RESEARCH ARTICLE

STEM integrated education and multimodal educational material

Cecilia Kikilia Tsoukala

Department of Early Childhood Education, University of Thessaly, Volos, Greece

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Correspondence to: Cecilia Kikilia Tsoukala, Department of Early Childhood Education, University of Thessaly, Volos, Greece; Email: kitsouka@uth.gr

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Abstract: The present research aims to underline the role of multimodal educational material in STEM Integrated early childhood education. Through social semiotics assumption that meaning arises in action and interaction, we argue that robotics, digital media, haptic materials, toys, books, tablets, actions, and artifacts have an active and dynamic role in multimodal learning and construct meaning in young children's STEM educational process. The literature review has revealed a research gap concerning combined multimodal aspects in STEM concepts for young children. We adopted a mixed-method collective case study design based on four case studies in which children interact with multimodal STEM educational material. Due to the principles for effective STEM teaching and the perspectives of integrated STEM education, our findings illustrate that MmEM in STEM concepts, through play-based, model-based, inquiry-based teaching practices (among other open-ended), may provide to children multimodal learning environments, engage them in authentic and meaningful learning, promote teamwork, communication and social skills, challenge and motivate them to make meaning of their learning.

Keywords: integrated STEM education, early childhood, educational material, multimodality

1 Introduction

In the 21st century, it is absolutely clear that Science has a leading role. The pace of scientific discovery is extremely swift. Scientific achievements and technological innovations occur daily and change the way we view the world and perceive our environment as we face the benefits and challenges of both globalization and a knowledge-based economy.

One possible way to deal with most of the ethical, technological, environmental, and social issues that arise seems to be the critical consideration of Science achievements through developing a more multi-literate society. Science, Technology, Engineering, and Mathematics (STEM) create and provide us with the lens to view the future in a more scientific literate way. In the field of educational research, STEM education has accumulated much attention (Hatisaru et al., 2019). The interdisciplinary nature of the world we live and work, demands a broadening of STEM education and research (Hoachlander, 2014). The integration of science, technology, engineering, and mathematics contextualizing teaching in real-world issues, and could make the disciplinary practices more relevant to students and teachers (Takeuchi et al., 2021). Integrated STEM education promotes teaching the four disciplines as one unit, as a coherent entity like it exists in real life (Breiner et al., 2012). The increased interest in STEM education has resulted in recent reconceptualization of what future STEM knowledge users need to know and how they should learn (Hwang & Taylor, 2016). The learning environment has been identified as a main contributor to successful STEM teaching (Maltese & Tai, 2010, Hatisaru et al., 2019). Integration is an essential characteristic of a learning environment if it is to be called STEM (Glancy & Moore, 2013), especially when STEM education is related to early childhood.

Early childhood is the natural starting point for introducing the STEM cognitive fields and children's engagement in related learning activities. Preschool and early-primary age is a significant period for children to discover the world. It is a developmental stage described by intense desire and spontaneous interest in acquiring knowledge (Helm & Katz, 2016). Children internalize and elaborate their personal experiences of the world around them, from the first years of their lives, interacting with the environment around them (Christidou, 2008). Acquiring children with opportunities to see, touch, and feel the learning in practice, within multiple embodiment ways, they can remember what they have learned, understand concepts on their own and build or enrich their knowledge. Early years education, as the first organized educational setting, is the learning environment where children's prior knowledge, experienced mental representations, perceptions, initial alternative ideas and interpretations can be expanded, modified, evolved, transformed in the direction of scientifically accepted ideas (Christidou, 2008; Kalogiannakis, 2018).

The importance of starting teaching in STEM cognitive areas and contexts during early childhood is apprehended and research suggests that the earlier children are introduced to STEM cognitive fields and engage in related learning activities (especially in a hands-on 'experiential way'), the more likely it is that students will develop positive feelings about science, technology, engineering and mathematics (Sanders, 2009). STEM education, if approached correctly, can provide opportunities for teachers to engage children in activities that leverage their interests, experiences and prior knowledge (Campbell et al., 2018). At the same time such experiences enhance children's appreciation of science and its value in everyday life (Fleer et al., 2006). STEM learning experiences provide students opportunities to apply the knowledge and skills they have already learnt or are currently learning. STEM education and Educational Robotics appear to support (Papadakis, 2021; Psycharis, 2018) and prepare students for the 21st century and 4th IR requirements. STEM and Educational Robotics are increasingly considered as the newest trends in education (Zygouris et al., 2017), offering real practical experiences to the students, while hands-on robotic activities and tasks -due to their play aspect- are fun and attractive for them (Atmatzidou et al., 2008; Karakose et al., 2021). The adoption of digital technologies in early childhood settings attracts the attention of an increasing number of researchers and scholars throughout the globe. Despite the proliferation of investigations focusing on learning through digital technologies in preschool and early primary education, there are fields of knowledge in which the impact of digital technologies has yet to be explored (Dorouka et al., 2021).

John Dewey has argued long before (1938) that the types of experiences that support future learning are those engaging students in a community of citizen learners and encourage them to think creatively and independently. The ideas of multidisciplinary problem solving, teamwork and collaboration, connecting learning to personal experience, multiple embodiments, and representational fluency provide the theoretical foundations for effective STEM learning environments (Glancy & Moore, 2013). When talking about and learning STEM content, future meaning makers are involved with multimodal actions. STEM teachers in every educational level need to draw upon multiple teaching approaches, and especially experiential and open-ended methods such as science inquiry, engineering design, project-based learning, and problem-based learning (Honey et al., 2014; Vasquez et al., 2013). Utilization of appropriate multimodal educational material in learning activities and environments to several teaching methods is appraised essential and therefore we consider that its role to the learning process and understanding of STEM contexts needs further research.

