International Journal of Engineering Education Vol. 33, No. 1(B), pp. 389–397, 2017
Printed in Great Britain

0949-149X/91 $3.00+0.00

Engineering for Children by using Robotics*

LILIANA FERNÁNDEZ-SAMACÁ, NELSON BARRERA, LUIS ARIEL MESA and WILSON JAVIER PÉREZ-HOLGUÍN
Robotics and Industrial Automation Research Group (GIRA), Electronics Engineering School, Universidad Pedagógica y Tecnológica de Colombia, Sogamoso, Colombia. E-mail: liliana.fernandez@uptc.edu.co, nelson.barrera@uptc.edu.co, ariel.mesa@uptc.edu.co, wilson.perez@uptc.edu.co

This paper presents an approach for K-12 Engineering education aimed to facilitate the concept learning in preschool and elementary school using simple robotic prototypes developed with active participation of children. The approach focuses on strategies for imparting engineering knowledge dealing some concepts related to subjects such as physics, electricity, electronics, mechanics and other fields related to engineering education by means of an open and affordable technology. The designed approach considers four stages to motivate the learning: sensitization, robot design, robot construction and evaluation. The paper also presents results about the impact assessment of the proposed K-12 approach through qualitative data gathering to know the children's impressions and a survey intended to know the opinion of the children's parents and schoolteachers about robots as a didactic resource.

Keywords: educational robotics; K-12 engineering education; STEM

1. Introduction

Currently, students are immersed in a highly digital and technological world offering a completely new and exciting perspective for life and education. The new technological resources are being used as a valuable mechanism to stimulate the learning, transform didactic strategies, and encourage autonomy and self-confidence of students in general, but particularly in K-12 education contexts. It is an issue that has gained much importance in recent years, and experiences about how to plan and develop learning activities that incorporate technology resources in education environments for children and youth, enhance and strengthen the research in this field.

Robotics is one of the technologies most commonly used worldwide to improve learning in the K-12 education. Educational Robotics takes advantage of the natural curiosity of children for exploring and manipulating their surrounding world, helping them to construct meaningful knowledge from their own experiences. The learning environments that use educational robotics offer proper conditions for learning with the active participation of students and the appropriate scaffolding in the proposed activities [1].

Educational robotics is based on Piaget's Constructivism, which suggests that 'Children have the ability of constructing their own knowledge in response to their experiences' [2]. In addition to Piaget's constructivism, Constructionism Learning Theory proposed by Seymour Papert, encourages the use of technology to consolidate learning, emphasizing that people learn most efficiently when they are engaged in making artifacts or real objects [3]. Papert considers that computers offer "unprecedented opportunities" to design educational alternatives for kids. In the same sense, robotics offers interesting prospects to develop constructionist approaches.

Engineering is a field of knowledge about the design and creation of human-made products and a process for solving problems [4]. This means that engineering education is more than a career in University; concepts related to engineering and technology are a transversal issue for all knowledge fields, people use technology in the current life independently of their profession or work. Therefore, educational approaches and facilities focused on learning engineering concepts and technology are very important at all educational levels and especially in the K-12 education.

Taking into account the advantages of educational robotics and the requirements of engineering education, robotics becomes a suitable resource for K-12 education because it (i) creates the suitable learning conditions, (ii) mixes technology and innovation, (iii) is an interesting support facility to encourage learning, (iv) involves the students in an inventive way and (v) offers the scaffolding for the current educational challenges.

Robotics has been widely used to encourage STEM (Science, Technology, Engineering and Mathematics) education. McLurkin et al. [5] described experiences using a low-cost robot for STEM education; Cielniak et al. [6] showed the integration of robotics in a curriculum of computer science; Vona & Shekar [7] presented an interdisciplinary course of robotics that includes class ses-

* Accepted 15 October 2016.

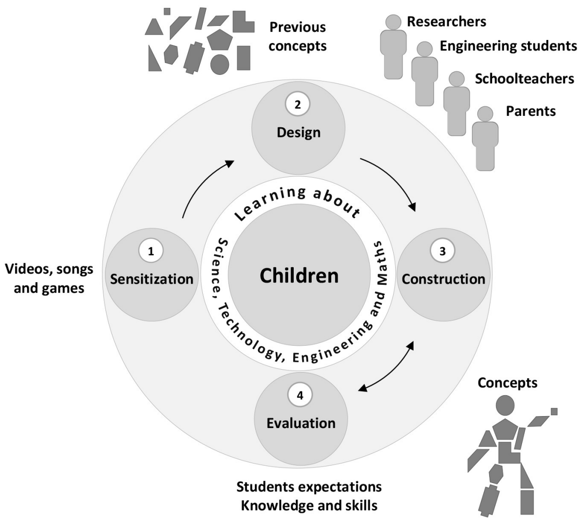

Fig. 1. K-12 engineering education approach for preschool and elementary school.

sions, lab exercises and a project to encourage competition-based learning; and Yilmaz et al. [8] introduced a design-oriented robotics educational model that considers two courses supported with lab practices. These works are in a special issue in Robotics Education [9], which addresses topics such as frameworks for distance education, platforms, teaching practices and novel approaches for engineering education. Other works related to STEM learning that uses robotics are [10, 11], the first one [10] promotes the learning by a robotics competition and the second one [11] focuses on supporting to teachers in how to implement STEM lessons by using Robotics, these lessons are oriented to elementary school.

