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Robotics and Programming Concepts in Early Childhood Education: A Conceptual Framework for Designing Educational Scenarios

Anastasia Misirli and Vassilis Komis

Introduction

The term "Educational Robotics" refers to the teaching practice during which the students use the robots to construct knowledge with the help of or for the robots themselves. The term appeared in the 1960s through the educational approach of the Logo programming language. Within this context educational robotics consists of an educational approach which recruits programmable devices to improve the learning process through project-based learning. It is defined by the use of Information and Communication Technologies (ICT) in its own affordances for observation, analysis, modelling and control of various physical procedures (Depover, Karsenti, & Komis, 2007). It concerns an approach which allows the learner to familiarise himself with the Information and Communication Technologies and use them to define a plan, to organise and find a specific solution to the given problem exchanging his opinion with those of others (Denis & Baron, 1993; Leroux, Nonnon, & Ginestié, 2005). The cognitive abilities that develop in early childhood with the use of robotics have been studied since the introduction of the Logo educational approach. A distinct category of educational robotics is the Logo-like programmable toys which are appropriate in early childhood and primary education. These programmable toys are programmable robots which are controlled by the user for the respective movement or path they are ordered to execute. In some cases the connection with the computing environment may be used. The child conceives and defines the commands which are introduced into the robot following the principles of the Logo programming language. This robotics subcategory is inscribed in the

A. Misirli (✉) • V. Komis
Department of Educational Sciences and Early Childhood Education, University of Patras, University campus, 26504 Rio, Greece
e-mail: amisirli@upatras.gr; komis@upatras.gr

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psychopedagogical approach of the Logo language, supporting the development of the metacognitive ability, with which the children reflect on the cognitive process adopted, improving the ability of problem-solving and promoting the ability of spatial orientation (Clements & Nastasi, 1999; Clements & Sarama, 2002).

An Overview of Programmable Toys in Early Childhood

The Logo programming language developed in the mid-1960s at the M.I.T. (Massachusetts Institute of Technology). At the same time various types of floor-robots which are programmed with the Logo language make their appearance to aid the implementation of the new programming language in educational contexts after further research activity. Since then a series of robots featuring a common Logo programming language implementation have been used for educational purposes.

A literature review of the integration of robotics in education allows us to distinguish two approaches: (a) the use of educational kits for the construction and function of the robotic system using the appropriate programming language and (b) the use of educational kits with pre-constructed robotic systems using the appropriate programming language.

The first category includes kits like LEGO®-WeDo™ and LEGO®-Mindstorms™. The second category includes the robotic programmable toys such as the Roamer, the Bee-Bot, the Pro-Bot and the Constructa-Bot. The latter require the user to design and compose a program and execute it in order to achieve a goal, thereby solving a problem. Their characteristic is that they are programmed by novice users either through the use of a computer or through the device itself. Most of the programmable toys use the ideas of the initial Logo floor robot—the Logo turtle—and have similar functional and operational characteristics.

Table 1 presents an overview of early childhood and primary education robotic devices (Table 1). It is clear that the majority of the robotic systems refers mainly to pre-constructed robotic devices the so-called “programmable toys” (Hirst, Johnson, Petre, Price, & Richards, 2003). Some have a more attractive appearance and function due to the production of sensory stimuli one of which is the Bee-Bot programmable toy while some others are less complex and are more of a machine such as the PIXIE. In any case, the child designs and defines the total amount of commands which are introduced into the robot following the principles of the Logo programming language. The added value of this specific programming language is the fact that it is appropriate for early childhood development and support abilities such as problem-solving, metacognitive thought as well as skills such as counting, spatial orientation and measurement (Bers, 2008; Highfield, 2010; Highfield & Mulligan, 2008; Highfield, Mulligan, & Hedberg, 2008; Papert, 1980).

Two interesting conclusions can be drawn from this table. First, programmable toys have been under development for the last 40 years within the context of Logo language paradigm. These toys have a Logo-like robust interface and are technological devices using this specific language.

