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Designing Stemie, the Evolution of the Kid Grígora Educational Robot

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Keywords: Robotics, Usability, STEM, Technology-Enhanced_Learning, Scratch, Mblock.

Abstract: STEM education advances at the same rate as the need for new and more evolved tools. This article introduces the latest version of the Kid Grígora educational robot, based on the work of Barradas et al. (2019). Targeted for students aged 8 to 18, the robot serves as an interdisciplinary teaching tool, integrated into STEM curricula. The upgraded version corrects what we've learned from a real test with 177 students from a Portuguese school and adds other features that allow this new robot to be used in even more educational STEM and problem-solving scenarios. We focused on the creation of a second beta version of the prototype, named Stemie, and its heuristic evaluation by three experts. After all the issues and suggestions from the experts have been resolved and implemented, the new version is ready for usability evaluation.

1 INTRODUCTION

As STEM (science, technology, engineering, and mathematics) education evolves, also the tools that teachers use need to evolve. This article introduces the next iteration of the development of the *Kid Grígora* educational robot by Barradas et al. (2019).

Designed to be used by students aged from 8 to 18, this robot was meant to act as an interdisciplinary teaching tool integrated into the curriculum of STEM areas. Due to the importance of adaptability to different STEM subjects, we decided to make it even more functional pushing even further the students' technical competencies. Together with the set of STEM-related exercises, currently under development, to be published in two books, aimed at students and teachers, this new version will provide an easier way for students to develop several skills such as Computational Thinking and Problem Solving and for teachers to more easily support them in this task.

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2 BACKGROUND

Based on the same concepts as previously, we revisit the concepts of computational thinking, problem-solving skills, and Visual Programming Languages.

2.1 Computational Thinking and Problem-Solving Skills

It's possible to define computational thinking as a set of processes involved in formulating a problem and its solutions in a way that a human or machine can effectively solve it (Wing, 2017), and it is more closely linked to conceptualization than to the coding process itself (Wing, 2007).

In the 21st century, children must have a range of functional and critical thinking skills related to information, media, and technology, and creativity, computational thinking and problem-solving are some of them.

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Barradas et al. (2021) studies on computational thinking showed some effective ways of developing those skills and consolidated the idea that if students must solve different types of unfamiliar problems in creative ways it makes them think creatively and get to better solutions. Also noted is the fact that students were developing their problem-solving skills, learning computer science concepts and having fun at the same time. This type of activity makes the knowledge constructed better comprehended and retained (Jonassen, 2011).

2.2 Visual Programming Languages

Visual programming languages, as noticed by Silva et al. (2015), provide higher levels of abstraction that turn out to be very useful when a project tries to reach a younger public. Typically with no previous programming experience, these users/students tend to start programming with Scratch at levels that go from elementary school to college, and subjects as diverse as math, computer science, language arts and social studies (Scratch Foundation, n.d.a).

Students can use Scratch to code with blocks and create interactive stories, animations, and even games (Resnick et al., 2009) learning to think creatively, reason systematically, and work collaboratively (Scratch Foundation, n.d.b).

Designed especially for ages 8 to 16, Scratch was made with simple grammar, and blocks with connectors that suggest where they can be connected (Resnick, 2012).

However, the real challenge of using Scratch for such a project is the Blocks themselves. Every piece of code needed to make a real robot work needs to be implemented. Data structures in Scratch are limited to simple variables and stacks which makes programming a complex algorithm and interaction with external and autonomous hardware may be a challenge.

On the other hand, the fact that in 2014, the source code for Scratch was officially released and set available at https://github.com/scratchfoundation, allowed the creation of several forks and add-ons. Some of these forks, such as mBlock, simplified the task of communication with external hardware and it allowed to reduce the complexity of code needed to program a robot (Mblock.cc., 2023).

This was achieved by adding a code translator module to the original Scratch code, that allows to code in blocks and translate them to languages such as C++ that the Arduino boards can be programmed with (Figure 1). Also, the functionality to create and add extensions to mBlock provides a higher degree of integration with external hardware.

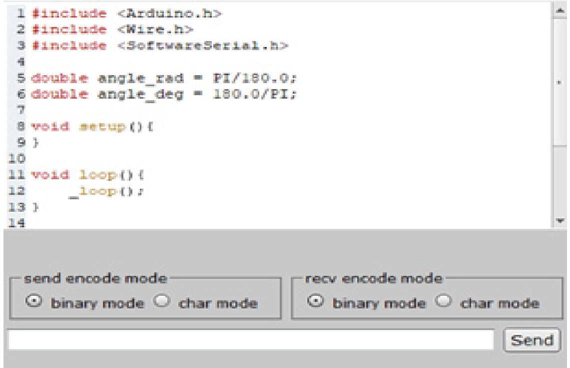

Figure 1: Arduino code generated by mBlock.