Nowadays, the market offers educational platforms for robotics such as LEGO Mindstorm®, VEX Robotics® and Bioloid®. These platforms intend to introduce people to robotics by offering assembling, customizable and programmable robots. These resources have been widely used throughout the world with remarkable success. Many institutions use commercial didactic platforms in different educational levels, taking advantage of their features and modular components. For example, reference [12] describes an experience carried out in a robotics course for senior level engineering. The work [13] presents the LEGO League as a scenario to enhance the education and motivation of engineering students. Other contributions like [14, 15] show experiences where LEGO robots are used in outreach programs to promote the enrollment of young people in engineering programs. Particularly, [14] describes the evaluation results from an annual LEGO robotics competition for students in elementary and middle schools.

Regarding robotics in school, several studies [16–19] show different contributions about the use of robotics in K-12 education. Benitti [20] presents a literature review regarding the use of robotics in school, in which authors show comparing tables about aspects such as the subject, robot type and age range of kids. The reported results in Benitti's review [20] allow noting that robotics not only supports the teaching of subjects related to it but also promotes the development of transversal skills, such as problem solving, scientific inquiry, social communication and thinking skills.

The use of LEGO robots is also common in K-12 education. In [21], authors present LEGO robots to support the learning of computer science in high school. Other studies like [22–25] use LEGO robots for learning STEM concepts in K-12 education. Pinto et al. [26] describe an experience in preschool and elementary school developed by using LEGO robots to learn concepts related to numbers, colors and geometry. Likewise, most of the reported works in Benitti's review [20] are developed using LEGO robots.

Concerning the use of robotics in childhood and the exploration of this resource as an educational technology in constructionist approaches, in [27], authors introduce an educational program in which robotic tools are used to engage kindergarten students in computational thinking and other topics, even robotics. In the same sense, the work presented herein proposes a K-12 approach based on constructionism theory to introduce some basic engineering concepts by using robotics. However, instead of to use LEGO robots or any other commercial platform, the proposed approach takes advantage of the design and construction of simple robots like a strategy to encourage the learning by doing. Thus, the robot appears as the pretext and target at a time for developing the academic activities of the approach.

The proposed K-12 approach considers four stages (namely, sensitization, robot design, robot construction and evaluation) to encourage the learning and offers an alternative to learn about robotics using practical exercises that involve schoolteachers and children. The developed approach seeks to propitiate the learning of STEM concepts, and it mainly focuses on preschool and the first grades of school. The approach focuses on strategies for imparting engineering knowledge through the robotics dealing topics related to physics, electricity, electronics, mechanics and other fields related to engineering education employing an open and affordable technology. This approach was developed by the Robotics and Automation Research group (GIRA) at Universidad Pedagógica y Tecnológica de Colombia in Sogamoso, Colombia. The results presented herein correspond to the experiences observed at a local school during two years in preschool and second grade.

The rest of the paper is organized as follows. The second section describes the designed K-12 approach. The third section shows examples of the designed robots. The fourth section presents the instruments used to assess the impact of the K-12 approach, which also consider techniques of qualitative research. Finally, the fifth section presents the concluding remarks.

2. Proposed K-12 approach

The proposed K-12 approach implies the design and assembly of a robot, as a strategy to design the evaluation and academic activities. Fig. 1 shows the stages of the K-12 approach, namely, sensitization, robot design, robot construction and evaluation.

2.1 Sensitization

This stage engages students in the robotics world. The sensitization stage considers five phases to catalyze the use of robotics as an educational resource (see Fig. 2). These phases are: (i) parents involving, (ii) ice breaking, (iii) how a robot is made up, (iv) what we want to do and (v) conceptualizing.

The phase 'parents involving' aims to parents know the importance, advantages and implications of robotics in the school's education. Here, researchers design workshops to identify the preconceptions that parents have about robotics by talking about the use of robotics in health services, home, army, school and industry, among others.

The phase 'ice breaking' focuses on getting the kid's attention. Researchers develop workshops aimed to engage kids in robotics through movies, video games, kid toys and robots assembled using commercial platforms such as LEGO Mindstorms® and Bioloid®.

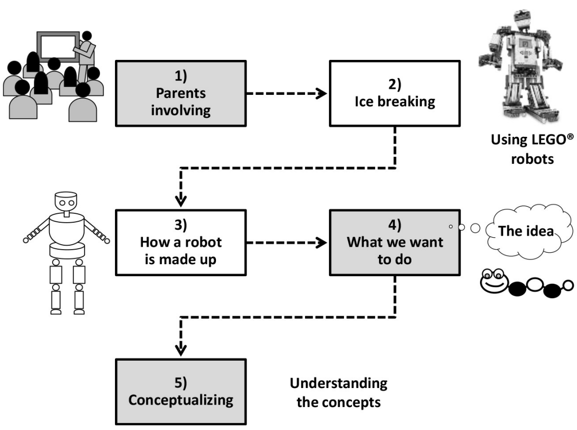

Fig. 2. Phases of sensitization stage.

