Usability Evaluation of an Educational Robot for STEM Areas

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Keywords: Robotics, Usability, STEM, Technology-enhanced_learning, Scratch, mBlock.

Abstract: This article describes the development cycle of an educational robot designed to act as an interdisciplinary teaching tool integrated into the curriculum of STEM areas (Science, Technology, Engineering and Mathematics). We focused on the creation of the alpha version of the prototype and its heuristic evaluation by three experts, with the objective of appraising both usability and potential design problems. After all the issues and suggestions from the experts have been resolved and implemented, a beta version was developed and evaluated in its usability by five representatives of end-users with different age ranges and robotics knowledge. The System Usability Scale score of 92.5 points - Best Imaginable - show a very stable and satisfactory robot, with almost no usability problems detected.

1 INTRODUCTION

STEM areas (Science, Technology, Engineering and Math) are continuously growing, but the number of technical workers do not accompany that growth. As the 21st century brings new challenges, students should be prepared for increasingly complex life and work environments that will privilege proficiency in Learning and Innovation Skills that include Creativity and Innovation, Critical Thinking and Problem Solving, Communication and Collaboration (Partnership, 2016). This article describes the usability tests of an educational robot developed for kids and teens (8 to 18 years old).

This robot is meant to work as an interdisciplinary teaching tool to be applied in the curriculum, promoting students' technical competences and allowing them to develop skills such as Computational Thinking and Problem Solving.

2 BACKGROUND

2.1 Computational Thinking and Problem-Solving Skills

Computational thinking is a mental activity carried when formulating a problem to admit a computational solution that can be carried out by a human or a machine (Wing, 2017) and involves solving problems and designing systems using concepts fundamental to computer science (Wing, 2006). Problem-Solving skills is the most relevant learning activity students can engage in because the knowledge constructed is better comprehended and retained (Jonassen, 2011).

2.2 Micromouse Portuguese Contest

This contest is an international competition held in Portugal since 2011. The main challenge is to have a full autonomous micro-controlled robot vehicle, explore an unknown maze and find out the optimum route for the shortest travel time from start to end (Silva et al., 2015).

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Barradas, R., Lencastre, J., Soares, S. and Valente, A.
Usability Evaluation of an Educational Robot for STEM Areas.
DOI: 10.5220/0007675102180225
In *Proceedings of the 11th International Conference on Computer Supported Education (CSEDU 2019)*, pages 218-225
ISBN: 978-989-758-367-4
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Competition is one of the key factors for motivation and getting physical results contributes to the formation of student's independence, developing their leadership skills and promoting a positive educational process (Bazylev et al., 2014). As robot competitions encourage students to apply their knowledge to real-world problems and motivates them to learn new concepts for themselves (Pack et al., 2004), participating in a contest like this may aid the development of Computational Thinking and Problem Solving capabilities.

2.3 Visual Programming Languages

As the robot is aimed mostly to small children, its complexity needs to be somehow reduced; thus, the use of visual programming languages (VPL). VPL helps children start programming by reducing the level of abstraction using graphical program elements rather than text.

2.3.1 Scratch

Scratch is a VPL created by the Lifelong Kindergarten group at the MIT Media Lab. Originally thought as an approach to programming, designed to be easy for all ages, backgrounds and interests, to program interactive stories, games, animations, and share their creations (Resnick et al., 2009).

Scratch was made with a simple grammar, based on graphical programming and blocks that are put together to create programs. To make it even easier, the blocks have connectors that suggest how they can connect, allowing only the creation of code that makes sense (Resnick, 2012).

2.3.2 mBlock

Also marking its presence in the VPL world, mBlock appeared as a graphical programming environment based on Scratch 2.0 Open Source Code, thus maintaining all its features, and adding some others that make it possible to program Arduino projects within the same interface (Mblock.cc, 2017). This fact and the feature that allows programmers to create custom software extensions adapted to specific hardware, turn it into a perfect tool to work with the product we are developing.

3 METHOD

To develop the prototype we decided to follow an Instructional System Design model (Clark, 2000), which we will refer to as ADDIE, the acronym of its five phases: Analysis, Design, Development, Implementation and Evaluation (Figure 1). In this article, we will only describe the Analysis, Design and Evaluation phases.