3 METHOD

Since the beginning, the development of the prototype was done following an Instructional System Design model (Clark, 2000), referred to as ADDIE, an acronym for Analysis, Design, Development, Implementation and Evaluation (Figure 2). In this article, we will describe another cycle of development namely the phases of Implementation, Evaluation, Analysis, and Design.

The Evaluation phase is fundamental and has been a part of the process since the beginning. It supplies information that feeds all the cyclic processes of design and development. It's very useful as a part of the spiral of analysis, design, development, and implementation as it contributes to the continuous improvement of the prototype (Lencastre, 2012).

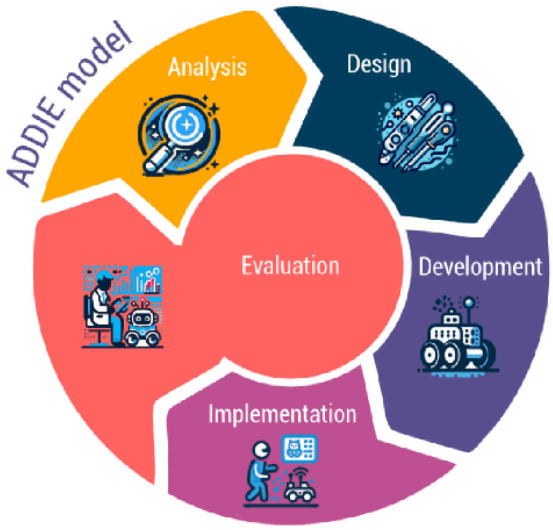

Figure 2: The ADDIE Model.

3.1 Implementation

In the school year of 2018/2019, we implemented a controlled test, in a real user scenario that involved 177 students, 100 from the 5th grade and 77 from the 6th grade of a Portuguese school. In that year, 6 lessons of the ICT and programming classes of those students were dedicated to assembling *Kid Grígora* and 6 more to use it, programming with mBlock.

The students in the study belonged to 8 different classes, 4 from each of the 5th and 6th grades of schooling. Classes had different durations for each year of schooling, being 150 minutes for the 5th year and 90 minutes for the 6th year. The distribution of the students per class is seen in Table 1. Each class had independent lessons and the students didn't mix while assembling the robot.

Table 1: Distribution of students per class.

	Number of students per class			
School year	A	B	C	D
5th	26	25	24	25
6th	17	16	23	21

At the beginning of the test, the students were randomly distributed in the classroom and were given a *Kid Grígora* kit with all the components they needed to assemble the robot (Figure 3).

Figure 3: Parts on the Kid Grígora kit.

The assembly instructions consisted of a set of 194 detailed photographs and 5 videos, available online, that allowed the students to build the robot step by step (Figure 4).

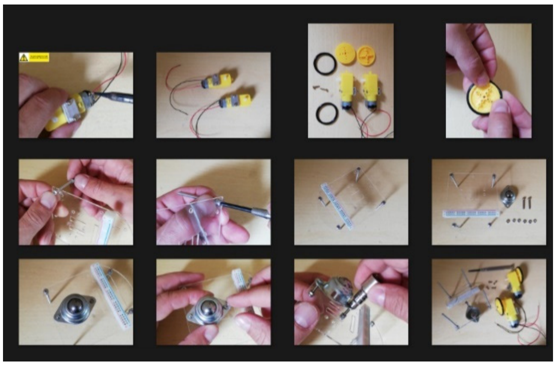

Figure 4: Sample of the assembly instructions.

At the end of the test, all students were supposed to have built a *Kid Grígora* robot (Figure 5).

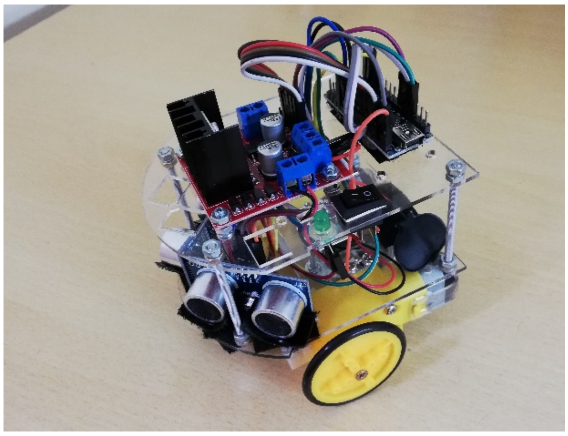

Figure 5: Assembled Kid Grígora.

After the assembly test, all 177 robots were collected by the responsible teacher and carefully reviewed, with all assembly problems noted for later analysis.

3.2 Evaluation

From the 177 students, we registered 22 (approximately 12%) that finished the assembly without any error. Also to take note is that 12 students (approximately 7%) were not able to finish the robot within the determined time (Table 2).