2 Theoretical Framework

Technology has changed tremendously in the last ten years (Lin & Hwang, 2018). The increasing emergence of smart mobile devices has driven numerous individuals to consider that the new software applications (mobile applications – apps) could be an excellent tool to provide instructional content to preschool and primary school-age children, provided that they are appropriately designed and age-suitable (Alade et al., 2016; Ampartzaki et al., 2021). Children's technological skills seem to develop from a very young age, mainly in the home context, by observing and mirroring parents' and older siblings' digital behaviors (Chaudron et al., 2018; Vaiopoulou et al., 2021).

On the other hand STEM Education has received a great deal of attention in the field of educational research (Takeuchi et al., 2021), and there is no doubt that the educational models and ideas presented under the STEM label have had a significant impact on thinking, discussion, and practice in schools worldwide (Mc Comas & Burgin, 2020). In the literature (Texley & Ruud, 2018; Tsupros et al., 2009), there is a variety of *STEM* which is an abbreviation for *Science*, *Technology*, *Engineering*, and *Mathematics* and *STEM Education* definition, and refers to teaching and learning in the fields of the above derivatives (Chatzopoulos et al., 2021). Moreover, STEM is used as a generic label for any educational program or practice, policy, or action involving one or more disciplines (Gonzalez & Kuenzi, 2012). Bybee (2013) points out that STEM education is different from other educational approaches in three key areas, as it aims to meet: (a) the challenges of global economic issues; (b) tackle global environmental and technological problems; (c) gather the knowledge required to improve the job-related skills required in the 21st century.

Science, Technology, Engineering, and Mathematics, as distinct disciplines, have different epistemological foundations for producing knowledge. However, a recent international trend in education is integrating these fields as a new synthetic approach to teaching and learning

(Hatisaru et al., 2019). Opinions about the existence of borders between the four cognitive areas or their integration, the ways and the degree of integration that occurs vary, and still, the findings are not yet clear. (Li et al., 2020). Academic research about STEM approaches becomes complicated as terms with very subtle differences enter the discussion. Terms, such as (a) "disciplinary", (b) "multidisciplinary", (c) "interdisciplinary", (d) "transdisciplinary" STEM education are under consideration (Drake, 2007; Takeuchi et al, 2021). These approaches include from the one-dimensional perspective: (a) where basic concepts and skills are taught separately in each discipline but also the multi-thematic perspective; (b) where concepts of cognitive areas are inherent in a common theme, to the interdisciplinary perspective; (c) the introduction of closely linked concepts and skills from two or more disciplines to deepen understanding and skills, and finally the most advanced interdisciplinary; (d) perspective on the adoption of an approach where knowledge and skills from two or more disciplines are applied to real problems and projects in order to shape the overall learning experience (Drake, 2007; Takeuchi et al., 2021).

2.1 Integrated STEM Education

The interdisciplinary perspective found in the term "Integrated STEM education" attaches great importance to the interaction between cognitive subjects. STEM education is perceived not as a curriculum of individual disciplines, but more as a way of organizing teaching by weaving the four disciplines together, in a common goal, as a single idea, in ways that teach them as a unit, as a coherent entity (Breiner et al., 2012) that attract and help students acquire 21st-century skills (Morrison & Raymond, 2009). Glancy & Moore (2013) promoted an integrated approach to STEM learning. In their vision of STEM learning environments, STEM practices use knowledge from different disciplines and problems are completed combining practices from two or more STEM disciplines (e.g., scientific experimentation and engineering design). STEM problems are interdisciplinary and grounded in the real world in that they are experienced by the community. In effective STEM learning environments students can relate to and engage with problems and make sense of them based on their own experiences.

Defining integrated STEM opens a new level of complexity from educational perspectives due to its conceptualization across a diverse range of international contexts and the different ways that individual disciplines are represented through integration (English, 2016). A consensus regarding the interdisciplinary STEM approach around the following findings is being noticed (Moore & Smith, 2014):

(1) Real environment issues engage students in authentic and meaningful learning (Bryan et al., 2015; Burrows et al., 2017; Kelley & Knowles, 2016; Sanders, 2009);

(2) Pedagogical practices are focused on students, including exploratory learning and design thinking (Bryan et al., 2015; Kelley & Knowles, 2016);

(3) The development of 21st-century skills such as creativity, collaboration, communication, and critical thinking are supported (Bryan et al., 2015; Honey et al., 2014);

(4) The connections between STEM branches are clear to students (Bryan et al., 2015; Burrows et al., 2017; Ellis, 2020; English, 2016; Honey et al., 2014; Kelley & Knowles, 2016).

Therefore, high-quality STEM interdisciplinary learning experiences should involve students in design challenges that allow them to learn from failure and participate in their redesign. Furthermore, they should use relevant frameworks for STEM challenges that are familiar to them, require learning with appropriate STEM content and material, involve students in content using student-centered pedagogical practices, promote communication skills and teamwork. Vasquez et al. (2013) proposed five guiding principles for effective STEM teaching: (1) focus on interdisciplinarity, (2) establishing relevance between disciplines, (3) emphasis on 21st-century learning skills, (4) activating / challenging students and (5) providing multimodal learning environments to students.

In the current study, the perspective we adopt argues that Science, Technology, Engineering, and Mathematics are integrated into an interdisciplinary field that creates complex learning environments in the educational process and involves students in authentic multimodal learning experiences (English, 2016; Hatisaru, et al., 2019; Honey, et al., 2014; Johnson et al., 2015; Kelley & Knowles, 2016; Li, 2018a; Sanders, 2009; Vasquez et al., 2013).

