Arduino for Developing Problem-Solving and Computing Competencies in Children

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***Abstract*—Fostering children's problem-solving and computational programming competencies is crucial at the current time. Like in other in-developing nations, children grew up with technology in Chile. Developing programming and problem-solving competencies in children seems a reachable task using high-level block-based programming languages. However, programming and electronics competencies often emerge at higher educational levels. This article presents that using Arduino can enhance the development of programming and problem-solving competencies in children and encourages them to think in new ways. This article uses TinkerCAD, an online emulator of Arduino, to teach fundamental electronic circuits and computer programming components. Using TinkerCAD effectively addresses various computing and electrical difficulties, such as turning on and off a group of lights and reading sensors to respond to the acquired values. This article seeks to develop problem-solving and computer programming competencies in primary school students, given the significance of both competencies, the open nature of Arduino, and the applicability of TinkerCAD, which permits using a block-based programming language. Children that took part in the trial saw an increase in their academic performance on average, which is a critical concomitant finding. The essential drawbacks of this project were the children's lack of knowledge of electronics and programming principles and the need to use a computer with an internet connection.**

Keywords*—Arduino; competencies; programming; problem-solving; children

I. Introduction

The ability to use other skills to achieve objectives and solve complex and specified problems are traits of problem-solving competency [1]. It refers to the skills students need to acquire to discover efficient, sophisticated, and worthwhile solutions to issues in the interest of long-term learning. Informally, a computing method with clear boundaries, known as an algorithm, accepts an input value or set of values and produces an output value or set of values. An algorithm is a series of precise, constrained, and obvious procedures for attaining a particular goal or objective [2]. Because programs created in programming languages reflect algorithms, algorithms are the foundation of programming [3]. So, programming is the process of giving a computer a set of instructions it needs to follow to do a certain job. As Knuth [4] proposes, programming can be a fun endeavor like writing poetry or music. Similarly, Vidal et al. [5] stress the need to acquire logical and computational abilities for problem analysis and solution delivery in both computer-based and real-world settings. Getting young people to think logically and algorithmically is one of the goals of the education systems in several European and South American countries [6].

High-level abstraction, main-focus skills, and algorithmic reasoning are necessary for developing programming skills in textual programming languages [6]. Contrarily, students who use textual programming languages usually spend more time understanding and adhering to syntactic conventions than comprehending, learning, mastering algorithmic abilities, and resolving issues. One strategy is to use the block-structured programming language Scratch [7], which is kid-friendly, to develop algorithmic skills. Come up with electrical computer solutions. Due to the programming requirements and the necessity to be wary about compromised physical components in the final execution of the electrical circuit, a reducible risk by employing simulators, it seems to be a challenging operation. As an open-source electronics platform built on simple hardware and software, Arduino intends to increase accessibility for interactive computing-electronic applications [8]. Aside from the warning about working with physical electronics, the essential parts of Arduino's programming approach for kids are the syntax, and semantic instructions of the C/C++ programming language [9].

TinkerCAD circuits [10], [11] seem to be intended to address issues with Arduino-based computing-electronic systems in terms of design and programming: When combined with Arduino-compatible electrical components, TinkerCAD, a block-structured programming language, may be used to build computer solutions.

The simplicity with which computing-electronic devices can be built and programmed using TinkerCAD platforms seems to be a feasible goal. Similar to that, the primary objective of this article is to respond to the following research question: Can people use Arduino to educate youngsters to enhance their problem-solving and programming skills? This article provides proof by outlining the positive results of a TinkerCAD and Arduino workshop for children of a primary school in Valparaiso, Chile. This paper presents TinkerCAD and highlights the results obtained to persuade students and instructors to use TinkerCAD in developing algorithmic and problem-solving abilities.

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In today's connected and computerized environment, programming and creating computing-electronic systems are challenging tasks [12], [13]. As Vidal et al. [10] highlight, developing children's programming and electronic abilities should be a stimulating challenge for their interest and motivation in computer and electronic systems. You may construct algorithmic and computing-electronic conditions, for example, to turn on a light using resistance or without it while properly understanding physical and scientific principles.