In total, we registered 330 errors distributed by 14 different types.

Table 2: Maximum and minimum results.

Grade	# STUDENTS	All correct	Not finished
5th	100	9	6
6th	77	13	6
TOTAL	177	22	12

To organize the collected data, we chose to categorize it into meaningful categories, by assigning a label to each one of the errors found.

Using categorization, allowed us to reduce our results from 14 types of errors to 3 different categories, more measurable and comparable:

- Structural Errors: issues related to the design and physical structure of the robot. In this category, we included all problems related to mechanical aspects, such as the lack of components in the final assembly, the fixing points, missing wiring, or the assembly of the robot;
- Powering Issues: related to the power supply to all the components of the robot. In this category, we included problems like missing power lines for certain components and mixing GND and Vcc or creating any sort of short-circuit;
- GPIO (General-Purpose Input/Output) errors: errors that are related to the connections between the Arduino microcontroller and the rest of the components. We included all incorrect wiring that may cause the input or the control signals from working.

In both grades of schooling, as shown in Tables 3 and 4, most of the detected errors fell into the *Powering Issues* category.

Table 3: Summary of detected errors for 5th-grade students.

# STUDENTS	STRUCTURAL ERRORS	POWERING ISSUES	GPIO ERRORS	AVG/STUDENT
100	55	123	13	1,91

As expected, the older students assembled the robots with a lower average of errors per student, although not much different.

Table 4: Summary of detected errors for 6th-grade students.

# STUDENTS	STRUCTURAL ERRORS	POWERING ISSUES	GPIO ERRORS	AVG/STUDENT
77	51	78	10	1,81

To better compare the results of both grades of schooling, we normalized the data. The results of the normalization can be analysed in Figure 6 and show that older students ended up making more mistakes in terms of structural errors than the younger ones. However, in terms of wiring the components, the 6th graders had a better performance than the 5th graders, with fewer errors in the *Powering Issues* category.

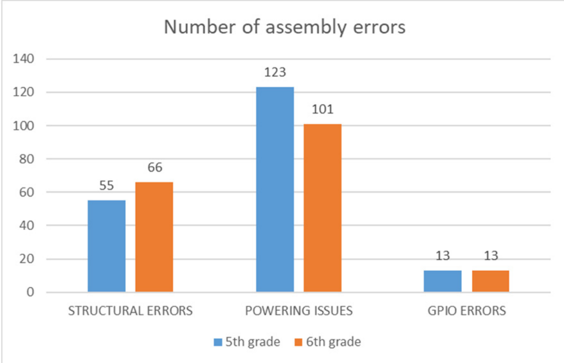

Figure 6: Normalized data comparison of assembly errors between 5th and 6th graders.

In terms of percentage, the distribution of errors is shown in Figure 7, with the category *Powering Issues* being the one in which the most errors were detected (61%). This very relevant information showed us that, at least for this age range, the information present in the assembly instructions needs to be more detailed in terms of powering all the components of the robot.

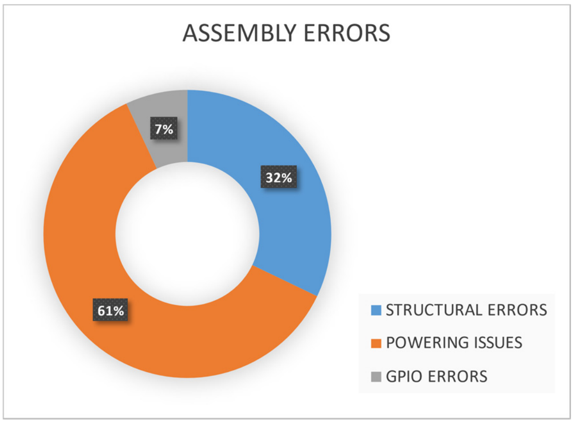

Figure 7: Pie chart of assembly errors.

Overall the results were very good, especially considering the age range of the students, with a global average of errors per student of 1,86.

In the second part of the testing, during 6 lessons, the same students used a simple framework, developed in mBlock (Figure 8) to program their robots in simple forward, backwards and turn movements, while reasoning to make their robots move and turn as straight as possible. In this part of the test, only the students who completed the robot in the previous task were involved.

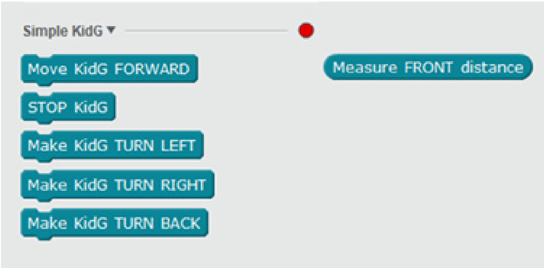

Figure 8: Extension developed for mBlock

After the 6 lessons, that functioned as a small stress test for the hardware, all the robots were rechecked, and the new problems were added to the initial results table and shown in Table 5.