2.2 STEM in early childhood

Technology can be appropriate to child development if it corresponds to their age, needs, interests, and socio-cultural context (Tzagkaraki et al., 2021). The digital culture in which young children live today includes the use of electronic tablets, e-readers, and smartphones that allow them to play and interact with myriad software and multiple forms of print and digital text (Rogowsky et al., 2018). Even though the introduction of technology in the context of early childhood education has been a point of debate and controversy, there is now a general agreement that it is considerable for young children to have some access which may aid them to familiarise themselves with a range of software (Marsh et al., 2017). Schools can also significantly influence the acquisition of digital competencies when integrating digital technology as active learning tools. However, which are the main factors influencing the adoption of digital technology devices as an instructional tool in early childhood education? According to Papadakis et al. (2021), a key determinant for the future adoption of new interactive technology in the learning procedure is the experience in this type of technology.

STEM approach is connected to almost everything in our society, and it is helpful for children to see and understand this connection from an early age. It is essential to provide students with opportunities to understand society's problems through rich and dynamic interdisciplinary STEM experiences (Moore & Smith, 2014). Integrated STEM Education agrees with the interdisciplinary nature of the world in which children will grow up and can help them learn more deeply, become better problem solvers, innovators, inventors, self-reliant, logical thinkers, and technologically literate (Morrison, 2006).

Early childhood is the starting point where children construct perceptions and representations, often complex and quite generalized, based on their interaction with the natural, social and cultural environment in which are developing (Christidou, 2008). Research suggests that the earlier children are introduced to the STEM cognitive fields and engage in related learning activities, the more likely they will develop positive feelings about STEM domains (Sanders, 2009). Campbell et al. (2018) argue that, STEM education can provide opportunities for teachers to engage children in activities connected to their knowledge, interests and experiences. Robotics, Mathematics, STEM, and Literacy are the fields found to provide most opportunities in early childhood, especially promising to cultivate interests early in technology literacy (Papadakis et al., 2019).

In addition, young children could learn STEM concepts through new digital technologies due to haptic feedback on participants' ability to learn. "Haptic" is related to manual interactions with environments and refers to exploring the environment (Han & Black, 2011). The aforementioned interactions can be associated with several topics, such as the reaction forces, the tactile stimuli, the temperature, and the motion. Haptic feedback is constructive for this type of learning since it supports more "real" experiences and a learning environment with more stimuli (Han & Black, 2011). In such a context, Alade et al. (2016) underlined that young children could learn science and mathematical concepts when provided to them in multiple ways. Another research conducted by Huber et al. (2016) confirmed that interactive technologies provide preschool-age children with remarkable gains on STEM learning and, through appropriate software applications, they can learn how to deal with problems.

Teaching of Science concepts often involves difficulties for early childhood children. Research argues that multi-sensory/multimodal approach to scientific knowledge leads to more effective learning, as it stimulates children's interest, enhances understanding and fosters the development of scientific thinking skills and therefore scientific literacy (Ainsworth, 1999; Brooks, 2009; DeJong & van Joolingen, 2008; Papandreou & Terzi, 2011; Smyrnaioy & Weil-Barais, 2004; Yore & Treagust, 2006). Especially in concepts which involve complex and inaccessible processes, it is argued that they can be made more understandable through multiple visual representations and through their multimodal approach (Posner et al., 1982).

The mathematical skills developed at an early age, such as number sense and ordinality, are strong predictors of later academic success (Hunting et al., 2012). Research has shown that early childhood environments are rich in opportunities for children to be involved in STEM, and sciences can be naturally integrated with mathematics and/or technologies through the activity of the child (Campbell et al., 2018). Additionally, a lot of studies (Bers, 2017, 2018; Chen et al., 2017; Leonard et al., 2016) have shown that while participating in construction-based robotics activities, young children may be interested not only in many aspects of robotics but also in learning many programming and computational thinking features (Poultsakis et al., 2021). More particularly, the use of robotics affects positively the development of skills related to STEM learning, such as measurement with non-standard units (Solomon et al., 2015), coding (Papadakis, 2020), relationship analysis (Kazakoff et al., 2013), interpretation of graphs (Mitnik et al., 2009). As a result, student's science literacy may be considerably improved (Vidakis et al., 2019).

In effective STEM learning environments children can relate to and engage with problems and make sense of them based on their own experiences. They are active, collaborate to complete learning activities, take ownership of their learning, and apply their knowledge and skills to real problems (Glancy & Moore, 2013). When talking about and learning STEM content, future meaning makers are involved with multimodal actions. So, it is important to provide them the appropriate multimodal educational material in STEM learning environments.

2.3 STEM education, multimodality, and educational material

The role of STEM Education strengthens "broad-based scientific literacy" with the main goal of the respective curricula "science for all", trying to improve education in all curricula at all levels of education (Marginson et al., 2013). Traditional teaching and learning practices need to be transformed to respond to the 21th century requirements and STEM teacher must try multiple teaching approaches, and create meaningful learning environments. Moore et al. (2013), argue that in order to prepare students to address the problems of our society, it is necessary for teachers to provide students with opportunities to understand the problems through rich, engaging, and powerful experiences that integrate the disciplines of STEM. Children will better understand scientific issues of our society and their future society, as citizens, if they develop various skills to make meaning in things.

The new epistemological framework for learning and education concerns socio-cultural approaches to constructing ideas. Mental evolution is recorded as integration into the historical, cultural and social character of the environment in which it occurs, where the role of Social Semiotics is underlined (Pantidos, 2019).