Table 1 Robotic devices for early childhood and primary education

Year of development	Name of Kit	Language	Category	Firmware	Novice users/ Age group	Learning Area	Image
Late 1970s	BIGTRAK (1979)	Logo	Programmable toy	MB	N/A	Maths Literacy Arts	
During 1980s	Tortue Jeulin T2	Logo	Programmable toy, Computer, Pedagogical material	Evreux	N/A	Maths Literacy Arts	
	Tortue Jeulin T3	Logo	Programmable toy, Computer, Pedagogical material		N/A	Maths Literacy Arts	
	Turtle (1985)	Logo	Programmable toy, Programming by computer	Valiant Technology	N/A	Maths Literacy Arts	
During 1990s	Roamer (1999)	Logo	Programmable toy		4–9	Maths Literacy Arts	
	Roamer-Too (2008)	Logo	Programmable toy		4–7	Maths Literacy Arts	
	PIXIE	Logo	Programmable toy, Software	Swallow	5–8	Maths Literacy Arts	
	PIP	Logo	Programmable toy, Software		7–12	Maths Literacy Arts	
	PIPPIN	Logo	Programmable toy, Software		7–12	Maths Literacy Arts	

(continued)

Table 1 (continued)

Year of development	Name of Kit	Language	Category	Firmware	Novice users/ Age group	Learning Area	Image
During 2000s	Lego Mindstorms RCX Brick (1998)	Logo	Construction kit, Software	Lego	>7	STEM	
	Lego Mindstorms NXT (2006)	Logo	Construction kit, Software		>7	STEM	
	Lego WeDo (2009)	Logo	Construction kit Software		>7	STEM	
	Bee-Bot (2005)	Logo	Programmable toy Software, Pedagogical material	TTS	4–7	Maths Literacy Arts	
	Constructa-Bot	Logo	Programmable toy		4–7	Maths Literacy Arts	
	Pro-Bot (2006)	Logo	Programmable toy, Software to transfer programs from the concrete object		7–12	Maths Literacy Arts	

Second they are supported by appropriate educational material and are, apart from the LEGO® robotics kits (LEGO® Mindstorms™ & LEGO® WeDo™), preconstructed systems requiring no construction. Their manipulation focuses on developing the user programming abilities rather than engineering/technology ones. Their educational applications focus on STEM whereas those which are addressed to younger children such as the Bee-Bot may cover other cognitive areas as well (Language, Arts). Most of the recent toys (Bee-Bot and Pro-Bot) have more user friendly (robust) interface and a more playful appearance.

Educational Robotics in Early Childhood Education

The implementation of educational robotics in early childhood education is seen as a way of introducing various concepts and developing different abilities.

Robotics is an interesting cognitive domain because it is a tool through which children have the opportunity to approach mathematical concepts, applying strategies such as problem-solving, inquiry and experimentation (Rogers & Portsmore, 2004). It is worth mentioning that robotics is an educational approach with a variable dimension, which it can be easily integrated in various educational settings (Bers & Horn, 2010). Furthermore, teaching about and through computer programming and robotics using developmentally appropriate approaches increases children's sequencing abilities (Kazakoff, Sullivan, & Bers, 2013). During the planning and constructing procedure of a robotic model children of early childhood put into action cognitive abilities which are under development (Papert, 1980). Programming concepts which may be developed within computing environments are not always developed for children of this age range. There are usually environments which require users to develop the ability of abstract thought.

Hirst et al. (2003) dealt with the review, the description and the presentation of robotic environments which are based on the technology of the LEGO® Mindstorms™ robotics systems. They propose that these specific systems bridge the gap between how the user acts concerning more abstract computing systems and specific conventional tools. They also propose that the creation of a more individualised system of a graphic microworld for novice users must be created so that they are progressively drawn towards a more advanced programming environment.

Therefore, educational robotics in early childhood education uses appropriate cognitive tools, emphasising on tangible use. The use of such tools which is the case of programmable toys is a factor of motivation infusing the interest in children and their actions towards learning. Those tools are developmentally appropriate as they are based on playing and consisting of meaningful action and reaction (Highfield, 2010; Highfield et al., 2008; Highfield & Mulligan, 2008).

Some researchers suggest that learning through interaction with a programmable toy, the construction of more abstract cognitive structures and the development of social skills is reinforced (Bers & Horn, 2010; Yelland, 2007).

However researchers such as Greff (1998, 2001) attempted to reinforce the learning context and developed appropriate teaching materials based on a language of graphic representation of the commands for the approach of algorithmic concepts. A positive aspect of this language was that it offered the user directness because of the appropriateness of its structure and planning during the creation of a program. Thus, algorithms were planned in order to direct the floor-robot to complete a specific path.

Other researchers used the programmable toy floor-robot Roamer in their study. João-Monteiro, Cristóvão-Morgado, Bulas-Cruz, and Morgado (2003) report the results of their teaching intervention within the context of the ICEI programme in preschool settings in Portugal. The floor-robot Roamer was used to support teachers in using the ICT as a cognitive tool. The added value of this particular robot lies in its potential to develop mathematical concepts in children in early childhood.