Table 5: Summary of detected errors after assembly and stress test.

	STRUCTURAL ERRORS	POWERING ISSUES	GPIO ERRORS	AVG/STUDENT
5th and 6th grades	185	211	23	2,37

This new table shows that there was an increase in both Powering and Structural issues. However, in terms of Powering, the increase is around 5% while in terms of Structural Errors, the increase was about 75% as seen in Figure 9. This fact also increased the average of errors from 1,86 to 2,37 per student. In terms of GPIO, there was no new record of errors.

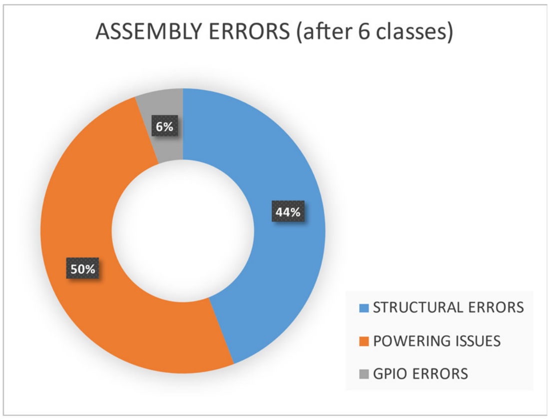

Figure 9: Updated Pie chart of detected assembly errors, after 6 classes stress test.

3.3 Analysis and Design Enhancements

The results after the 12 classes for assembly and stress use showed that the platform, although usable, needed some improvements in both Powering instructions and in terms of Structure.

It is possible to perceive from Barradas et al. (2019) that *Kid Grígora*'s simple structure was held together by M3 screws and hex screw nut. Also, the 3 front sensors were held to the main platforms by velcro tape. Although in the usability tests, there were no problems reported related to those components, what happens is that after some use, the hex screw nuts tend to get loose if not tightened well, and the structure was shaken. This fact caused almost every occurrence of errors in the structure, post-assembly. In terms of Powering issues, they were related to faulty batteries and bad soldering, not detected on the first inspection.

As we previously mentioned, to try to solve the Powering issues, we decided to create more detailed assembly instructions, using the same type of pictures but adding detailed text and tables with information on where to connect each of the jumper cables in the robot. (Figure 10).

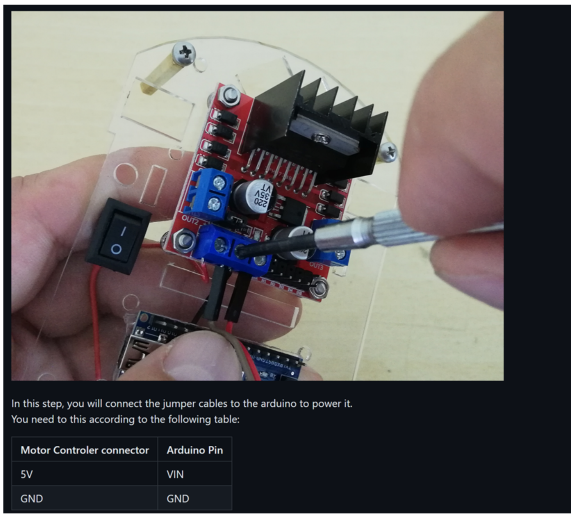

Figure 10: Updated assembly instructions.

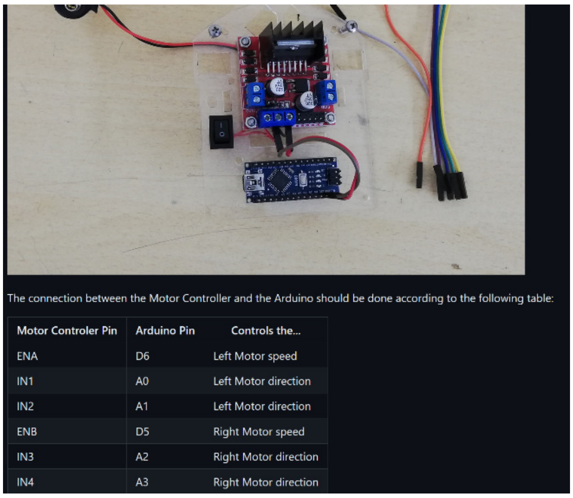

Figure 11: L298N connection to Arduino Nano.

Although there were not many errors in terms of GPIO, we decided that the new instructions should also have a table with every IO pin used in Arduino (Figure 11).