Social Semiotics assumes that "*meaning arises in action and interaction*" (Kress, 2018) and that *multimodal literacy needs to be more fully integrated into the curriculum in ways that can be inspired (. . .) such as playing with toys or computer games* (Van Leeuwen, 2005). Young children combine and use multimodal symbolic systems, like playing or drawing, to express themselves and communicate with others long before writing (Kress & Bezemer, 2008). The acknowledgment of multimodal interactions is vital in STEM education because they can reveal what ideas are being communicated and appropriated by students in ways that their words alone may fall short, especially in early childhood. The actions that take place when talking about and learning STEM content are multimodal (Lee, 2019). Detailed multimodal analyses of interactions around STEM content and practices reveal how complex this coordination work can be and remind us to consider how multiple communicative modalities are at work when learning and communicating within a disciplinary domain (Kress et al., 2001).

The perception that the construction of scientific knowledge is a process that requires the emotional and experiential involvement of the student and the adoption of culturally significant tools of communication and expression, as they appear in everyday contexts, can reshape the content of the teaching FE.

In the context of multimodality theories, semiotic resources include actions, materials, or artifacts that users employ to communicate meaning. That explains why human organs and inanimate materials, musical instruments, clay, colors, robotics, technologies or digital media, haptic materials, toys, books, or tablets have an active and dynamic role in multimodal learning (Mills, 2016; van Leeuwen, 2005) and thus Educational Material (EM) is included.

We consent in the definition that:

"Educational Material is any entity (resource, tool, object, artifact), of any medium and of any materiality (natural, industrial, digital) integrated into a suitable environment learning activity and design enriched by a grid of potential dynamic interactions, can help a teacher to train and student to learn" (Dimitracopoulou, 2018).

Based on the above consideration, we define Multimodal EM (MmEM) as the EM that combines modes of expression leads to combined representations, cognitive structures, and shapes meaning.

The role of EM is considered to be very important as it directly affects learning when students interact with it and indirectly through its interactions with teachers. The use of an appropriate EM, especially at younger ages, provides children with the opportunity to approach knowledge multi-sensitively and create relevant representations and cognitive structures (Yore & Treagust, 2006).

Children build their understanding of STEM concepts, processes, and phenomena based on personal experiences, abilities, and knowledge construction presupposes their active engagement (Driver et al., 1994). Scientific explanations constitute a mixture of modes of expression - symbolic, verbal, and visual (Anagnostopoulou et al., 2012), where children must have an active engagement. Hatano & Inagaki (1997), have argued that teaching tools and artifacts used in the activities and learning environments also affect the understanding of the concepts. Óskarsdóttir (2008) proposes the integration of a variety of teaching tools and techniques such as the use of illustrated books, interactive computer tasks, discussions, group activities, drama and argues that a combination of group presentations, information and discussion, as well as hands-on activities would be very effective in teaching science concepts. There are limited studies focused on multimodal aspects in EM (Unsworth, 2004), and recently there is research interest concerning preschool children (Coleman & Dantzler, 2016; Papadopoulou & Christidou, 2004).

In recent years growing recognition of the power of play is noticed, both in its own right and concerning learning (Resnik, 2007). Playing with a range of materials might be seen to expand make-meaning, and learning material can be as simple as a piece of wood or chalk or as complex as a robot (Lawn & Grosvenor, 2005). Playful learning environments can significantly facilitate learning complex topics across various STEM disciplines (Sengupta et al., 2019).

However, utilization of appropriate multimodal educational material in learning activities and environments to several teaching methods is considered essential. In the literature we did not find research findings that combine play-based learning and other open-ended teaching methods with EM. Hence, there is no research that correlates the multimodal dimension of EM with learning STEM concepts in early childhood. Therefore we consider that further research about the role of multimodal EM to the learning process and understanding of STEM contexts is needed.

3 Design of Study

The present study investigated how multimodal educational material inspired learning and understanding in four STEM contexts in STEM integrated early childhood education settings. In this research context, national and international research ethics guidelines were followed, such as the guidelines suggested by Petousi & Sifaki (2020).

We adopted a mixed-method collective case study design (Stake, 2000) to provide an in-depth understanding of the role of Multimodal Educational Material (MmEM) in integrated STEM education contexts.

According to Creswell (2013) and Yin (2003), case studies explore a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) or phenomena over time through detailed, in-depth data collection involving multiple sources of information. In a collective case study, we use information from different studies to formulate the case for a new study. The use of past studies allows additional information.

Our Case Studies (CSs), within four (4) STEM contexts, were:

(1) CS1: Educational robotics - The bee game in the playground

(2) CS2: The internal structure of the human body

(3) CS3: The life cycle of the butterfly

(4) CS4: Familiarizing preschoolers with Nature of Science through plant growth

Case studies were implemented in central Greece within three years in public early childhood settings (kindergarten schools). CS1 was conducted as post-graduate research and published by Tsoukala & Halkiadaki (2014). CS2 and CS3 were included in the researcher/author's Thesis (Tsoukala, 2014; Tsoukala & Christidou, 2016, 2018). CS4 was implemented during the Erasmus+ project "Creativity in Early Years Science Education (CEYS) (2014-1-EL01-KA201-001644)", presented in ESERA 2017 Conference and published (Tsoukala & Stylianidou, 2018).

The common ground and crucial component elements among the four CSs was that all of them a) were investigating the role of EM in the understanding of scientific concepts by preschool children and b) the common methodological and pedagogical choice for the involvement of children with MmEM, in a playful way meaningful to them.

Three of the four types of research (3/4) applied mixed-method, and one (1) was action research on a small scale. Data collection tools were similar among all CSs concerning children's design representations, children's model constructions with plasticine/clay, children's artifacts, semi-structured interviews (SSI) with children, audiovisual data during children's activities, researchers' portfolios/memos.