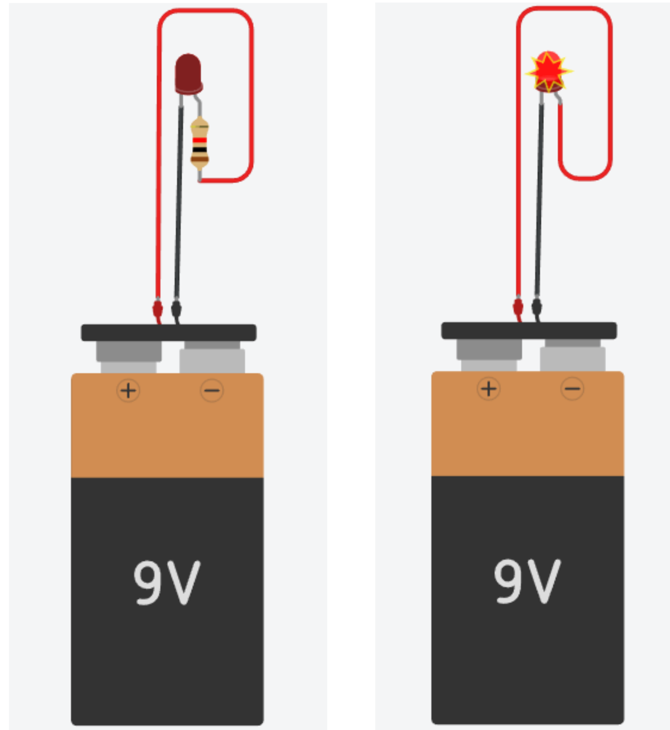
This article may be summed up as follows: In Section II, the TinkerCAD platform, Arduino, and an example of its block-structured programming language are introduced. The participants and setting of the workshop "Programming and Electronics for Everyone" conducted in Valparaiso, Chile, are explained in Section III. One of the experiments made by students is shown in Section IV. The academic performance enhancements of the workshop participants are highlighted in Section V. Section VI describes related work. Section VII presents conclusions of this worrk. Section VIII presents the main findings and suggests research directions.

II. TINKERCAD CIRCUITS AND ARDUINO

To create computing-electronic solutions using Arduino, TinkerCAD is a free, user-friendly web platform [14] for 3D design, electronics, and scripting [15], [10]. To enable students to combine computers and electronics in low-cost, open-hardware settings easily, Arduino was established in Italy in 2005 [16]. As Peace [17] argued, a vast selection of inexpensive hardware and software compatible with Arduino is available on the market. Liquid Crystal Displays (LCDs), sensors, and integrated web development platforms like TinkerCAD are available. TinkerCAD-based solutions are facilitated and supported by TinkerCAD. TinkerCAD considers a design area for the solution's hardware parts, a classification of the many more hardware parts, and a coding area for the software. Fig. 1a shows a straightforward example of how to turn on a led by connecting it to a 9-volt battery, which is analogous to the electrical "Hello World" program [6]. Fig. 1b, on the other hand, illustrates an unsuccessful operation for the same purpose without using a resistor.

Fig. 2a shows a hardware design created in TinkerCAD to turn on a red LED. It is similar to Fig. 1, except the Arduino is in charge of the positive and ground signals. This method may be modified to cyclically turn on the light for t_1 seconds and then turn it off for t_2 seconds by adding code. Creating Arduino solutions requires extensive programming abilities because of the new syntax and semantics of the related C/C++ programming language. Like Scratch, TinkerCAD supports programming solutions utilizing block-structured languages [18]. Fig. 2a and 2b presents the color-coded division of blocks: output (blue), input (purple), notation (gray), control (yellow), mathematics (green), and variables (rose). That figure additionally shows the block-structured code for turning on and off the LED for times t_1 and t_2 along with the variables declaration section.

Fig. 2b shows a semaphore simulator that is an extension of Fig. 2a. This figure also presents the associated block-structure code for the semaphore functioning. Fig. 2b does not use variables to define the light-time of each LED: the green LED will be turned on for 5 seconds (pin 2), the yellow LED for 3 seconds (pin 3), and the LED red for 5 seconds (pin 4), respectively.



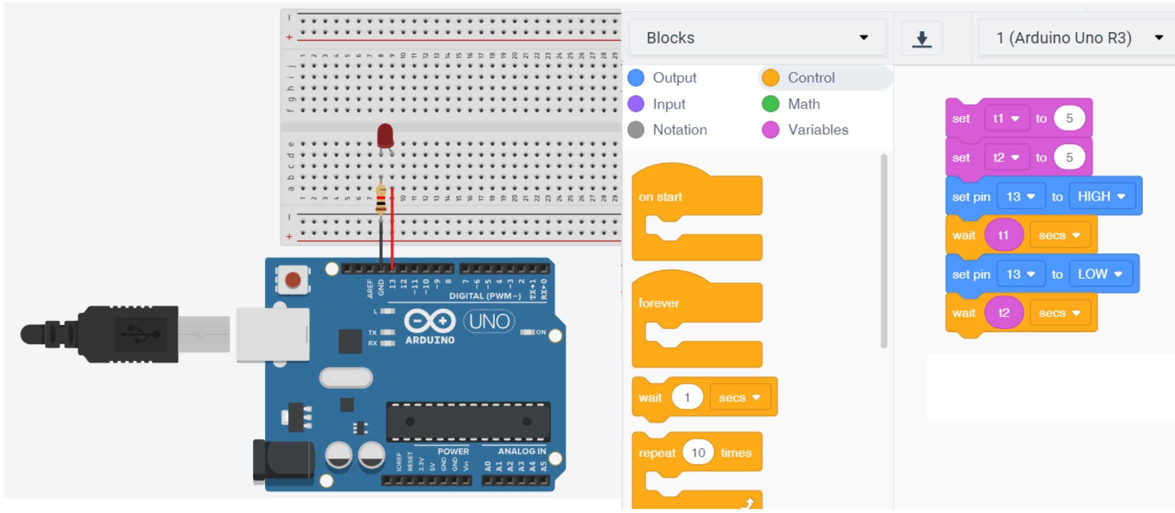
(a) Turning on a LED Successfully (b) Turning on a LED Unsuccessfully