To cope with structural problems, we decided to change the structure holding points and don't use the M3 screws anymore, as we concluded that, for children of this age, that wasn't the best solution. After browsing the market for solutions, we chose to use M3 brass female spacers instead.

3.3.1 Upgraded Hardware Components

Remembering that we were creating an educational tool, the decision to upgrade the hardware came from the idea of enhancing the educational impact of our robot. As we were making changes, we decided to create a more versatile platform with other types of sensors and actuators. This should allow both students and teachers to use it, integrated with more scientific and technological subjects. Increasing problem-solving scenarios enables students to engage in more challenges across multiple STEM subjects and not only Robotics.

After meeting with teachers from STEM subjects such as Sciences, Physical Chemistry and Maths, the changes in Table 6 were made:

Table 6: Comparison of changed components.

Old version	Upgraded version
3 Ultrasonic sensors	1 Ultrasonic Sensor
1 Green LED	1 RGB LED
-	3 Infrared line sensor
M3 screws	M3 brass female spacers
Velcro Tape	Nano PU Gel Tape

Due to these changes, the list of components of the upgraded version of our robot is the one in Table 7 and Figure 12.

Table 7: List of components of Upgraded Version.

Quantity	Component
1	Arduino Nano
2	Geared DC Motor
1	3-channel infrared tracking module
1	HC-SR04 Ultrasonic Sensor
1	L298N DC Motor Driver
1	RGB LED module
1	9v Battery Holder Clip
1	Mini ON-OFF Switch
1	Mini Breadboard
1	USB cable
35	Jumper cables (10/20 cm, M-F & F-F)
1	Caster Ball
2	Plastic Wheels
4	Spacer M3 10mm
4	Spacer M3 30mm
2	Motor Bracket Holder (with screws)
2	Acrylic Platform 3mm
2	O-Ring

The upgraded version would still be controlled by an Arduino Nano, as this small microcontroller proved to be very reliable and its small form factor is very important for this project.

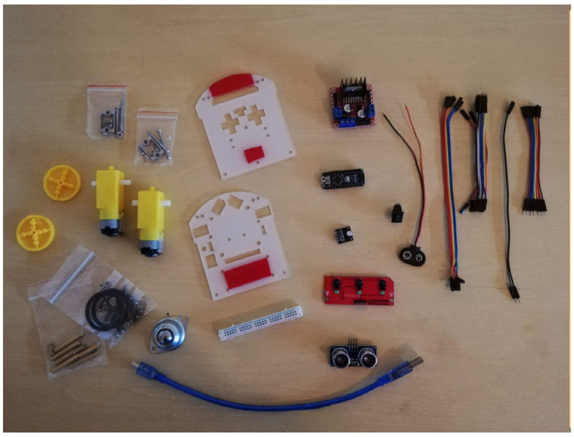

Figure 12: Components of the upgraded version.

Due to these small, but important, changes, the main platforms had to be slightly modified to accommodate the new components. The initial idea from Barradas et al. (2019), was to use 3D printed platforms for the robot. The robots used in the test we described already used acrylic laser cut platforms, much more inexpensive than the 3D printed version. For this upgraded version we opted to maintain the acrylic version but also have the option to use laser-cut MDF (Figure 13).

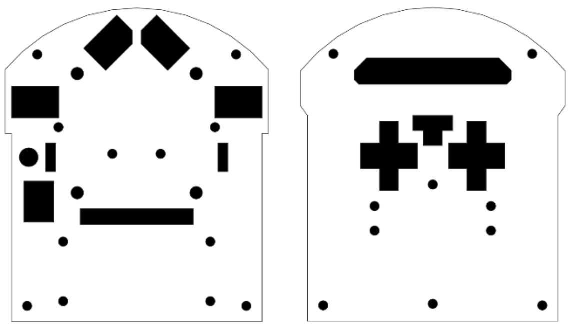

Figure 13: New design of the platforms.

These new platforms were made specifically for the two planned versions of our robot. The top platform, with specific holes for signal and power wires that connect to Arduino, holes for motor current wires, a specific one to place a power switch, and another one for the LED. As for the lower platform, there are specific rounded holes to attach the motor bracket holders and the Caster ball, as well as wholes for the jumper cables to go through to the breadboard and components like the 3-channel infrared tracking module and the HC-SR04 Ultrasonic Sensor. Both platforms also have round 3mm holes to attach the brass spacers that will join the two platforms and give the robot stability. The design of these platforms also reflects the changes needed for the future upgraded version of *Kid Grígora Semi-Pro*, not the object of this article.

3.3.2 Programming Interfaces

The main idea about the programming interfaces used in *Kid Grígora* remains in this upgraded version: to build a programming framework, simple enough to be used by small children, allowing them to explore the full potential of the robot.