A look at the studies published in the last decade shows that the use of Logo-like programmable toy Bee-Bot lies in the centre of the scientific interest for this specific age group.

Beraza, Pina, and Demo (2010) in their study presented teacher-orientated robotics activities in order to support teachers in their practice. They claim that the programmable toy Bee-Bot is suitable for early childhood and primary education but provides limited programming opportunities. For this reason and for encouraging teachers in designing suitable educational scenarios with programmable toys robots they proposed the use of the Arduino platform.

In the study by Highfiled (2010) 33 children of early childhood and their teachers chose the Bee-Bots and Pro-Bots from a range of robotic toys. Through a learning process of a combination of robotic toys and engaging tasks mathematical thinking and sustained engagement was promoted.

Pekarova (2008) studied the development of effective teaching practices and attractive activities for children through digital technologies in early childhood education. Her results show the need of an organised context for teaching programming concepts with the use of the Bee-Bot. However, since this procedure is not sufficient enough for activating children's inner motives, the formation and the organisation of appropriate problem-solving tasks as well as the development of teaching materials are required.

Highfield and Mulligan (2008) describe various instances where early childhood and primary school children interacted with the programmable Bee-Bot toys. The desired outcome came through the experimentation with the programmable toy as children applied different strategies in order to discover its functions and features. Especially the experimentation gave children the opportunity to discover the feature of programmable toy to rotate rather than move aside. Similar outcomes have also been stated by Highfield et al. (2008) for the development of mathematical concepts in children of early childhood when using the Bee-Bot programmable toy. This toy facilitates children's learning and in particular the way to approach topics such as measurement and geometrical transformations as opposed to traditional teacher-orientated teaching.

Similar conclusions are drawn by De Michele, Demo, and Siega (2008) where children from primary education used the programmable toy Bee-Bot to program through mathematical concepts of multiplication and addition in typical classroom teaching practices.

Overall, research has shown that there is no systematic and principle-based framework for teaching educational robotics concepts in early childhood settings. What appears to be missing is a developmentally appropriate educational context for developing programming abilities and reinforcing inner motives of children in early childhood. This is important because integration and use of a programmable toy within an appropriate teaching and learning context may infuse cognitive development (Depover et al., 2007) such as mathematical skills and problem-solving abilities in children.

Furthermore, Csink and Farkas (2010) gave emphasis to the use of floor-robot Roamer to teach programming concepts integrated within the curriculum and the additional methodology. They also propose teaching programming that should be in a context with role-playing and 3D games instead of using computer software. The same point of view for integration of programming concepts within the official curriculum is shared by De Michele et al. (2008). Scientific activity in the field of educational robotics and especially in the field of programmable toys seems to influence the curriculum of various countries such as those of England, Australia, Croatia, Estonia and Hungary (Csink & Farkas, 2010) as well as that of Greece in which a clearly distinct thematic approach has been integrated for the teaching of programming. In some cases like England, Australia, Scotland and Greece there is an explicit reference to the use of programmable toys. In England specifically programmable toys have been integrated in the mathematical learning area and children learn to program by designing paths, a procedure through which they develop abilities such as spatial orientation. In Australia the Ministry of Education introduced a teaching guide concerning the integration and use of the Bee-Bot programmable toy in early childhood education (Kopelke, 2007). In Greece a new curriculum proposal announced in 2011 (The Greek Institute of Educational Policy, 2011) is currently being piloted and includes the integration and use of programmable toys in early childhood and primary education. In addition, in Malta since 2011 and Scotland since 2013 educational programmes targeting the use of the Bee-Bot programmable toy have been launched. In these countries, the Bee-Bot programmable toy is being used as a teaching and learning tool in several academic subjects (ICT, Mathematics, Language, Social Studies, and Physical Education).

A Methodology Framework for Educational Scenarios in Programming and Robotics in Early Childhood

As the preceding literature review of educational robotics in early childhood education clearly shows, the relative research is limited in references of implemented teaching activities without systematic educational design or organization. In some cases the researchers have tried to gather students' representations concerning the content of the robot (through the use of a single question) as well as try to record and present students' programming strategies during free experimentation of the children with the Bee-Bot (Pekarova, 2008). In other cases an attempt to trace children's initial representations and their manipulation of the Bee-Bot is recorded. However, there is still lack of systematic observation and recording of children's learning processes (Highfield, 2010; Highfield et al., 2008; Highfield & Mulligan, 2008).