The phase 'How a robot is made up' is devoted to help children to construct the concept 'robot' by identifying its parts and main features. In this phase, workshops involve activities such as drawing a robot and putting together a puzzle. Children discuss 'what is a robot' and talk about the materials used for its construction and its possible applications.

In the phase 'What we want to do', children choose the thematic and type of robot that they will construct. Taking into account that the proposed approach uses previous concepts [28], the chosen thematic must be widely known by all of the stakeholders. This approach exploits 'animals' as a main thematic for designing the robot because children feel strongly attracted to this topic and they have access to much information about it from TV programs, video games, books and pictures. Other topics and types of robots can be chosen as long as these meet the kids' expectations.

Finally, the phase 'Conceptualizing' focuses on understanding some basic engineering concepts. This phase employs workshops that compare the senses of the human body to the sensors used by the robot, for example, the relationship between eyes (vision) and CCD sensors or ears (hearing) and microphones. Similarly, the concept of processor is associated to the human brain; DC motors, gears and pulleys to muscles; and the energy that the robot needs to operate is linked to the food consumed by living beings. Workshops can also be related to animals and seek to help children to understand specific concepts; for example, a brief discussion about bats is useful to explain the function of an ultrasonic sensor. Other material and activities are developed to teach concepts that are not easily associated with animals or human beings, such as magnetic fields, electromechanical forces, etc.

Once an animal is chosen, researchers motivate children to observe aspects of the animal, such as body parts, what it eats, where it lives, how it behaves and which senses it uses to interact with its environment. Kids can understand the differences and similarities between the chosen animal and human beings and analyze what components are necessary to build the robot. For example, if the chosen animal is a ladybug, kids can identify, by means of comparison workshops, the number of legs, arms, wings, etc., that it has. Then, kids think about the motion of the robot to emulate the real animal (e.g., in the natural world, a ladybug has legs but a ladybug robot could use little wheels).

In short, the conceptualizing phase offers a holistic space to learn concepts related to subjects such as physics, electronics, mechanics, technology, mathematics and biology through the design of a robot intended for exploring the play-dimension of chil-

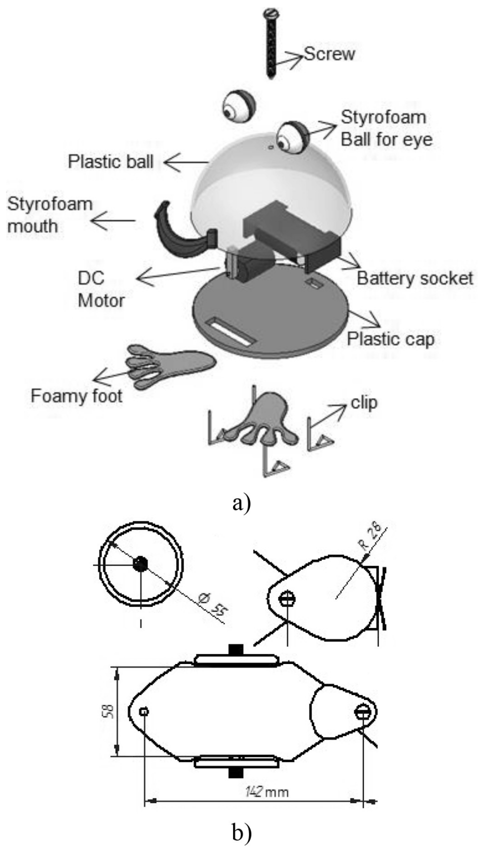

Fig. 3. (a) Parts of the robotic prototype inspired in a frog, (b) wheel, head and body unit of robot inspired in a worm.

dren. In this space, concepts are dealt together; robotics appears as an excellent excuse to encourage learning by playing [29].

2.2 Robot design

This stage stresses on discussing characteristics of the chosen animal to define the features of the robot. For example, it is possible that in the sensitization stage, the children have observed that a real ladybug is able to fly; however, implementing this function in the robotic prototype is a very complex and expensive task. Therefore, flying is a specification that is discarded for the ladybug robot.

Thus, researchers propose to children several draft prototypes of robots meeting parameters such as the aesthetics aspect, safety cautions, cost, easiness to build, the use of available or second-hand materials, and the use of as few screws and pieces as possible. Fig. 3 shows sketches of proposed robots for preschool grade and second grade.

2.3 Robot construction

The robot construction and design stages have a cyclical relationship and compose the basis of most of the academic activities.

Once the robot model is defined in the design phase, researchers use comparison workshops—similar to those used in the sensitization stage—to explain to children each part of the robot, its function and construction. Researchers also plan hands-on sessions to guide children and schoolteachers during the robot construction and execute some tasks, specially, those that offer a risk for children or require precision and/or programming abilities. The approach also centers in enhancing the aesthetic dimension of children. Therefore, children also carry out activities such as cutting the robot's pieces, painting and decoration, besides tasks related to the assembling of the robot.

Figures 3 and 4 shows an example of two robots designed during the K-12 Engineering Education Approach, which were inspired by two animals very common in their school-farm, a frog and a worm (these were called FrogBot and WormBot).