However, due to the new features added, as the new components demand new programming functions, we had to develop a different set of commands. Looking at Figure 14, it is possible to perceive some differences in the developed framework for this version. We decided to use a terminology where the two engines can be controlled separately and with different speeds. To do so, we created a *motorFRONT* procedure that moves the motors forward and allows us to change the speed of each of them, by using it with its number (motor 1, Right side, or 2, Left side). Following the same idea, we created a *motorREVERSE* procedure that moves the motors backwards, and a *motorSTOP* that stops each motor. Combining these blocks you can control both motors, each one of them independently, allowing the students to create their own set of movements. In terms of using the sensors, we created a *readDISTANCE* procedure that allows easy use of the ultrasonic sensor and a *readLINEsensor* procedure that reads the floor under the sensor to try to find out whether there is a white or black line to follow. To allow an easy way to use the RGB LED, we created a *LED* procedure, fed with the RGB values of the colour you want to display on the LED.

Figure 14: Programming framework.

The framework was built in a way that the teachers and more advanced students could analyse all the details of the programming. Instead of creating a black box with impossible-to-analyse functions, we created simple procedures in mBlock, leaving all the code visible for them to study and change if needed (Figure 15).

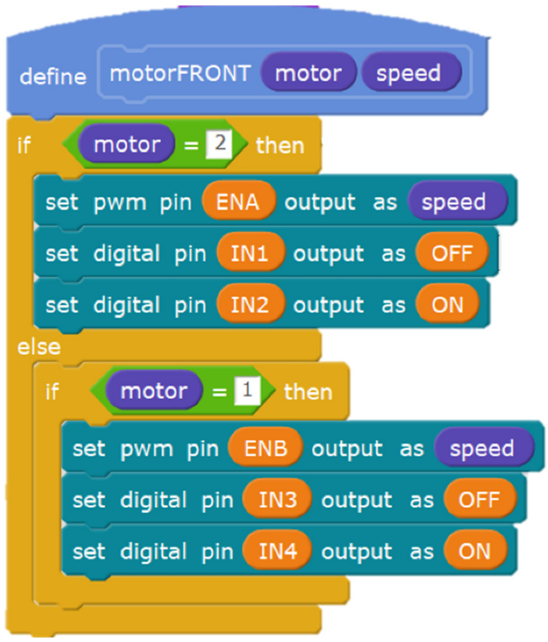

Figure 15: Procedure motorFRONT.

3.3.3 Add-on Features

More than to develop a robot, we wanted to create something that children could relate to and would like to use and learn about.

To make the robot more attractive to children, we decided to create some add-ons to allow **personalization**. Using personalization, we expect to create a sense of ownership and identity so that children should become more attached to the robot. Personalization also allows them to express their creativity in aspects such as choosing colours, accessories, or even other design features.

To easily allow personalization, we developed a set of 3d printed parts, that can also be replicated in cardboard, in case there is no 3d printer available. One of the 3d printed parts is a mask adapter (Figure 16). It's a part that can be attached to the front of the robot, holding onto the brass spacers. With holes for the Ultrasonic sensor, this 3d printable part allows children to build a mask and attach it to the robot.

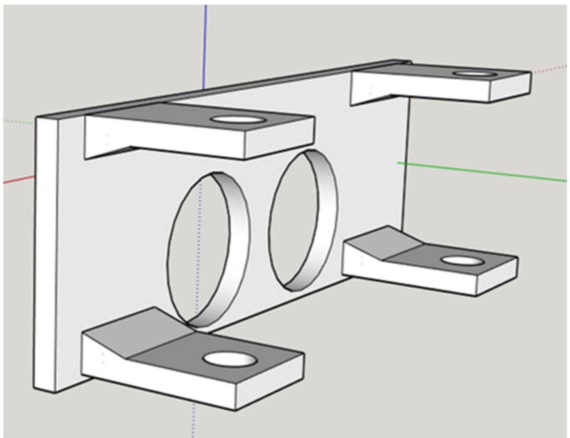

Figure 16: 3D printable mask adapter.

In the case of younger children who could find it hard to build their masks, we also created some 3D printable add-on masks just for the children to paint. These masks attach to the mask adapter and children could choose from a set of different characters (Figure 17).

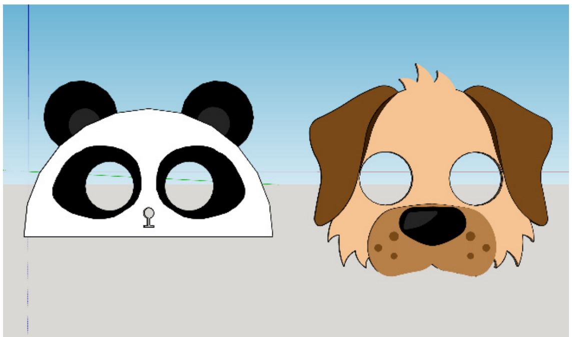

Figure 17: 3D printable masks.