In the above studies we can additionally observe that there is no specific or organised meaningful context. In other words, they lack in presenting a context suitable for teaching programming as well as for problem-solving situations. Especially the more recent studies use the researcher's demonstration of a particular path and the aim is that children reproduce the same path (Highfield et al., 2008; Highfield & Mulligan, 2008). On the contrary it is Pekarova (2008) who claims that the programmable toy has attractive features and functions for children of this age but these elements are not efficient enough. There is a need for a clear and appropriate planning program construction orientated for the reinforcement and the function of teamwork.

Greff (1998) shows that the creation of a pseudo-language through the graphic representation of the commands of the Roamer programmable toy is an appropriate teaching strategy for the visualization of the programming procedure. This procedure provides user with the opportunity to not only visualize a program but also reflect on and correct its content. This visualisation technique was evaluated by other researchers using a different methodology. In the study of João-Monteiro et al. (2003), the users were asked to programme the toy to reach a desired position or goal as it is represented on a coloured patterned command on a card.

It is worth mentioning the fact that most studies which used the Bee-Bot programmable toy were not integrated in typical classroom teaching practices. They appear to be more focused on free experimentation with the tool and orientated towards the implementation form the scientists themselves who act either as facilitators of the research or are supported by the classroom teacher (Highfield et al., 2008; Highfield & Mulligan, 2008; Pekarova, 2008). On the other hand, Greff (1996) reports the implementation of a teaching intervention towards the development of a programming ability while placing the children either in the position of the robot or in the position of the user under real classroom conditions. Moreover, Greff (2001) and João-Monteiro et al. (2003) describe cases of use of the Roamer robot in typical classroom conditions for the development of programming and mathematical concepts.

As far as the cognitive context is concerned, concepts referring to either premature programming structures (the sequence of commands) or belonging to mathematical learning areas (counting, shapes) were approached. João-Monteiro et al. (2003) in their study implemented the cross-curricular approach in order for children to construct programming concepts.

The primary aim of this study is to propose an appropriate educational framework for organising the teaching process, one that emphasises the understanding, design and implementation of robotics and programming concepts. The study is situated in the wider scientific research context of robotics use in early childhood education. It follows the *design based research* mixed research model and uses the method of multiple case studies for collecting qualitative and quantitative developmental data (Kelly, Lesh, & Baek, 2008). This kind of research deals with the design, development and evaluation of educational programmes or constructions as part of the teaching practice in such a way that the most efficient conditions for teaching and learning are assured for the benefit of everyone involved (Depover et al., 2007).

Since there is no existing framework for teaching programming in early childhood the approach proposed below is an innovative, new tool for educators. This framework is based on a conceptualization where methodological and pedagogical issues are suitably integrated to facilitate the teaching and learning process, thereby addressing the deficiencies of former studies identified above. Such deficiencies have resulted in unsystematic and unstructured educational interventions, which failed to address issues related to the teaching of programming, educational practices and pedagogical principles. The teaching of programming includes concepts such as algorithms, programs, memory and debugging. Moreover, a structured and systematic educational intervention should give emphasis on and carefully select the appropriate teaching approaches. Such issues refer to defining an objective and the goals which meet early childhood children's needs, to using additional teaching strategies, to comprising didactic transposition on programming concepts and to developing appropriate teaching material. These teaching practices are based on pedagogical principles such as project-based learning, child-centred learning, collaborative learning, and well-organised learning environments.

The proposed educational and methodological framework includes seven (7) distinct phases (Fig. 1) for designing an educational scenario. The importance of designing an educational scenario is to include issues of programming concepts, educational practices and pedagogical principles to lead the teaching process. Therefore the selection of a specific subject orients teaching to set an objective, as well as the goals for delivering its content through seven (7) distinct phases, which in fact present different instances of the planning and the implementation process. These phases are found in the core part of the whole design are closely interrelated and interact at the same time (Komis, 2010; Komis, Tzavara, Karsenti, Collin, & Simard, 2013).

From an educator's point of view designing an educational scenario is very important as it addresses issues such as the integration of ICT at least in some of the phases using a computer or robotic device during its implementation and application. The structure of current methodology describes the method with which the participants (in our case early childhood educators) are asked to use ICT in a suitable planned and well-organised context. Thus, the educational scenarios used within this study adopt concepts and themes of computer science and mathematics curricula expecting children to construct programming concepts by using the Bee-Bot programmable toy.