FrogBot is a very basic robot developed for preschoolers, which is easy to assemble, and its main function is jumping. The construction of this robot uses affordable materials such as paper clips, one screw, a plastic ball, small polystyrene balls and foamy pieces. Fig. 3a shows the FrogBot's parts and Fig. 4a presents its final appearance. The electrical circuit is very simple; a battery energizes a DC motor through a switch, and the DC motor has a short beam (that acts as a flywheel) connected to its shaft. When the DC motor is activated, its vibration makes the robot jump. The clips work as springs. This example, usual in the BEAM robotics, involves several activities that allow children to easily link words such as motor, switch and battery to actual elements and to construct the concepts of voltage, current and magnetic field. The activities of FrogBot are also oriented by schoolteachers and

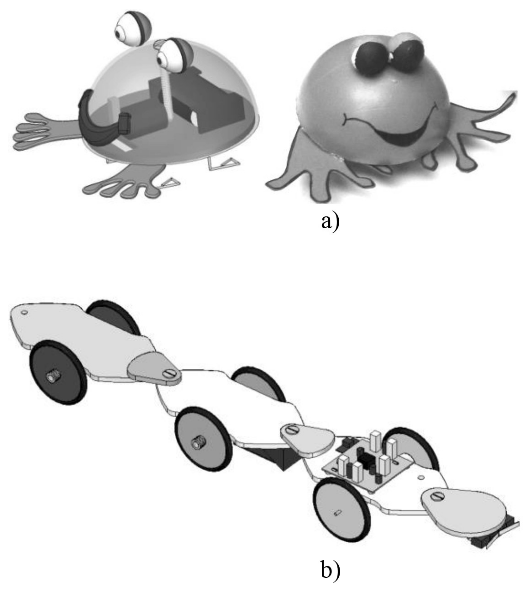

Fig. 4. (a) Frogbot, assembled robot (b) depiction of the assembled WormBot.

researchers to explore the multiple intelligences of children [30]. For example, cutting pieces seeks to enhance the children's fine motor skills related to the kinesthetic intelligence, which is an important goal in preschool education.

The WormBot is a robot designed to be used in second and third grade. This robot incorporates more advanced concepts, like mechanical advantage, serial and parallel circuits, transmission of motion, programming, and forward and reverse bias. This challenge involves the use of new vocabulary like processor, microcontroller, transistor, resistor, LED and sensor.

The robot uses a small PCB for controlling two DC motors. This circuit is based on a microcontroller that receives signals from sensors (two limit switches to detect collisions with objects) and generates two PWM signals (Pulse Wide Modulation) to control the DC motors, with a period of two seconds and a duty cycle of 50%. The PWM signals operate alternatively, so when a DC motor is turned on, another is turned off, thus, causing the zigzag motion of the worm robot. If the WormBot hits an obstacle, one of the limit switches (working as worm antennas) changes the state of a microcontroller input, making the opposite DC motor goes in reverse for two seconds to change the direction of movement of the robot. Rubber rings are used to improve the grip of the wheels. Fig. 4 presents the pieces that made up this robot.

It is important to note that despite children do not know about programming of microcontrollers, they understand perfectly its function in the robot operation, arousing their curiosity to learn new engineering topics.

2.4 Prototype evaluation

The evaluation comprises peer-assessment, self-assessment and assessment by teachers. The workshops have become evaluation spaces that allow observing the learning outcomes and interaction of participants. In workshops, children can learn from experiences of their classmates. Stories, problems and solutions help children to judge their own work. They also carefully revise the work of others, give comments and suggestions, discuss the adopted solutions and analyze those that were discarded. At the end of the academic year, children present their robots in an academic event in which their parents and teachers participate.

3. Impact assessment of the proposed approach

It is worth mention that the assessment of the approach impact stresses on knowing the acceptance of it as an educational strategy to encourage the STEM learning through robotics, but not on evaluating the learning outcomes of a Robotics syllabus. To assess the impact of the K-12 approach, different methods for data gathering were used. Considering the age range of the children, researchers preferred to use drawings made by kids, participant and non-participant observation, interviews and field notes to obtain information from children. Moreover, taking into account that parents and schoolteachers observed the development of the activities, two questionnaires were designed to know their opinions about the effect of the robot construction process on the children's learning.

In both questionnaires, the queries are presented as statements. Questionnaire 1 (for parents) asks about four aspects: (1) robotics as a didactic resource; (2) robotics as a way to keep in touch with technology; (3) the robot features; and (4) knowing how the robot construction activity favors the relationship between parents and children. Questionnaire 2 (for teachers) considers the same aspects changing the fourth one by 'the suitability of the workshops used in the sensitization stage'. The responders used a rating scale that ranges from 1 to 5 to answer the questionnaires, in which 1 means 'no compliance' and 5 is 'an excellent level of compliance of the statement'.

The reliability of the Questionnaire 1 was evaluated using the Alpha Cronbach Coefficient via Equation (1) [31].

$$\alpha = \left(\frac{k}{k-1}\right)\left(1 - \frac{\sum S_i^2}{S_{sum}^2}\right) \quad (1)$$

In this equation, k is the number of the survey items, S_i^2 is the variance of each item, and S_{sum}^2 is the total test variance. Coefficient values between 0.8 and 1.0 indicate a good reliability of the survey. The Alpha Cronbach Coefficient for this questionnaire was 0.942.