Also in the add-on category, and with the idea of adding some extra features to our robot, we developed an **App for Android**, with which children can control their robots by phone.

After uploading a specially designed firmware to the Arduino and connecting an HC-05 Bluetooth module, it is possible to use the app to control the movements and some other features of the robot. The development of firmware was done in mBlock, to maintain the coherence with the rest of the code and the *Stemie ControlApp* (Figure 18) was developed in MIT (Massachusetts Institute of Technology) AppInventor a visual programming environment, Blocks-based, to create Android Apps, developed by the MIT.

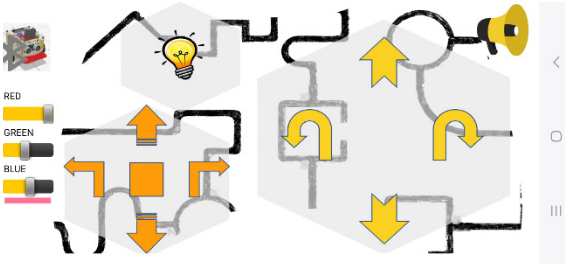

Figure 18: Screenshot of the Stemie ControlApp.

3.4 Development

Building upon the concepts and the prototype by Barradas et al. (2019), the original idea of *Kid Grígora* was to have an educational robot that could be used as a teaching tool to be integrated into the curriculum. Also, a secondary objective was that it had to be designed small enough to allow children to use it in the *Micromouse Portuguese Contest*.
All the changes we made in this upgraded version led to a robot that, in its base version, is not capable of participating in that competition, but that's more usable in general, in STEM areas. Because of that, from now on, it will be known as *Stemie* (Figure 19).

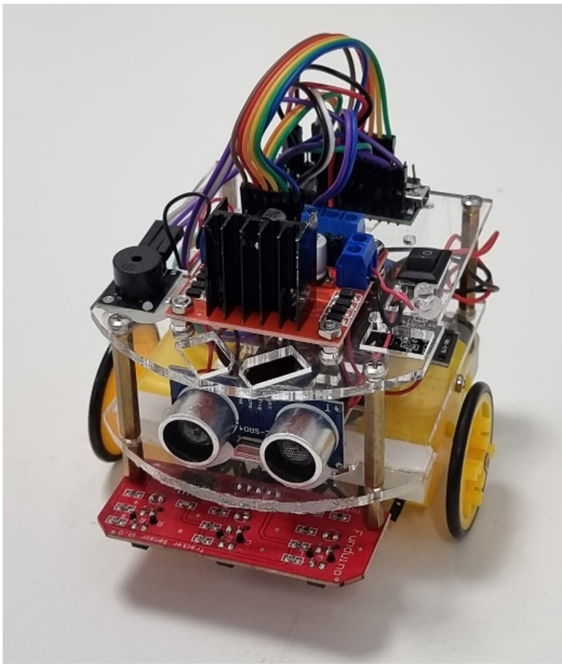

Figure 19: Stemie the robot.

3.4.1 Building the Second Beta Version

Stemie was built upon *Kid Grígora*'s foundations, with a different design but simpler and faster to build.

After its construction, it was then, subjected to a test in a heuristic evaluation by experts. This evaluation had the objective of appraising both usability and potential design problems and gathering suggestions from the experts on how to solve the problems they found and, possibly, add new features.

To test the prototype, we chose double experts (Nielsen, 1993) experienced not only in usability but also with specific expertise in robotics as they potentially find 1.5 times more problems than simple usability specialists (Nielsen, 1993). We used three ICT and Robotics teachers from 3 different countries (Italy, Lithuania and Croatia).

The evaluations were carried out according to each expert's agenda and started with an explanation of the expected use of *Stemie* by end-users, as a STEM tool. The evaluators had knowledge of the previous version and had previously been given the new robot's parts and the updated assembly instructions, and were asked to assemble it.

After the tests, each expert was asked to fill out a heuristic evaluation questionnaire to report possible problems, by using Nielsen's severity rating scale (Nielsen, 1993). In this scale, they used numbers from 0 to 4 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 the product can be released".

About the strong points of the heuristic evaluation, all the experts mentioned the evolution in structure stability, using brass spacers instead of screws and hex nuts and that the robot should be even easier to build now. Although like in Kid Grígora's evaluation, all the experts said that it was a good idea to use standard electronic components, easy to find and replace, in case of malfunction. Also mentioned was the large number of problem-solving tasks that it is possible to solve using *Stemie*. Two of the experts mentioned the fact that the instructions were very detailed on both the electrical connections and the GPIO pins, which would make it easier for children to assemble the robot.

The weakest points in the heuristic evaluation (ratings 3 and 4) are summarized in Table 8.