Based on the above conceptualization, a teaching model was developed for educational robotics which was structured after appropriate adaptations as those which emerged by analysing former studies. So a conceptual model was created of an educational scenario appropriately structured and adapted to the cognitive early childhood children's needs. Anticipations and adaptations that took place aspired to minimise methodological faults with the aim of maximising the validity of research findings. Pekarova (2008) mentioned that emphasis on teaching programming in early childhood children should be given to plan a well-organised and systematic teaching intervention. Particularly, all the adaptations that were taken into account were divided into two categories concerning different approaches such as (a) methodological and (b) pedagogical.

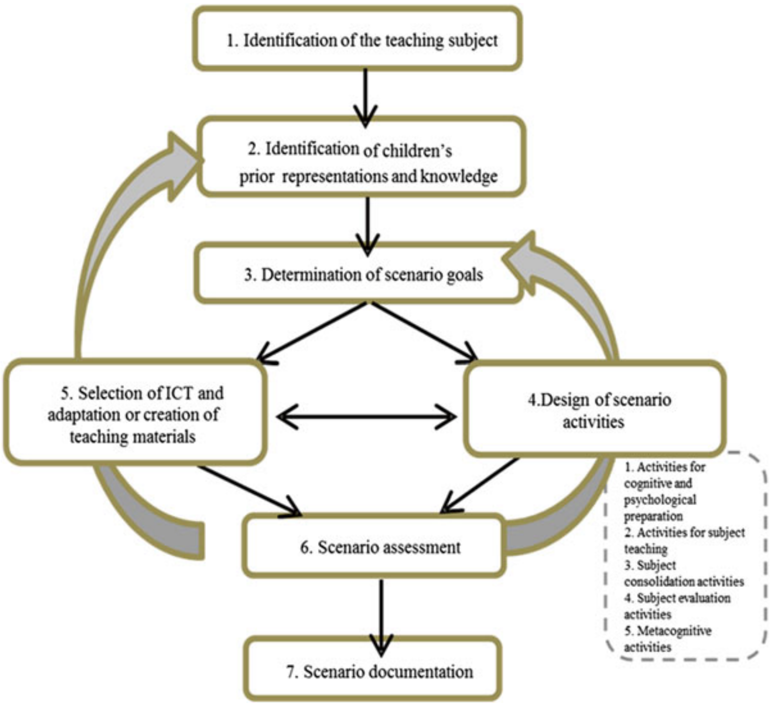

Fig. 1 The phases in designing educational scenarios for robotics

Methodological Approaches

The methodological approaches include: (a) the organisation of the educational scenario, (b) the introduction and the integration of didactic transposition of programming and informatics concepts, (c) the development of instructional design, (d) the integration of inherent teaching strategies in pedagogical and informatics design, (e) the use of explicitly stated teaching contracts and (f) the development of research protocols (instruments gathering data) for each individual.

Educational Scenario

The organisation of the educational scenario (structure and content) followed a spiral developmental procedure, comprising the six (6) following steps: (1) Design, (2) Implementation, (3) Evaluation, (4) Modification, (5) Re-implementation and (6) Re-evaluation with the aim of potentially adapting it in every different educational context or group of children. The interventions which used the programmable toy Bee-Bot do not explicitly mention a systematic implementation to gather data for evaluation and feedback for modification (De Michele et al., 2008; Highfield, 2010;

Highfield et al., 2008; Highfield & Mulligan, 2008; João-Monteiro et al., 2003; Pekarova, 2008). Every educational scenario we designed was pilot tested in a typical classroom setting, before being formally implemented by the in-service teachers.

Didactic Transposition of Programming and Informatics Concept

Moreover, in the published literature there is no illustrated integration of didactic transposition of programming and informatics concepts. All of them are giving more emphasis on the development of abilities concerning mathematical concepts, rather than programming and informatics ones. In our case, the integration of programming and informatics concepts created a more explicit context not only for the children but also for the teachers. For children it is self-evident to deliver the epistemological knowledge under appropriate transposition, while for the teachers it was necessary since they had no previous experience on robotics.

Instructional Design

A development of instructional design underlined the teaching of programming and informatics concepts by increasing the level of cognitive difficulty. This meant that each educational scenario had been designed by increasing the difficulty level in its goals and activities. Researchers, using interventions focused on curricular subjects may have used similar adaptations, however this is not clearly stated (De Michele et al., 2008; João-Monteiro et al., 2003).

Teaching Strategies

Being a more structured and theory-based educational scenario, this has integrated inherent teaching strategies such as problem-solving, cognitive conflict and inquiring. Especially in pedagogical and informatics educational design these strategies provide an ascending engagement and learning process.

Teaching Contract

Furthermore, the use of an explicitly stated teaching contract, customised for each activity was clearly defined, in order to arrange the class' settlement and to motivate the self-regulation of group members, as well as that of the whole class.