3.1 Parents' feedback

Table 1 has the queries for Questionnaire 1, twenty-six parents responded to the survey, all queries were graded over 3.4, and the score average of the queries was 3.8 (see Fig. 5). These results indicate that parents feel that robotics positively influences their children's education.

An analysis about the aspect 'robotics as didactic resource' shows that most of parents graded the queries of this aspect with four and five, indicating that they agree that the robot is a support resource in the classroom (see Fig. 6).

It is worth noting that in the aspect 'robotics keeps in touch with technology', parents scored the query QP4 with 4.0, which stresses on the

Table 1. Questionnaire 1 for Children's Parents

Robotics as didactic resource	
QP1:	Your kid was stimulated with the robot construction activity.
QP2:	Your kid speaks with confidence about the robot, its purpose and functions.
QP3:	Your kid developed the robot construction activity under her/his responsibility with little or no help.
Robotics keeps in touch with technology	
QP4:	The robot construction helps your kid to deal with topics about physics, electronics and mechanics. Please, list the new topics related with robotics mentioned by your kid.
Robot features	
QP5:	The robot was inexpensive.
QP6:	The robot was easy to build.
QP7:	The robot can be assembled without the advice of an expert.
QP8:	The robot design takes into account the expectations and interests of children.
Favoring of relationship between parents and kids	
QP9:	I participated in the construction of the robot.
QP10:	I spent more time with my kid during the construction of the robot.
QP11:	I learned about robotics thanks to my kid.

* The original text of questionnaires is in Spanish.

children's knowledge about physics, electronics and mechanics. Likewise, parents state that their children talk about new topics, such as microchips, motors, electronic components, mechanisms, springs, lights, pulleys, and antennas, when robotics is included in their syllabus.

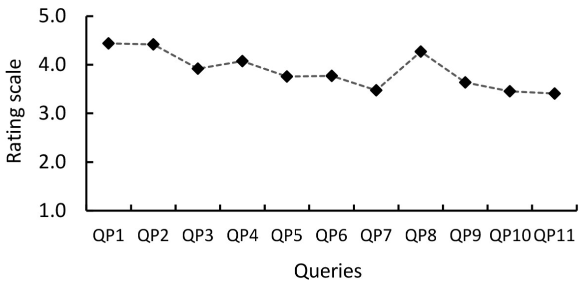

Fig. 5. Results of Questionnaire 1. The horizontal axis corresponds to the number of the query. The rating scale used is from 1 to 5, 1 = no compliance and 5 = excellent level of compliance of the statement.

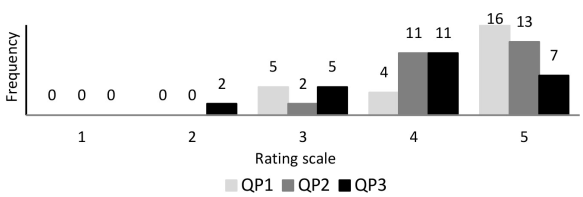

Fig. 6. Robotics as didactic resource. Responses to queries QP1, QP2 and QP3. The horizontal axis corresponds to the qualification of the query. The scale used is from 1 to 5; 1= no compliance and 5 = excellent level of compliance of the statement. The standard deviations are 0.646, 0.397 and 0.793, respectively.

Regarding the aspect of 'robot features', some parents consider that the robot is not inexpensive enough. Though the cost of the robot is about US 20, this price can appear a little high for some parents, taking into account the average income of the families (in Colombia, the minimum wage is about US 260). Likewise, some parents think that their children should be more involved in the assembling activities, especially those related to programming. In this regard, it is important to note that some activities require expertise and equipment not usually available in schools. Finally, query QP8 obtained the best score average of this group of statements; most parents graded this query with 4.0 or 5.0 (see Fig. 7).

The last group of queries is devoted to measure how the parents are engaged in the robotics world through their children (QP9 and QP10) and allows knowing whether the work on the robot makes parents spend more time with their children (QP10). Although most of the parents scored the questions with a level of compliance of four and five (see Fig. 8), some admit that they were not committed enough with the robot construction. When parents were consulted about 'who helps their children with the homework and assignments', many of them mention relatives, such as sisters, grandparents, aunts or uncles, for this task.

Questionnaire 1 also has open questions aimed to identify positive and negative aspects of the approach. Regarding to positive aspects, the parents stated opinions such as "it helps my kid to develop his/her intellect", "it helps to open his/her

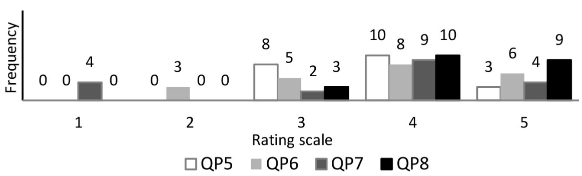

Fig. 7. Robot features. Responses to the queries QP5, QP6, QP7 and QP8. The horizontal axis corresponds to the qualification of the query. The scale used is from 1 to 5; 1 = no compliance and 5=excellent level of compliance of the statement. The standard deviations are 0.467, 0.993, 1.933, and 0.471, respectively.