Table 8: Severe and catastrophic errors found, according to Nielsen's heuristics.

Nielsen's heuristics		
Interface (IN)		Degree
IN1	Visibility of system status	3
IN5	Error prevention	4

Regarding **IN1**, one of the experts mentioned, that although Stemie had an LED to visibly show the system status, it would be more useful if it also had audible status. Related to **IN5**, all of the experts stated that there was an error in the connection of pin A6 to the 3-channel infrared tracking module, as A6 and A7 on an Arduino Nano are pure analogue pins and cannot be used as digital pins. Only A0-A5 can be used as digital pins in that build of Arduino.

The results of the heuristics analysis led to some changes in the final product. Regarding **IN1**, we decided to add a Buzzer module to the parts list, add a new chapter to the Assembly instructions and create a mBlock extension (Figure 20) to allow the Buzzer to be used as a musical instrument, allowing even more activities to be done with *Stemie*.

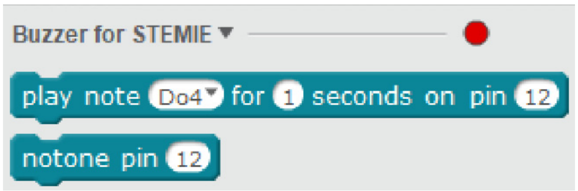

Figure 20: Buzzer for Stemie extension.

Using the mBlock platform that allows users to write custom extensions programmed in JavaScript, in a way to add new functionalities to the programming environment, we created two new blocks to be used by students. The extension is made by two essential parts: the definition of the block that shows in the mBlock application and the translation to C++ code which can be uploaded to the Arduino Nano for execution. The following is an example of the code:

```
   "extensionName": "Buzzer for
STEMIE",
   "description": "An extension for
using a Buzzer with STEMIE",
   "version": "1.5",
   "author": "",
   "homepage": "",
   "sort":0,
   "javascriptURL":"js/buzzer.js",
   "firmware":"1.0",
   "extensionPort":0,
   "blockSpecs": [
    [
    "w",
```

```
    "play note %d.notes for %n seconds
on pin %n",
    "tone",
    "Do4", "1", "12",
    {
    "setup":"pinMode({2},OUTPUT);\n",
    "inc":"",
    "def":"",
    "work":"tone({2},{0}, {1}*1000); //
write to buzzer\ndelay({1}*1000);",
    "loop":""
    }
    ],
    [
    "w",
    "notone pin %n",
    "notone",
    "12",
    {
    "setup":"pinMode({0},OUTPUT);\n",
    "inc":"",
    "def":"",
    "work":"noTone({0});\n",
    "loop":""
    }
    ]
   ]
```

To solve **IN5**, we changed the assembly instructions, moved the connection from pin A6 to pin D4, and made some changes in the programming framework to reflect those changes. To make it even easier to perform such changes in the future, we added to the Framework a procedure where all the GPIO pins can be configured by the final user (Figure 21).

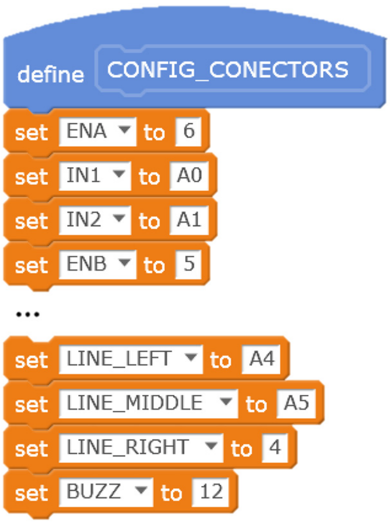

Figure 21: Excerpt from the config_connectors procedure.

7 CONCLUSIONS

Built upon *Kid Grígora*, *Stemie* marks a significant evolution on our educational robotics platform, aligning it with the requirements of STEM education. The comprehensive testing we've done with 177 students from a Portuguese School led to some valuable insights on assembly errors and showed us how important it was to have even more detailed instructions, especially due to the age range of our end-users. Following the ADDIE model, we analysed, implemented and evaluated, and from the collected information we addressed both structural and powering errors found by the end users.
After the test and further analysis, we upgraded some of the hardware in the robot which allows students to explore even more scientific experiments, promoting computational thinking and problem-solving skills in even more STEM subjects. The heuristic evaluation by STEM experts provided even more feedback on the design and allowed the correction of some errors. As STEM education evolves, it's up to us to create tools that allow children to learn while playing.

8 FUTURE WORK

Future work includes usability tests with representative end-users and a real stress test. It also includes the full development of Stemie, complemented with STEM exercises to use in educational environments. Stemie's Extended edition, for older students, equipped with different sensors and actuators, will also be a focus, aligning our work with the original idea of participation in the *Micromouse* Contest.

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