Research Protocols

To trace pre and evaluate post-intervention children's ideas, conceptions and representations using Bee-Bot and its functions, research protocols were developed and filled for each individual. Additionally, this process includes children's personal

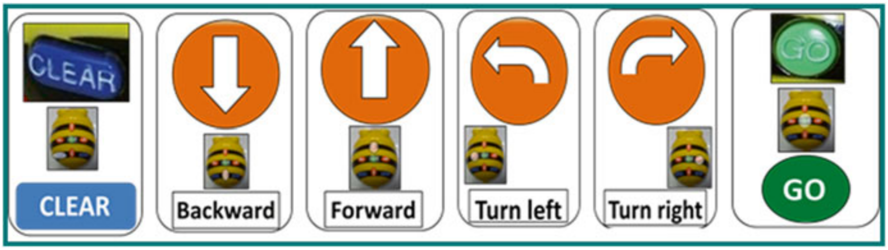

Fig. 2 Graphical representation of Bee-Bot's commands on cards

graphic representations (pre and post drawings) showing their ideas about the Bee-Bot. These two different protocols provide the educator with the opportunity to verify early childhood children's verbal representations, since at this age different approaches are required to facilitate verbal communication.

Pedagogical Approaches

The pedagogical approaches include: (a) the development of a pseudo-language, (b) the development of additional teaching materials, (c) the initiation/organisation of an appropriate learning context and (d) the appropriate adaptation for implementation by in-service teachers in typical classrooms settings, taking the role of facilitators and co-researchers.

Pseudo-Language

The development of a pseudo-language, through a series of graphical representation of commands on cards—based on Greff's study (1998), who had argued that developing such language is developmentally and pedagogical appropriate for the visualization of programming procedures for children in early childhood. This procedure provides the user with the opportunity to not only visualize a program but also reflect on and correct its content. In particular, every command of Bee-Bot's interface has been represented on a card containing three different semiotic systems. Those are: (1) the image or representation of the real object/button, (2) the image of Bee-Bot's interface with the additional button highlighted and (3) the word corresponding to the additional command (Fig. 2).

Every synthesis of card-commands constitutes a full program, which could be executed by the Bee-Bot (Fig. 3). It is also structured according to the program's syntax process (CLEAR–COMMAND OF DIRECTION/ORIENTATION-GO) and placed vertically following of the principles of the Logo language. Each card is 15 cm wide, the same as the Bee-Bot's step length, facilitating children to develop learning strategies for the interrelation between cards, the Bee-Bot's step and the squares of gridded mats.

Fig. 3 Examples of programs developed by a team while working on a teaching activity on orientation concepts

Teaching Materials

Alongside the previous pseudo-language teaching material was developed to support and facilitate the teaching process. Gridded mats of 15 cm each square (the Bee-Bot's step length) on A3 laminated papers were created. This kind of material enabled children to consider the sequence of commands of an algorithm. The child/user is supported and reinforced to find the appropriate commands/cards of orientation and direction, visualizing the program, matching each command/card to a square. Moreover, a series of additional pictures or 3D objects (animals, toys, sticks/ribbons for measuring, adhesive bookmarks), were customised for each educational scenario depending on the learning context they were integrated to.

Learning Context

For each educational scenario an adequate learning context was designed, so as to introduce problem-solving situations as well as to support the educator's teaching practices concerning programming concepts. The so-called learning context initiated an inquiry/problem-solving situation with a developmentally appropriate way, taking into account the children's prior knowledge and experience on programmable toys, as well as programming and mathematical concepts. Through this context open questions (questions stimulating productive activity) were set up for each goal to lead inquiry and problem-solving activities. The learning context takes advantage of the Bee-Bot's animated and playful appearance, enabling children to inquire. In that way the programmable toy is integrated as a member of the team, enabling children to relate to its action and see themselves as co-researchers.

The previous adaptations are based on Papert's ideas about creating a developmentally appropriate constructivist programming environment where concrete material facilitates the construction of abstract ideas and reflection on them (Papert, 1980).

Role of Teachers

Last but not least, an appropriate adaptation for implementation by in-service teachers in typical classrooms, taking the role of facilitators and co-researchers was taken into account. This approach is implied by the broader context of educational robotics thus is the constructionism (Papert, 1980) and the social-constructivism (Vygotsky, 1978). Each teaching activity provided teachers with the knowledge of the learning process they should have, in order for children to construct knowledge. Each activity is comprised of: the learning goal, the question to be explored (inquiry question), one or more teaching strategies, the additional teaching material, the class organisation, the description of the process and finally the conclusion—reference to the prospected learning outcome. Moreover, the scenario documentation (phase 7) comprised of useful references (scientific knowledge) on the children's cognitive development on each teaching subject, additional appropriate vocabulary on programming concepts and guidelines on how to assess and implement the interviews with each child.