The Evaluation phase is fundamental and should be a part of the process from the beginning because it supplies information that feeds all the cyclic process of design and development and is very useful when as a part of the spiral of analysis, design, evaluation, etc., by contributing to the continuous improvement of the prototype (Lencastre, 2012).

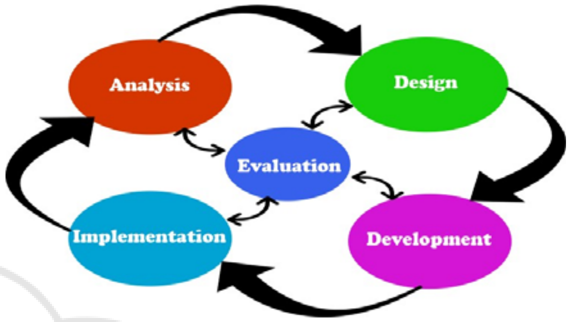

Figure 1: The ADDIE Model.

3.1 Analysis

The analysis phase is the foundation of a learning or training process (Clark, 2000), and allowed us to study the target audience of our educational product. By knowing their previous experience, education level, age, computer experience, among others, it is possible to anticipate learning difficulties and create boundaries to the complexity of the product (Nielsen, 1993).

Through documentary analysis and classroom observations, we tried to create a profile for the target audience of our product.

As we are targeting both Primary and Secondary school students, the first thing we have to consider is the age difference between the younger and the older students. In our analysis, the average age is 11.3 years old. In addition, the concepts and academic level differences are an important fact to consider. A relevant information is the fact that some of the students in our study already have some basic knowledge of robotics and programming in Scratch (Resnick et al., 2009), because Introductory Programming classes are a part of their curriculum. In addition, we also need to consider the latest government recommendations stating that every children from Primary to Upper Secondary education should have Programming and Robotics classes.

3.2 Design

The results obtained led us to idealise Kid Grígora (Fig. 2), an educational robot used as a teaching tool to be integrated into the curriculum. Besides that primary objective, Kid Grígora was designed to be small enough to allow children to use it in the Micromouse Portuguese Contest robotics Competition.

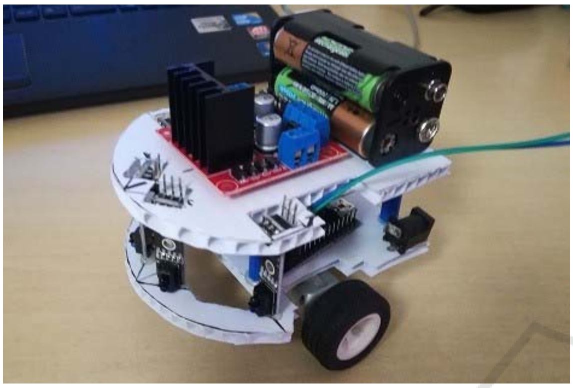

Figure 2: Alpha version of Kid Grígora.

3.2.1 Heuristic Evaluation of the Alpha Version

The alpha version of the prototype was tested in a heuristic evaluation by experts, with the objective of appraising both usability and potential design problems. In addition, to gather suggestions from the experts on how to solve the problems they found, before performing usability tests with representative users. To test the prototype, we chose double experts (Nielsen, 1993) experienced not only in usability but also with specific expertise in the interface under evaluation as they potentially find 1.5 times more problems than simple usability specialists (Nielsen, 1993). We used three experts, with ages from 40 to 48 years old, with a degree in areas related to computing, electronics and robotics. The average of teaching experience is 15 years and 9 years of business experience in developing software and electronics.

The evaluations were carried out on October 9-12, 2017, with a duration of approximately 90 minutes. It started with an explanation of the expected use of the robot by end-users, in particular on its use as an educational tool, but also on its possible use in a robotics contest. Then, the evaluators were given the robot's parts, a set of tools and assembly instructions and were asked to assemble the robot.

During the tests, each expert was asked to answer a heuristic evaluation questionnaire to report possible problems. To report the problems, they used a 0 to 4 Nielsen's severity rating scale (Nielsen, 1993) in which 0 means "I don't agree that this is a usability problem at all" and 4 means a "Usability catastrophe: imperative to fix this before product can be released".