The total number of the pupils involved in the four (4) CSs was seventy one (71) kindergarten students, between 4 to 6 years old (mean age = 66.0 months), thirty three (33) girls, and thirty eight (38) boys. They were of similar socioeconomic status, native Greek speakers, some of them with speech problems. The researcher was the teacher in all classroom settings.

Educational Material (EM) applied in the STEM contexts followed principles so as a) to provide multimodal affordances, b) to decontextualize the concepts appropriately under consideration, c) to provide multiple visual representations, d) to enable children to be involved consecutively with tangible objects in hands-on activities, in robotics and digital activities, and play-based experiences, e) to deal with and construct models artifacts, f) to encourage the formulation of hypotheses, inquiries, g) to encourage creative & critical thinking, h) to promote co-operation and social skills,) to promote embodied expressions.

The MmEM included: (1) printed and digital texts (knowledge books, storybooks, animated videos) with many visual representations (pictures, shapes, graphs); (2) digital interactive games, digital software and microworlds (Kidspiration, Scratch, Geogebra, Javascript); (3) educational robotics activities with the floor programmable robot Bee-Bot®; (4) individual and group board games; (5) construction material for 2D and 3D artifacts.

We present part of the MmEM (Figure 1a, 1b, 2, 3, 4) used in each of the four CSs to understand easily.

Figure 1a MmEM in CS1 - Educational robotics - The bee game in the playground

Figure 1b MmEM in CS1 (playground model at Final stage)

The present study is part of a reflective research focusing on the investigation of appropriate learning STEM environments and teaching methods, as they are identified in the aims, processes, and results of multiple case studies. We want to highlight STEM approaches focused on developing children's acquisition of 21st-century skills, which take fully into account the characteristics and needs of childhood.

Results of the specific four CSs are presented in this paper. Data analysis was conducted based on the research design of the four case studies and a standard categorical aggregation (Stake, 2000) to indicate their common ground. We combined narrative descriptions with graphics in order to work with the information systematically. Thematic analysis from the data of the 4 CSs was performed, looking for common themes and followed a systematic and differentiated hierarchical encoding, from line-to-line categorization (open coding), establishment of relationships between the categories (axial coding) that will end in the selection of a category – category central – that connects all the other categories (selective encoding) (Strauss & Corbin, 1998, 2007).

Figure 2 MmEM in CS2 - The internal structure of the human body

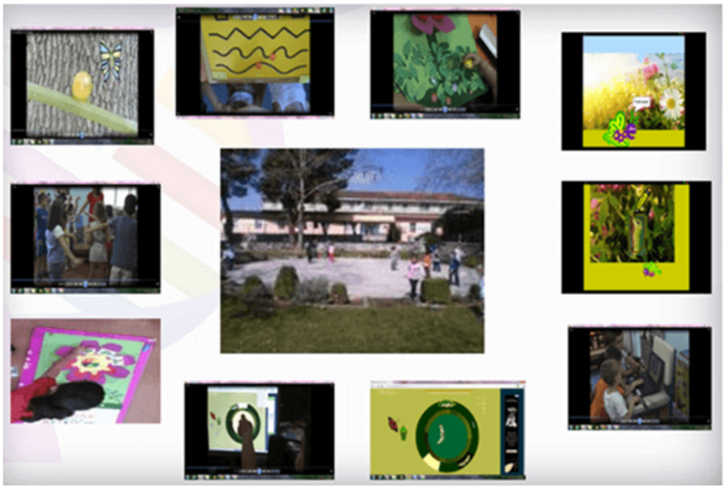

Figure 3 MmEM in CS3 - The life cycle of the butterfly

Figure 4 MmEM in CS4 - Familiarizing preschoolers with Nature of Science through plant growth

4 Findings

Based on our analysis to answer the research question about how Multimodal Educational Material inspired the learning process and understanding in STEM integrated early childhood education settings, within four STEM concepts, we could argue that MmEM affects the learning process and children's understanding of STEM concepts, in play-based, inquiry-based and model-based contexts, where dynamic activities meaningful for children are implemented.

We start by presenting open coding in narrative texts in Table 1, to give the reader a complete picture of the process based on the actual texts of the investigations under analysis. Then we will take an insight in depth through graphic results per case (Figure 6-13), and finally composed results in a synopsis of first level codes and the corresponding theoretical categories are presented in Table 2 and Figure 5.

Table 1 Open coding per case study

Case Study	Open Coding
CS1	"The context of coexistence of representational means/modes played a vital role. However, the combination into a playful and dynamic context was effective because it made sense for children and motivated them to participate actively. The playful form on which the process was based and the switching of digital and haptic representational means during the activities seems to have been supportive."
CS2	"The involvement of children with physical (hands-on) and digital EM is thought to have helped to refine their understanding of the internal structure of the human body. This belief results from the improvement in the level of children's understanding."
CS3	"The multi-sensory form of the EM used, and the combination of haptic and digital mediums seemed to have greatly supported the development and understanding of the concept, helping children to modify their previous mental structures, about the life cycle of a butterfly."
CS4	"The combination of inquiry activities with access to various forms of EM, both haptic and digital, seems to have motivated children to think critically and to act scientifically. Children in their work with the EM were active, in contexts with meaning for them."

