study, based on 160 first graders, when explorred how STEM learning can develop students' thinking ability, using Project Based Learning. The course consisted of 6 lessons, concerning the solution of water purification problem. Students were asked to design ways and products for the wastewater management. Students came up with a technological solution, using the knowledge of biology, chemistry, physics and mathematics. It was therefore found that through STEM training, students developed critical thinking, solving the problems assigned to them.

Plasman & Gottfried (2018) examined the mechanisms, emerging through applied STEM courses and their role in helping students with learning difficulties, graduate from high school to carry on with college, whereas found that those with learning difficulties attended STEM courses, can significantly increase their educational results. Research showed that the general student population benefited as well from applied STEM courses implementation, the benefits of which, were greater for those students with learning disabilities.

English (2018), conducted research to identify, monitor and evaluate student learning, while focusing on design, inquiry processes, reasoning, reproductive skills and STEM-based conceptual development. The four-year study incorporated the four STEM disciplines with an emphasis on design. The research involved 34 students between the 3rd and the 6th grade. The Fancy Feet activities, as tend to be called, included activities requiring students explore first their shoe numbers by measuring their feet, as well as the sizes and characteristics of their

shoes, to finally experiment with the materials built, so that they determine their properties. Following to exploring the role of shoe design, they designed and created their own pair of shoes. Research highlighted the last element of the activity, the design and construction of students' shoes. Students appeared to use design strategies, sketching their shoe designs, via testing, redesigning and improving them, to manage develop their own design goals and limitations.

Slekiene & Lamanauskas (2020) analyzed in high school students the use of STEAM program "Knowledge of Energy and Thermal Processes in Nature", so that they investigate the effectiveness of experimental practices in science teaching. In the research participated 70 high school students and the program was based on STEAM learning while using research (Inquiry Based Learning). Students were asked to perform 5 experimental projects lasting two hours each, aiming to formulate a research hypothesis and make measurements, calculations, data analysis, formulate conclusions and check the correctness of the hypothesis, to generalize finally their findings. Students acquired skills in designing and performing an experiment, formulating a hypothesis, analyzing and explaining results and drawing conclusions, whereas seemed to develop communication skills too. Furthermore, they acquired practical skills, so that work performs properly and safe, using the appropriate devices and tools.

Socratous & Ioannou (2020) investigated the value of ER-Educational Robotics in promoting students' metacognitive thinking in STEM learning. The 2 months study involved 21 public school students in Cyprus, among which two children with special educational needs could be found. Students were asked to program a robot and solve various problems according to the instructions given to them, through STEM-based problem-solving learning, with the use of the EV3 educational robotics tool. Results showed a statistically significant skills that contribute to the metacognitive regulation of knowledge improvement, such as the design, monitoring and debugging strategies, using educational robotics. In addition, the ability of students to monitor their own learning seemed to be enhanced. Finally, there was a significant improvement in problem-solving skills, documented through the STEM interdisciplinary approach of the educational robotics activities.

Conclusion

Students with specific learning disabilities present cognitive deficits, which are mainly caused, by the dysfunctions of the executive functions of working memory, such as coding, organization, processing and retrieval of information. However, developed metacognition, can help these students improve further the metacognitive strategies and skills through which they will be able to monitor, control and evaluate for themselves, the way they are learning, finally leading them to better academic performance. These skills are referred as the skills of the 21st century and seemed to be in complete harmony with the 8 pillars of metacognition, such as self-awareness, self-monitoring, self-regulation, adaptation, recognition, discrimination and consciousness, At the same time, they promote critical thinking, creativity and finally innovation, through problem solving and the STEAM method. Students hereby asked to identify and understand a problem, in order to connect the individual elements, design and evaluate the effectiveness of a solution. Research investigating the effectiveness of STEAM learning in metacognitive skills development, strategies and a high level of competences (i.e creativity and critical ability) in students with specific learning disabilities are limited and therefore would be of great interest, further one to be actualized in this group of children.

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