Therefore the idea was to divide each educational scenario in two distinct sections. The first section (shared across all scenarios) introduces programming concepts and provides children with basic skills/knowledge to understand the functions and the use of the programmable toy. Within that section a transition from exploration and investigation to more structured activities is applied. Respectively those skills were delivered and extended in the second section where children were engaged in more open-ended activities focused on inquiry and experimentation of mathematical and programming concepts. Mathematical concepts such as spatial awareness are aside to programming concepts due to the Logo-language structure. For example in one educational scenario children applied the robot step as a unit of measure to extend their understanding on length concepts.

The conception and design of educational scenarios of robotics and programming in early childhood education adopt concepts from the cognitive fields of computer science and mathematics. The scientific field of educational robotics concerning the use of the programmable toys is part of the learning theories of constructionism and social constructivism (Bers, 2008; Depover et al., 2007; Papert, 1980; Resnick, 2006). Both these theoretical models lead to the development of abilities of a cognitive style such as inquiry, experimentation, observation, and recording as well as of a social context such as cooperation and discussion with others, reflection on final conclusions and share the results.

An Empirical Investigation of the Framework

Subjects and Setting

The framework outlined above has been implemented for 3 years (2010–2013) through the scientific European project Fibonacci by 46 educators and 864 children between the ages of 4–6. Eventually valuable data was gathered from 38 educators and 674 children. It follows the *design based research* mixed research model and uses the method of multiple case studies for collecting qualitative and quantitative developmental data (Kelly et al., 2008). A concurrent triangulation approach was applied which “provides quantitative statistical results followed by qualitative quotes that support or disconfirm the quantitative results” (Creswell, 2009). The quantitative analysis of the data has not yet been completed; however initial results provide interesting details about the proposed framework.

Measures and Data Collection

Concerning the techniques gathering the quantitative data; different research protocols (instruments) were developed and introduced to the distinct phases of an educational scenario (Fig. 1). All these instruments were tools for educators for recording and evaluating the learning process. A structured interview was introduced at the phase where children’s prior representations and knowledge about the programmable toy Bee-Bot were to be identified. It comprised of eleven (11) open-ended questions and was used to assess pre and to evaluate post-intervention children’s ideas. These questions formed the categorical variables. The results from the post-intervention interview are embedded in the phase where the scenario activities are designed and particular to the sub-category of subject evaluation process. In the same sub-category three more instruments have been applied. After the first section of teaching activities (function and use of programmable toy), an instrument for assessing every child’s prior knowledge on the mathematical concepts was introduced. Another instrument was used to record each child’s evaluation on the programming and maths concepts. Its structure provided us with more categorical variables. Moreover, every child was accessed for his reflection on the programmable toy. All these instruments shared the same technique of a structured interview.

Data Analysis

As far as the qualitative analysis is concerned, data from records and videos has been collected but not yet completed. In particular, records are written notes kept by teachers on a daily basis during the implementation of an educational scenario along with notes regarding each child’s evaluation on programming and maths.

The data gathered from several case studies (92 children) on the first year of the implementation, indicated that children were having difficulties understanding orientation concepts (Komis & Misirli, 2011). This educational scenario was focused on measurement, enabling children to use the robot step as a unit of measure. The findings indicated the need to engage children with spatial concepts and especially directionality. Therefore an appropriate educational scenario was implemented. In the third year, one more scenario was developed. It was aimed to develop concepts of iteration and sequencing of patterns as those could be initiated through the concept of a program and its structure.

The analysis clearly shows the development of algorithmic thought and programmable abilities as well as the evolution of abilities in diverse mathematical structures. The development and the evolution of these specific cognitive abilities is facilitated through designing and implementing developmentally appropriate educational scenarios which in turn lead to the creation of relative cognitive representations on the function and the use of the Bee-Bot programmable toy (Komis & Misirli, 2011, 2012; Misirli & Komis, 2012).

Data gathered through structured interviews and drawings from ninety two (92) children show a significant shift to more qualitative representations in the post tests. This became apparent by the fact that more explanations was provided (by the children) about the programmable toy's functions and controls (Misirli & Komis, 2012). The interpretation of these preliminary findings attributed to the conception of appropriate teaching activities illustrating and highlighting programmable toy's functions and controls (Greff, 2005).