Talking about the strong points of the heuristic evaluation, all the experts mentioned that the robot was very easy to build, mostly because of its small number of components. They also referred the physical similarity to professional built Micromouse robots. Two experts referred that because it has almost no soldering parts, it should be suitable for all target users, eventually with the help of an adult. All experts referred the use of standard components as a strong point as they are easy to buy, making it easy to replace damaged parts and due to their low price, they make this robot an educational tool, potentially for everyone.

The weakest points in the heuristic evaluation (ratings 3 and 4) are summarized in Table 1.

Table 1: Related severe and catastrophic errors, according to Nielsen's heuristics.

Nielsen's heuristics		
Interface (IN)		Degree
IN1	Visibility of system status	4
IN3	User control and freedom	3
IN4	Consistency and standards	4
IN7	Flexibility and efficiency of use	3
IN8	Aesthetic and minimalist design	3
IN9	Help users recognize, diagnose, and recover from errors	4
IN10	Help and documentation	3

Regarding IN1, two experts mentioned that the robot had no information on the status. Related with IN3, all of the experts stated that the robot needed to have an ON-OFF switch and one of them referred that as older students may require a little more control over the robot, it should be useful to have it equipped with encoders and gyros so that more elaborated algorithms could be implemented. One of the experts, referring to IN4, mentioned that the Traction system would not work at very high speeds as the motor connected directly to wheel brings speed but almost no torque. The difficulty on perceiving the robots movements, when working with youngest students, was mentioned by one of the experts as being potentially a problem, related to IN7. All experts mentioned that the type of battery used could be lighter, thus reducing the overall weight of the robot. Still related to IN7, one of the experts mentioned that the use of IR Sensors might be too difficult to program and understand by young students. Regarding the design and IN8, all the experts mentioned that the battery positioned on the top of the robot would create a very high gravity center. The fact that the robot has no error messages led one of the experts to signal a catastrophic error related to IN9. Referring to IN10, all experts mentioned the fact that it will be necessary to have detailed help on the electrical connections assembly because children may have some difficulty understanding it.

3.3 Development

3.3.1 Building the Beta Version

Although only Major and Catastrophic problems (ratings 3 and 4) were described, before building the beta version, all reported problems and suggestions of the experts were solved and implemented, as summarized in Table 2.

Table 2: Solutions for usability problems found.

Heuristic	Problem found	Solution
IN1	No information on the status	Add a Status LED
IN3	The robot needs an ON-OFF switch	Change the electrical connections and add a power switch
IN3	Equip the robot with encoders and gyroscope	Create a SemiPro version with encoders, Gyro and accelerometer (Figure 3)
IN4	Traction system would not work	Use motors with reduction (Figure 4)
IN7	The type of battery used could be lighter	Change the type of battery from 4xAA 1.5v to a 9V battery
IN7	The use of IR Sensors might be too difficult to program and understand by young students	Use simpler Ultrasonic sensors in Kid Grígora Rookie, but keep the IR sensors in Kid Grígora Semi-Pro (Figure 3)
IN7	It may be difficulty to perceive the robots movements, when working with youngest students	Create an add-on to the Kid Grígora Rookie, with a pen, for the students to visualize the trajectories (Figure 6)
IN8	The battery positioned on the top of the robot would create a very high gravity center.	New battery type allows a different position in the chassis, lowering the height and center of gravity
IN9	No error messages	Use a LED to display Error codes
IN10	More detailed help on the electrical connections assembly	Created new electrical schematics suitable for kids

The results of the heuristics analysis led to the idealization of two models of our robotic platform, mainly due to the age difference and academic levels between our target audiences.

Kid Grígora Rookie is the simpler of the two models. Aimed to students aged from 8 to 15, this robot allows younger students to make their first steps in robotics and programming. The price and the ease of build have been taken in consideration, to make it affordable and easy to assemble.