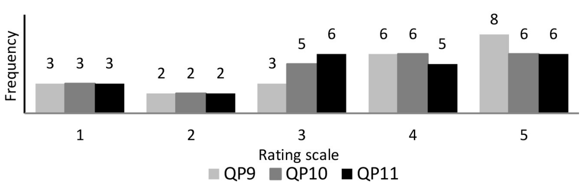

Fig. 8. Favoring of relationship between parents and kids. Responses to the queries QP9, QP10 and QP11. The horizontal axis corresponds to qualification of the query; the scale used is from 1 to 5, 1 does not compliance and 5 excellent level of compliance of the statement. The standard deviations are 1.67, 1.10 and 2.05, respectively.

Table 2. Questionnaire 2 for Schoolteachers

Robotics as didactic resource	
The robotic prototype:	
QT1:	Eases the teaching and learning of the concepts.
QT2:	Helps kids to learn autonomously.
QT3:	Encourages the work by projects.
QT4:	Promotes the research abilities of kids.
QT5:	Develops the aesthetic dimension.
Robotics keeps in touch with technology	
QT6:	The robot helps kids to improve their knowledge retention.
QT7:	The robot construction helps kids to deal with topics about physics, electronics and mechanics.
QT8:	The kids identify easily each component of the robot.
QT9:	The robot brings the technology to the classroom.
Please, list the new support resources used in the class related with robotics.	
Robot features	
QT10:	The robot was inexpensive.
QT11:	The robot was easy to build.
QT12:	The robot can be assembled without the advice of an expert.
QT13:	The robot design takes into account the expectations and interests of children.
Suitability of the workshops used in the sensitization stage.	
The activities used in the sensitization stage are consistent with	
QT14:	The age of the kids.
QT15:	The school grade.
QT16:	The syllabus.

* The original text of questionnaires is in Spanish.

mind", "it helps to develop his/her creativity and understand why and how lifeless things can move", "it promotes autonomy", "it is as a toy that moves", etc. About negative aspects, parents said things such as "it is very expensive", "my kid almost cannot manipulate the elements for assembling the robot by himself without help. . ." etc. In short, most of parents think that the robot design and its construction contributes largely to the education of their children, especially in the development of creativity and learning about electronics, mechanics and technology; however, some considers that kids need more autonomy for the robot assembly.

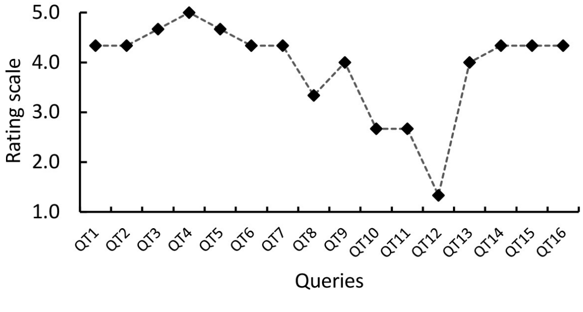

Fig. 9. Results of Questionnaire 2. The horizontal axis corresponds to the number of query. The rating scale used is from 1 to 5, 1 = no compliance and 5 = excellent level of compliance of the statement.

3.2 Schoolteacher feedback

Table 2 presents the queries of Questionnaire 2. Fig. 9 presents the average of each query. The schoolteachers recognize the effectiveness of the designed approach in developing research abilities. Teachers consider that robotics enhances knowledge retention and helps to understand technological concepts. However, as parents, teachers think that some kids cannot identify completely the components of the robot (see the score for QT8).

The aspect 'robot features' obtained the lowest of the score averages. Teachers also consider that robot construction is expensive for the participating families. QT12 was graded with a level of compliance of less than 2.0, which means that they consider important the advice of experts in this type of approach. On the other hand, they think that robot design really takes into account the expectations of children (QT13).

Finally, the average grade for the suitability of workshops was 4.33. This score is an important result for this research because workshops are the key strategies for the K-12 designed approach and organize all of the academic and evaluation activities. As positive aspects, schoolteachers remark the use of new support resources, the development of skills and the strengthening of creativity.

3.3 Qualitative observations

The children attended the workshops with special interest and devoted to learn concepts of mechanics and electronics. At workshops aimed to make the children able to identify the robot parts, children were encouraged to draw a robot with a list of its main parts. In children's drawings, researchers could observe that children usually link the term 'robot' to a humanoid robot. Kids also identify diverse components, features and functions of their robots. Among the more commonly listed functions are talking, walking, flying and playing, whereas some of the most remembered components are wheels, lights, sensors, DC motors and antennas. Similarly, children link robot features as the power supply system to the sun's energy. Children also include feelings and emotions, such as sympathy, happiness and friendship, as features that they want for their robots.