Concerning the development of algorithmic thought, this was formed through the cognitive process of problem-solving which in our case demanded from each child to plan a spatial path. Thus, a spatial path is sufficiently abstract for this age group, the pseudo-language—a series of card commands—alongside the developed teaching material engaged children in tasks were algorithms were visualised (Komis & Misirli, 2011). The same study showed that a small group of children tried to plan a path mentally without visualizing it. Moreover, gender differences were not significant but differences among different age groups were. The pre and post assessment showed that children aged five and six understand programming concepts more easily.

A very interesting finding is the design and the programming of algorithms by early childhood children (Komis & Misirli, 2013; Misirli & Komis, 2013). During this cognitive construction of an algorithm the children follow two (2) steps: (a) initially they verbalise the abstract conception of the algorithm and (b) they proceed to the syntax of the algorithm by implementing the programming stages respectively. While the syntax procedure takes place, a variance of the amount of commands which are used and rate between three (3) cards-commands and twelve (12) cards-commands for direction and orientation, is observed. On the whole the design of scenario activities (phase 5), were structured and organised to initially familiarise children with the abstract process of conceiving an algorithm. According to Vygotsky (1978) thought is considered as "inner speech" and is the result of language. The "inner speech" was in educational scenario the time when children verbalised (thinking aloud) an algorithm and thus planned their program and consequently organised a strategy to process. This cognitive construction leads children to modelling the solution of a problem as they form it verbally and consequently indicate it by their finger or the programmable toy itself. Moreover, all the activities of a scenario (phase 5) had a teaching contract placed from the very beginning when children were introduced to the activities of cognitive and psychological preparation. It is worth mentioning that all children for the 3 years intervention proceeded to verbalizing an algorithm having the programmable toy as system of reference and not their body as it was proposed from the studies of Greff (1998) and De Michele et al. (2008).

Discussion

The preliminary findings drawn from the present conceptualization and its implementation show that although the programmable toy Bee-Bot has a limited command set (Beraza et al., 2010; Kazakoff et al., 2013) it may be a cognitive tool for children if a systematic, structured, principled and theory-based framework is used. The application of the educational scenarios in typical classrooms in early childhood education, showed that preliminary concepts of programming could be developed through the use of programmable toys. Thus the cognitive potential (Depover et al., 2007) applies not only to the development of mathematical abilities but also to the development of programming abilities and problem-solving situations.

Our proposed framework is validated by quantitative and qualitative data gathered from cases where in-service teachers integrated the educational scenarios in their teaching, without having prior knowledge neither on robotics nor on educational scenarios. This implementation in typical classroom contexts also distinguishes our approach from other researches on programmable toys, which were conducted mostly by researchers and in some cases they have demonstrated to children how to input a program (Beraza et al., 2010; Highfield, 2010; Highfield et al., 2008; Highfield & Mulligan, 2008; Pekarova, 2008). Furthermore, our work demonstrates that the methodological and pedagogical approaches we used to underline this conceptualization, were efficiently addressing the deficiencies of previous studies. Our findings show that although children had no prior experience with programmable toys they finally achieved the cognitive objectives set through inquiry-based activities. They were able to build sequential programs based on graphical representations and transfer them to the programmable toy's tangible interface in a learning context, underlined by appropriate methodological and pedagogical approaches. It seems that the development of programming skills (algorithmic thinking, concept of memory, debugging, structure of sequence, and inputting strategies) requires an appropriate conceptualization to efficiently motivate young children. Based on these preliminary findings, we reach the same conclusion as Highfield et al. (2008): "the Bee-Bot has the potential to enhance children's development of mathematical concepts, particularly … measurement processes much earlier that traditionally expected." On the top of that we also found spatial orientation (Misirli & Komis, 2013) and sequencing skills.

The present study has drawn conclusions from a specific educational context, but the findings need to be validated in other educational contexts. Several questions such as the role of the teacher in the learning process, the potential differences if the educational scenario is applied it a digital rather than a physical environment, the transfer of programming concepts to other learning areas and metacognitive processes remain open. Our study could be extended and expanded in the future allowing for the above questions to be answered.

In conclusion, the conceptual framework proposed above consists a tool with cognitive potential for early childhood children to develop initial programming concepts via a developmentally appropriate and supportive learning environment. It allows each child to create his/her personal learning "trajectory," one that fulfils his/her own learning needs. There is evidence to suggest that this conceptual model can be integrated into everyday teaching practices and into the everyday processes. In addition, it does not necessarily require educators to be specialized in educational robotics and programming.

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