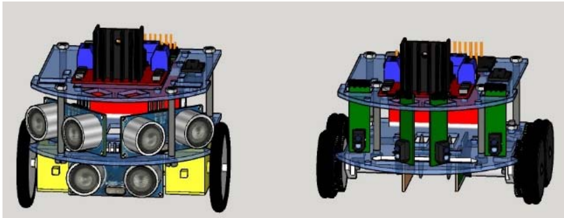

Figure 3: Kid Grígora Rookie and Semi-Pro 3D art, Beta versions.

Kid Grígora Semi-Pro is the most complex, having more powerful specifications, allowing students, from 15 to 18 years old, to apply knowledge from other areas like Mathematics or Physics. With a more powerful processor, motors with encoders, a three-axis gyroscope and accelerometer and four infrared distance sensors, this model allows a much more accurate control of movements.

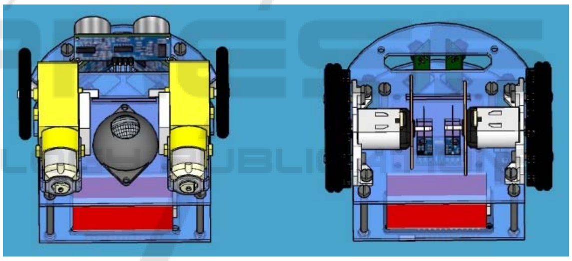

Figure 4: Final design of the Traction System in the Beta version of Kid Grígora Rookie and Semi-Pro.

3.3.2 Usability Tests with Representative Users

The usability tests with representative users were carried out on December 18-22, 2017. Nielsen (2000) states that "after the fifth user, you are wasting your time by observing the same findings repeatedly but not learning much new". Therefore, we chose five representative users with different age ranges and robotics knowledge to evaluate our prototype.

Although we developed and built both models of Kid Grígora, as in our analysis, our target medium range was 11.3 years old, in this article we will focus on the tests performed with Kid Grígora Rookie.

The tests were carried by five students, aged from 11 to 17, two boys and three girls, and had an average duration of 127 minutes, with a 15-minute pause for

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the users to rest and then regain their focus on the tasks. As for background on robotics, only two users were already engaged in extra-curricular robotics activities at school. The other three had never been in close contact with robotics.

Figure 5: Representative user performing Usability test.

Starting with a simple explanation on the basics of the assembly and best practices to do it, the users were given the robot's parts, a set of tools and the assembly instructions in the form of a gallery of pictures and videos, and were asked to assemble the robot. In all tests, we used the think-aloud protocol, letting users verbalize their thoughts as they move through the interface (Nielsen, 1993), and audio recording to gather data.

At the end of the tests, the users were asked to fill a SUS satisfaction questionnaire (Brooke, 1986), whose average satisfaction results were given a meaning by using the adjective scale of Bangor et al., (2009). The obtained results are summarised in Table 3.

Table 3: Summary of usability tests results by representative users.

	User 1	User 2	User 3	User 4	User 5	Avg
Sex:	F	M	M	F	F	
Age	16	13	11	11	17	13.6
Previous robotics?	N	N	N	Y	Y	
Length (min)	131	134	147	120	103	127
Rating	92.5	85	90	95	100	92.5
Meaning	Best Imaginable	Excellent	Excellent	Best Imaginable	Best Imaginable	Best Imaginable

The mean result of the five tests was 92.5 points, Best Imaginable, meaning that there were almost no usability problems detected with the prototype. The analysis of the results show that the representative users were unanimous giving the Strongly agree score to the question "I think that I would like to use this robotics kit frequently" and the to Strongly disagree to the question "I found the robotics kit unnecessarily complex" which shows the good acceptance of this robotics kit. The analysis of the think-aloud showed that most of the difficulties lied in the part of the wiring, particularly in those users who have never had contact with robotics. This led us to think that perhaps an introductory session on the concepts of electronics and wiring will be necessary before end-users start using the kit.

4 KID GRÍGORA ROOKIE HARDWARE COMPONENTS

To build Kid Grígora Rookie, we chose to use only standard electronic components like Arduino Nano, L298N Motor Controller, two Geared DC Motors, three HC-SR04 ultrasonic sensors and a 9v battery, easily available in both local and online electronics stores.