4. Concluding remarks

The proposed K-12 education approach exploits the creativity of the children using diverse strategies to motivate the learning of STEM topics. The designed workshops take advantage of the previous knowledge and curiosity of children to integrate engineering education in K-12 curricula. The workshops are designed according to the four stages defined in this approach. For example, in the sensitization stage, workshops seek to introduce robotics as a technological resource for learning by means of playful activities. The approach employs strategies such as: (i) games, songs and videos for phases 'parents involving' and 'ice breaking', (ii) brainstorms in the phases 'how a robot is made up' and 'what we want to do', and (iii) hands-on sessions for the conceptualizing phase and stages related to the design and construction of robots. The experience acquired on the application of this approach demonstrated that these activities are fundamental in motivating students to achieve a significant learning attitude.

The qualitative and quantitative results showed that the designed K-12 approach helps children to understand concepts related to STEM topics and promotes the development of transversal skills, such as teamwork, decision-making, self-learning and problem solving, as well as others related to the educational grade and context.

The survey results show that children's parents and schoolteachers think that the robot is a good didactic resource that helps children improve their knowledge retention and stimulate their creativity, innovation and research abilities. Moreover, they consider that robotics brings the technology to the classroom and the robot facilitates knowing new concepts about engineering. However, they state that the robot is not enough inexpensive and some assembling activities are unknown to children. For this reason, the Robotics and Industrial Automation Research Group (GIRA) at Universidad Pedagógica y Tecnológica de Colombia is using recycling materials and cheaper components in order to decrease the cost of robots, which are mainly oriented to public schools, children who cannot pay the cost of the current robot prototypes, and contexts in which commercial platforms are not affordable.

More than 100 children have participated in the experiences developed with the designed K-12 approach so far. Currently, researchers are applying the designed approach in third and fourth grade; in this instance, students use line follower robots by using electronic platforms as Arduino®. Although children do not use bioinspired robots, the approach stages are kept in the development of these new experiences. Researchers are working on an assessment approach focused on student learning to evaluate the effectiveness of robotics in the learning of STEM subjects.

Acknowledgments—The GIRA researchers thank the schoolteachers, parents and children of Friedrich Frobel Elementary School, located in Sogamoso, Colombia, for their contribution and collaboration to develop this research.

References

1. J. d. J. Velasquez Navarro, *Ambientes lúdicos de aprendizaje. Diseño y operación*. D.F: Trillas, S.A., México, 2008.
2. E. R. V. Sánchez, Educatrónica: Innovación en el aprendizaje de las ciencias y la tecnología: Ediciones Díaz de Santos, 2007.
3. S. Papert, The Children's Machine, *Technology Review,* **96**, 1993, pp. 28–37.
4. L. Katehi, G. Pearson and M. Feder, Eds., *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, Washington, D.C.: Committee on K-12 Engineering Education; National Academy of Engineering and National; Research Council, 2009, pp 27–45.
5. J. McLurkin, J. Rykowski, M. John, Q. Kaseman and A. J. Lynch, Using Multi-Robot Systems for Engineering Education: Teaching and Outreach With Large Numbers of an Advanced, Low-Cost Robot, *Education, IEEE Transactions on*, **56**, pp. 24–33, 2013.
6. G. Cielniak, N. Bellotto and T. Duckett, Integrating Mobile Robotics and Vision With Undergraduate Computer Science, *Education, IEEE Transactions on*, **56**(1), 2013, pp. 24–33.
7. M. Vona and N. H. Shekar, Teaching Robotics Software With the Open Hardware Mobile Manipulator, *Education, IEEE Transactions on*, **56**(1), 2013, pp. 42–47.
8. M. Yilmaz, S. Ozcelik, N. Yilmazer and R. Nekovei, Design-Oriented Enhanced Robotics Curriculum, *Education, IEEE Transactions on,* **56**(1), 2013, pp. 137–144.
9. T. Padir and S. Chernova, Guest Editorial Special Issue on Robotics Education, *Education, IEEE Transactions on*, **56**(1), 2013, pp. 1–2.
10. A. Eguchi, RoboCupJunior for promoting STEM education, 21st century skills, and technological advancement through robotics competition, *Robotics and Autonomous System*, **75**, 2016, pp. 692–699.
11. C. Kim, D. Kim, J. Yuan, R. B. Hill, P. Doshi and C. N. Thai, Robotics to promote elementary education pre-service teachers' STEM engagement , learning , and teaching, *Computers &. Education*, **91**, 2015, pp. 14–31.
12. C. N. Thai and M. Paulishen, Using Robotis Bioloid systems for instructional Robotics, in *Southeastcon, 2011 Proceedings of IEEE*, 2011, pp. 300–306.
13. D. Oppliger, Using FIRST LEGO League to enhance engineering education and to increase the pool of future engineering students (work in progress), in *Frontiers in Education, 2002. FIE 2002. 32nd Annual*, 2002, 3, IEEE, 6–9 Nov. 2002, pp. S4D-11-S4D-15.
14. T. Karp and A. Schneider, Evaluation of a K-8 LEGO robotics program, in *Frontiers in Education Conference (FIE), 2011*, IEEE, Rapid City, SD, October 12–15, 2011, pp. T1D-1-T1D-6.
15. J. U. Quevedo-Torrero, Attracting K12 Students with Standardized Outreach Activities, in *Information Technology: New Generations (ITNG), 2011 Eighth International Conference on*, IEEE, Las Vegas, NV, 11-13 April 2011, pp. 1099–1100.
16. C. Saygin, T. Yuen, H. Shipley, H. D. Wan and D. Akopian, Design, development, and implementation of educational robotics activities for K-12 students, in *Proceedings of 2012 American Society for Engineering Education Annual Conference & Exposition,* ASEE, June 10–13, 2012, San Antonio, TX, United states.
17. D. V. Lu and R. Mead, Introducing students grades 6–12 to expressive robotics, in *7th Annual ACM/IEEE International Conference on Human-Robot Interaction, HRI'12,* March 5–8, 2012, Boston, MA, United states, p. 411.
18. R. J. Dorsey and A. M. Howard, Measuring the effectiveness of robotics activities in underserved K-12 communities outside the classroom, in *118th ASEE Annual Conference and Exposition,* June 26–29, 2011, Vancouver, BC, Canada.
19. J. Brough, M. Baker and D. Casadonte, Work in progress–Classroom and distance components of a GK12 program placing graduate students in high school classrooms, in *Frontiers in Education Conference (FIE),* IEEE, Rapid City, SD , October 12–15, 2011, pp. T1C-1-T1C-2.