Table 2 Axial categories

	Case Study	Modality of Educational Material	Consequences in learning process	Consequences in STEM concepts
Educational Material (EM)	CS1	Co-existance of representational means/modes of EM Switching digital and haptic EM	Vital Effective Motivated	Development on scientific understanding, Digital skills, Socials skills, interaction
	CS2	Physical and digital EM	Motivated Active participation	Improve scientific understanding
	CS3	Multi-sensory EM Combination of haptic and digital EM	Motivated Great supported	Modify previous mental structures
	CS4	Various forms/modes of EM	Motivated	Improve Scientific literacy skills
Context	CS1	Playful and dynamic Equal distribution on digital environments – Robotics- Hands on Activities Balance Entertainment and Learning	Active participation Supportive Made sense for children	Development on understanding, Digital skills, Socials skills, Interaction
	CS2	Play-based learning activities Visual representations Model-based learning activities	Motivated Active participation	Improve scientific under-standing Improvement of scientific modelling skills
	CS3	Play-based learning activities Visual representations Model-based learning activities	Motivated Active participation	Improve scientific under-standing Improvement of scientific modelling skills
	CS4	Inquiry-based activities Meaningful for children	Active participation	Think critically Active scientifically

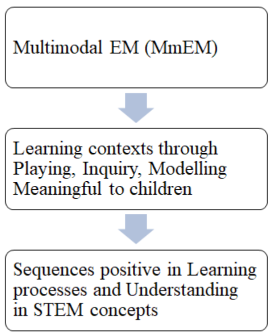

Figure 5 Relationships between theoretical categories

Studying separately the results in each case study will provide us with valuable and detailed insights within an analytical view.

On the results of CS1, as it can be noticed in Figure 6, there is a parallel development among the aspects Understanding- Skills Development- Interaction and among their specific components.

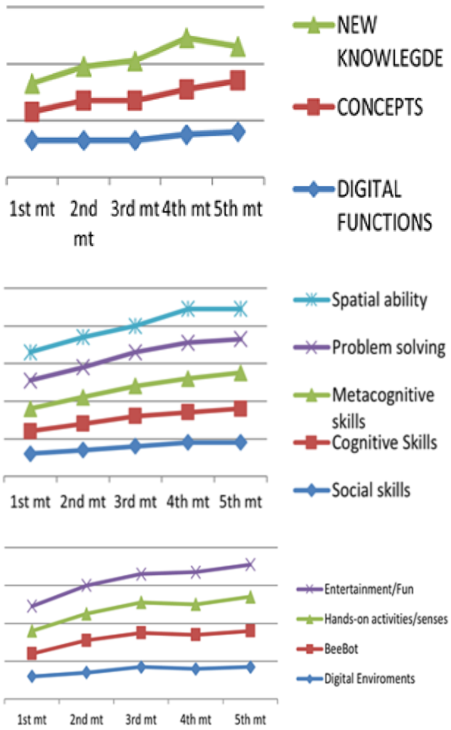

Figure 6 Development of Understanding, Skills and Interaction on CS1 - Educational robotics - The bee game in the playground

On the other hand, as shown in Figure 7, in CS1 there was an equal distribution among Digital Environments, BeeBot, and Hands-on activities.

Figure 7 Distribution among Digital Environments, BeeBot and Hands-on activities

We believe it is essential to underline the balance between Entertainment & Learning during the activities, as shown in Figure 8.

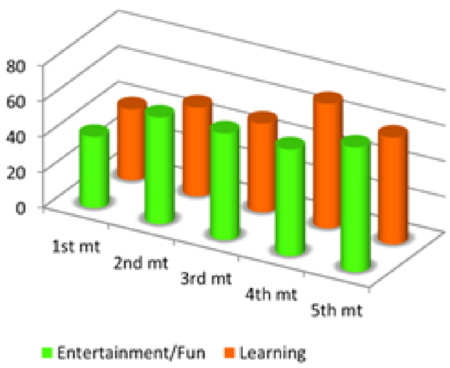

Figure 8 Relation between Entertainment and Learning

Additionally, social skills were equally developing with children's conceptual understanding, as is shown in Figure 9.

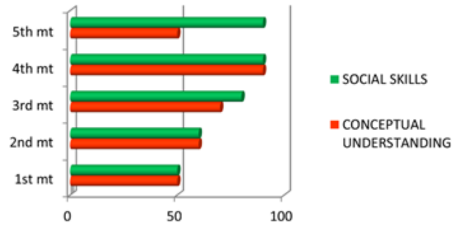

Figure 9 Development of children's Conceptual Understanding and Social Skills

On the results of CS2 in Figure 10, the elevation of children's understanding of the internal structure of human body to the adequate and high adequate levels during the meta-tests, within all research tools, is indicated.

UNDERSTANDING LEVEL	Drawings		Model-constructions		Interviews	
	Ptest 1a	Mtest 1a	Ptest 1b	Mtest 1b	Ptest 1c	Mtest 1c
High adequate	0	12	1	8	0	4
Adequate	23	12	22	16	23	20
Inadequate	1	0	1	0	1	0

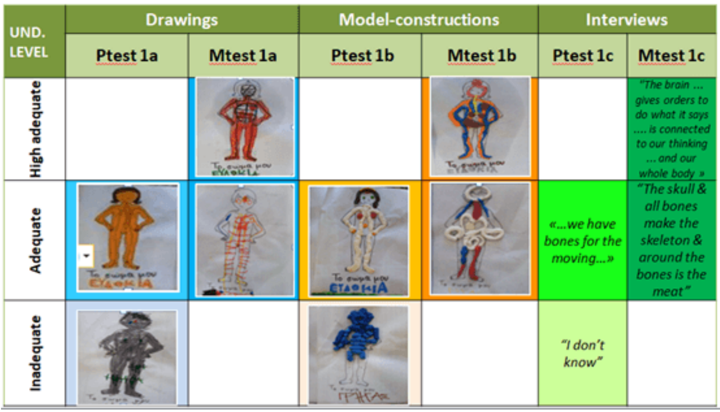

Figure 10 Elevation of children's understanding on CS2 - The internal structure of the human body

The evolution in CS3's of children's understanding about the life cycle of the butterfly to the adequate and high adequate levels during the meta-tests within all research tools is even higher than in CS2, as shown in Figure 11.