For the pen add-on, we designed two 3D printed parts that can be easily fit in a standard 9G servo.

Figure 6: Assembled Kid Grígora Rookie with and without the pen add-on.

5 PLANNED SOFTWARE INTERFACES

5.1 Extensions for mBlock

Currently under development, the two mBlock (Mblock.cc, 2017) extensions will be one of the core components of this project (Figure 7).

The Simple KidG extension will have a basic set of blocks to move the robot, like Move Forward, Turn Right and Turn Left, and will be used, typically by students from 8 to 12 years old.

To students from 12 to 15 years old, the KidG extension provides a greater level of control over the robot, with different left and right motor speeds and

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different sensor distance measuring, allowing students to do different kinds of interactions with the robot.

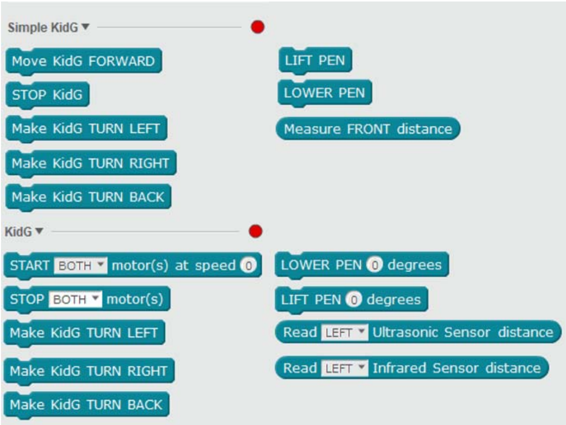

Figure 7: Proposed mBlock extensions.

5.2 Android Apps

In order to reach our younger audience, we have planned the development of two type of Android Apps, typically to be used by students from 8 to 12 years old.

The KidG Remote Control will allow young students to remotely control the robot and explore all its movement possibilities.

The KidG Step by Step will allow students to create simple algorithms, send them to the robot and watch it execute them (Figure 8).

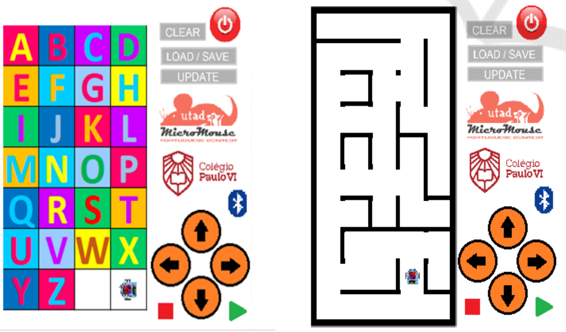

Figure 8: Different possibilities of android apps.

5.3 Virtual Maze

Virtual Maze (Figure 9) is a configurable representation based on a real world maze, programmed in Scratch. This project was designed to provide students a first contact with the Micromouse Contest using it to simulate simple Maze Solving algorithms.

Future versions will include a Bluetooth connection to the robot, allowing it to replicate the robot's movements on the screen to a real robot, in a real maze.

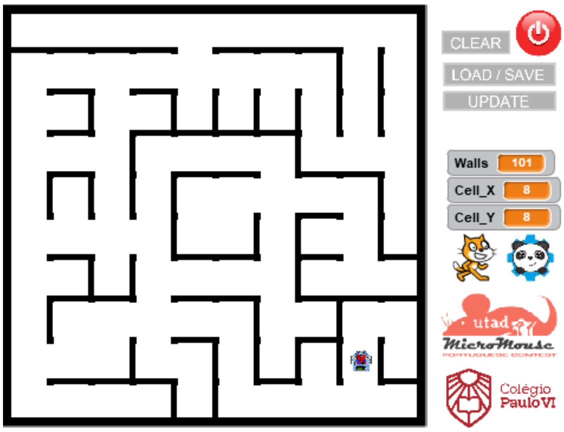

Figure 9: VirtualMaze implementation in Scratch/mBlock.

5.4 C++ and the Arduino IDE

Implemented as Firmware and typically used by older students, the planned Arduino libraries will allow students to program Kid Grígora with C++ while providing high levels of abstraction to interact with the hardware. Planned functions include movement procedures, like MoveForward, TurnLeft, TurnRight, TurnBack, and sensing functions, like ReadDisplacement, isWallLeft and isWallFront. By using this firmware, students will be able to create more structured and complex algorithms to control their robots.