20. F. B. V. Benitti, Exploring the educational potential of robotics in schools: A systematic review, *Computers & Education,* **58**(3), 2012, pp. 978–988.
21. G. Kiss, Using the Lego-Mindstorm kit in German Computer Science Education, in *Applied Machine Intelligence and Informatics (SAMI), 2010 IEEE 8th International Symposium on*, IEEE, Herlany, Jan 20–30, 2010, pp. 101–104.
22. L. E. Whitman and T. L. Witherspoon, Using legos to interest high school students and improve k12 stem education, in *Frontiers in Education, 2003. FIE 2003 33rd Annual*, IEEE, Boulder, CO, November 5–8, 2003, pp. F3A_6-F3A_10.
23. D. Franz and B. B. Elmore, Work in progress–collaborative outreach to ‘‘atrisk’’ middle school students using LEGO robotics, in *2009 39th IEEE Frontiers in Education Conference*, IEEE, San Antonio, TX, October 18–21, 2009, pp. 1–2.
24. E. Kolberg and N. Orlev, Robotics learning as a tool for integrating science technology curriculum in K-12 schools, in *Frontiers in Education Conference, 2001. 31st Annual*, IEEE, Reno, NV, 2001, **1**, pp. T2E-12-13.
25. E. M. Jimenez Jojoa, E. C. Bravo, and E. B. Bacca Cortes, Tool for Experimenting With Concepts of Mobile Robotics as Applied to Children’s Education, *Education, IEEE Transactions on*, **53**(1), 2010, pp. 88–95.
26. M. L. Pinto Salamanca, N. Barrera Lombana and W. J. Pérez Holguín, Uso de la Robótica Educativa como herramienta en los procesos de enseñanza, *Ingeniería, Investigación y Desarrollo*, **10**(1), 2010, pp. 15–23.
27. M. U. Bers, L. Flannery, E. R. Kazakoff and A. Sullivan, Computational thinking and tinkering: Exploration of an early childhood robotics curriculum, *Computers & Education*, **72**, 2014, pp. 145–157.
28. J. S. Bruner, *The process of education*. Harvard University Press, 2009.
29. J. Huizinga, *Homo ludens*. Barcelona: Alianza Editorial, 2004.
30. M. K. Smith, *Howard Gardner and multiple intelligences*, The encyclopedia of informal education, 2002.
31. R. Ledesma, AlphaCI: un programa de cálculo de intervalos de confianza para el coeficiente alfa de Cronbach, *Psico-USF*, **9**(1), 2004, pp. 31–37.

Nelson Barrera Lombana received a Bachelor’s degree in Electronics Engineering and an M.S. degree in education from Universidad Pedagógica y Tecnológica de Colombia, Sogamoso, Colombia. Currently, he is a PhD student in Education and an Assistant Professor at said university. His research areas are Engineering Education and Digital Design.

Liliana Fernández-Samacá, received a Bachelor’s degree in Electronics Engineering from Universidad Pedagógica y Tecnológica de Colombia, an MS degree in industrial automation from Universidad Nacional de Colombia and the PhD in electronics engineering at Universidad del Valle, Colombia. She is an assistant professor at the Universidad Pedagógica y Tecnológica de Colombia. Her current research interests include Control Systems Education, Project-Based Learning and Engineering Education.

Luis Ariel Mesa received a Bachelor’s degree in Electronics Engineering from Universidad Pedagógica y Tecnológica de Colombia, Sogamoso, Colombia, where he is a lecturer. His research areas are Renewable Energy and Educational Robotics.

Wilson Javier Pérez Holguín, He received a Bachelor’s degree in Electronics Engineering from Universidad Pedagógica y Tecnológica de Colombia, an MSc degree in industrial automation from Universidad Nacional de Colombia and a PhD in electronics engineering from Universidad del Valle, Colombia. He has been an assistant professor in the Electronics Engineering School at Universidad Pedagógica y Tecnológica de Colombia since 2005. His research areas are Microprocessor Testing, Educational Robotics and Digital Design.