CS4's purpose of the study was to familiarize children with Nature of Science, and in Figure 12 is indicated the scoring of naïve (simplistic) scientific and scientific understanding as children were exposed to a range of activities and forms of EM. It could be noticed that as 'no scientific understanding' goes lower, naïve and scientific understanding goes higher.

The composing results on Children's Understanding and Motivation during the learning processes during the four CSs, and the effect of the MmEM are presented in Figure 13 and 14.

Composing open coding line to line and results per case lead us to create the following axial categories: Educational Material (EM) – Context - Modality of Educational Material - Sequences in learning process - Sequences in STEM concepts, as presented in Table 2.

The establishment of relationships between Multimodal EM, Learning Contexts and STEM concepts is presented in Figure 5. Selective encoding, meaning a category that connects all the other categories, will be reported in future paper after the reflective research is completed.

UNDERSTANDING LEVEL	Drawings		Model-constructions		Interviews	
	Ptest 2a	Mtest 2a	Ptest 2b	Mtest 2b	Ptest 2c	Mtest 2c
High adequate	5	21	6	21	5	20
Adequate	11	3	10	2	10	3
Inadequate	8	0	7	0	8	0

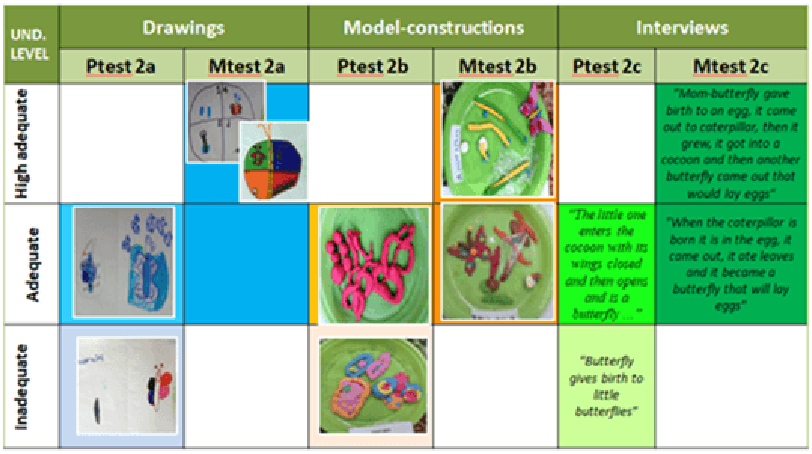

Figure 11 Elevation of children's understanding on CS3 - The life cycle of the butterfly

Activity	No scientific	Naïve scientific	Scientific
1."What is this thing called Science?"	7	7	1
2. "Who is a scientist? - Draw a scientist"	5	9	1
3. "Hello Mrs Science"	2	10	3
4. "Time to collect data for plants by outdoor inquiries"	2	12	1
5. "Conceptual map"	2	10	3
6. "Planting seeds"	1	12	2
7. "Keeping data in Scientist's Book"	2	10	3
8. "Making predictions and experiments"	1	9	5
9. "Research via Books and Web"	1	11	3
10. "Constructing Models of Plants"	2	11	2
11. "Reflection activity"	1	9	5

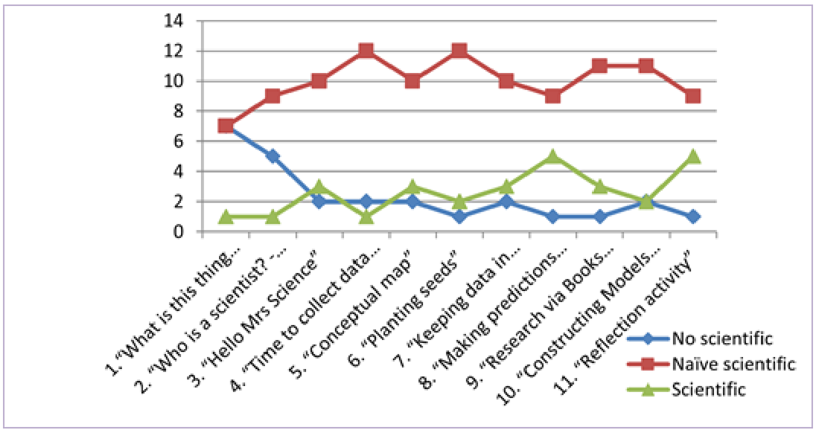

Figure 12 Elevation of children's understanding on CS4 - Familiarizing preschoolers with Nature of Science through plant growth

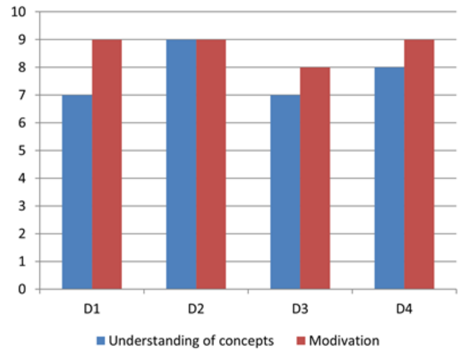

Figure 13 Composed results on children's Understanding and their Motivation within the four CSs (Domains)

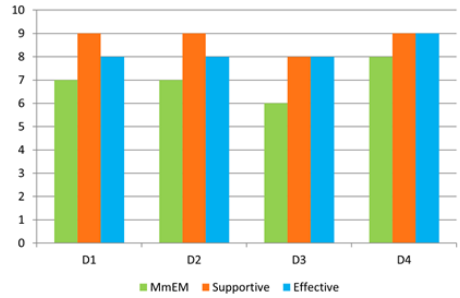

Figure 14 Composed results on MmEM's support and effectivity on Children's Understanding during the learning processes within the four CSs (Domains)