6 EDUCATIONAL USES

6.1 Primary Education

For this range of ages, 8 to 12 years old, our main objective will be creating activities aimed to develop Computational Thinking with Kid Grígora Rookie, the Android Apps and the Simple KidG mBlock extension. Using real-life problems and scenarios and interacting with virtual environments, created in mBlock, children can take their first steps in robotics and programming.

6.2 Lower Secondary Education

Simulating in the Virtual Maze allows students from 12 to 15 years old, to further develop their Problem-Solving skills by placing them on the control of a robot that needs to find the center of a maze. By creating Maze Solving algorithms, students can test their algorithms on screen and later, with their assembled robot and the KidG mBlock extension and bluetooth, they can debug their algorithms in both Virtual Maze and real life. Later, still using mBlock, they can develop a program to work autonomously and enter the Micromouse Portuguese Contest.

6.3 Upper Secondary Education

With the focus on older students and aiming the participation in a Robotics Competition, the use of the custom firmware created in the form of Arduino libraries allows students, mainly from 15 to 18 years old, to take a step forward and no longer be limited to making their robot sense their way in the track and react. Using the libraries and deeper programming concepts and algorithms, students can create real autonomous navigation systems and path optimization algorithms for the robot. They can use them, for example, to participate in a Micromouse competition, find all possible ways to the centre of a maze, return to the starting point, backtrack the optimal route (Silva et al., 2017) and run to the centre the fastest it can.

7 CONCLUSIONS

Problem solving and Computational Thinking are two of the most needed skills for 21st century students. Following an Instructional System Design (Clark, 2000) we created a prototype of an educational robotics kit, aimed at children and teens aged from 8 to 18, to be used in scholar activities. In the Analysis phase, we gathered enough information to idealize the alpha version of the product, later tested by experts.

All usability issues detected were corrected in the development phase in which we created the beta version, tested by representative users. In the satisfaction test, the prototype obtained 92.5 points, Best Imaginable, that show a very stable and satisfactory robotic platform, with almost no usability problems detected, which serves as an incentive to the next phases.

8 FUTURE WORK

Future work includes usability tests of Kid Grígora Semi-Pro and the software interfaces, the development of other add-ons (see Figure 10) to increase the flexibility of the platform and the development of activities adapted to each age range.

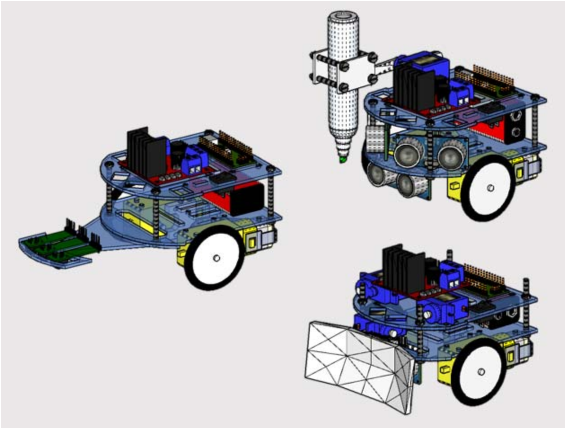

Figure 10: Planned add-ons for Kid Grígora.

ACKNOWLEDGEMENTS

This work is partially financed by the ERDF - European Regional Development Fund through the Operational Programme for Competitiveness and Internationalization - COMPETE 2020 Program within project POCI-01-0145-FEDER-006961, and by National Funds through the FCT - Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) as part of project UID/EEA/50014/2013.

This work is funded by CIEd – Research Centre on Education, project UID/CED/01661/2019, Institute of Education, University of Minho, through national funds of FCT/MCTES-PT.

This work was partially funded by National Funds through the FCT - Foundation for Science and Technology, in the context of the project UID/CEC/00127/2019.

We want to thank Colégio Paulo VI (Gondomar, Portugal), and the students of year 6th and 7th, for their collaboration and the authorisation to perform this research on their premises.

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