5 Conclusions

The multi-modality of EM affects, inspires and have positive consequences in learning processes and children's understanding in STEM concepts, within play-based, inquiry-based, modelling-based teaching practices and when meaningful for children contexts are implemented. The relationship established among them is in agreement with Yore & Treagust (2006), claimed that the use of an appropriate EM, especially at younger ages, provides children with the opportunity to approach knowledge multi-sensitively and create relevant representations and cognitive structures. Hence, as MmEM affects the learning process and content knowledge – due to our research, it confirms that the integration of a variety of teaching tools, materials and techniques would be very effective in teaching science concepts (Hatano & Inagaki, 1997; Óskarsdóttir, 2008).

Different modes of EM proved to act dynamically, mutually supportive, and complementary to one another and refine the children's mental representations that shaped new meanings. Findings of our research illustrate that MmEM was highly supportive and effective on the content knowledge understanding, on the four CSs. MmEM highly motivated children, in equal or higher level to the concepts' understanding among all cases. Children implemented new STEM knowledge connected with pre-existing perceptions that led to more scientific knowledge. Our findings seem to corroborate with many researchers who claim that multi-sensory/multimodal approach to scientific knowledge leads to more effective learning, because it stimulates children's interest, enhances understanding and fosters the development of scientific thinking skills and therefore scientific literacy (Alade et al, 2016; Ainsworth, 1999; Brooks, 2009; DeJong & van Joolingen, 2008; Papandreou & Terzi, 2011; Smyrnaioy & Weil-Barais, 2004; Yore & Treagust, 2006).

Glancy & Moore (2013) have argued that in effective STEM learning environments children can relate to and engage with problems and make sense of them based on their own experiences. They are active, collaborate to complete learning activities, take ownership of their learning, and apply their knowledge and skills to real problems (Hatisaru et al., 2019). Children in all four CSs by acting and interacting on/with MmEM in a multi-sensory learning environment, were prompted to be active participants, think critically, and act scientifically.

MmEM led children among the four cases to combine social skills to concepts' understanding and play-based learning to scientific literacy confirming researches of Lawn & Grosvenor

(2005), and Resnik (2007) who have argued about the 'power' of playing with a range of materials to expand making-meaning and the finding by Sengupta et al. (2019) that playful learning environments can significantly facilitate learning complex topics across various STEM disciplines.

Furthermore, due to the principles for effective STEM teaching (Vasquez et al., (2013), and the perspectives of integrated STEM education, our findings illustrate that MmEM in STEM concepts, through play-based, model-based, inquiry-based teaching practices (among other open-ended), may provide to children multimodal learning environments, engage them in authentic and meaningful learning, promote teamwork, communication and social skills, challenge and motivate them to make meaning of their learning and the situations around them, to become inventors and critical thinkers.

6 Discussion

It is almost certain that our findings are based on a small number of CSs, outline the context in thick lines, and involve several limitations. For this reason, other research has to be conducted to corroborate these findings to examine the role of MmEM in further STEM integrated concepts in different educational settings.

We argue that it is necessary to explore the role of MmEM in the light of its semiotic use in multiple learning environments (multicultural, formal, and informal) and all school ages (early childhood, primary and secondary education). Further research should examine the teacher's role and more learning strategies and practices that may support the multimodal use of EM and the form of the supportive educational policy.

In recent years, the growing cultural and linguistic diversity in our country and all over Europe, and the rapid evolution of technology and media, are changing the way individuals and societies communicate. They form a new socio-cultural reality whose management presupposes the development of new meaning-making skills. Teachers and educators are asked to bring students from all cultural backgrounds into contact with meaningful daily meaning-making practices using a wide range of modes, tools, ways and methods. We believe that the utility of MmEM in these practices is useful for further research.

'The river of Technology does not flow back' Daskalakis (2018) quoted.

Nowadays, young children are increasingly exposed to new technologies (Wood et al., 2016). Many investigations underline the significance of the successful use of new interactive technologies in the learning process for young children to get ready for the requirements of the 21st century (Stockless, 2018). More specifically, there is an excellent possibility for new interactive technologies to improve young children's positive attitudes toward school and mathematical thinking (Papadakis & Kalogiannakis, 2019). There is also a high potential for new technologies to facilitate children's active involvement with robotics and STEM education concepts. Furthermore, new technologies can significantly support the instruction of emergent literacy in the setting of preschool or early-primary education (Oakley et al., 2018; Rogowsky et al., 2018; Neumann, 2018). According to the literature, the effectiveness of new digital technologies in the thematic areas of Robotics, Mathematics, STEM, and Literacy is generally favorable.

STEM Education in early childhood is here to stay and integrated STEM education shows us the path to a synthetic way to view and think about academic disciplines, contexts, and Knowledge. The perception that the construction of scientific knowledge is a process that requires emotional and experiential involvement and the adoption of culturally semiotic modes of communication and interaction can reshape the content of teaching (Pantidos, 2019).

Teachers and policy makers in early years education, as it is the first step to formal knowledge where children's prior knowledge, experienced mental representations, perceptions, initial alternative ideas and interpretations can be expanded, modified, evolved, transformed in the direction of scientifically accepted ideas (Christidou, 2008; Kalogiannakis, 2018), should consider STEM education at this step as tremendeous important for children's positive feelings about Science, Technology, Engineering, Maths, about their scientific and technology literacy, about the meaning they make of every action and interaction. Maybe this is a way for future citizens and meaning makers to respond to the 21th century requirements and create a better world in future.

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