Fig. 1. Flipping a Led Both Successfully and Unsuccessfully with an Arduino.

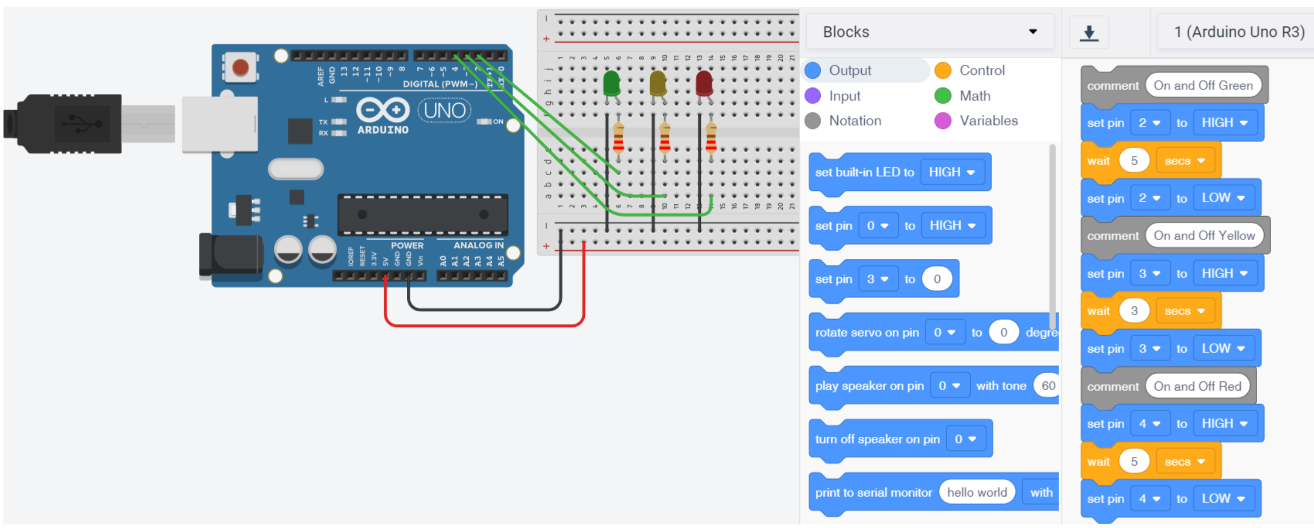
Another amazing feature of TinkerCAD is the ability to produce Arduino C/C++ code from a block-structured code solution. TinkerCAD is a great online tool for researching Arduino-based computing and electronics solutions.

III. WORKSHOP ON PROGRAMMING AND ELECTRONICS FOR EVERYONE

A project called "Future Education" links universities, basic colleges, and schools in Chile's Valparaiso region to provide seminars in various subject areas at participating higher education institutions [19]. "Future Education" develops activities that include students in experiments and debates with academics and researchers from various subjects using a rigorous and active approach. To help nine primary school students from four different schools and cities in the Valparaiso region develop their programming and computing-electronic skills, "Programming and Electronics for Everyone" was included in the 2020 edition of "Future Education". Specifically, there were two schools with three students (schools A and B), one school with two students (school C), and one school with one student (school D). The 5-session program, titled "Programming and Electronics for Everyone", had a start date of October and a finish date of mid-November 2020. The first two days of the training covered the fundamentals of Arduino and TinkerCAD programming environment. After that, students went over basic sensor tools and response ideas as the



(a) Turn On and Off a Red LED in TinkerCAD.



(b) Simulate a Semaphore in TinkerCAD.

Fig. 2. Turn On and Off a Red LED and Simulate a Semaphore in TinkerCAD.

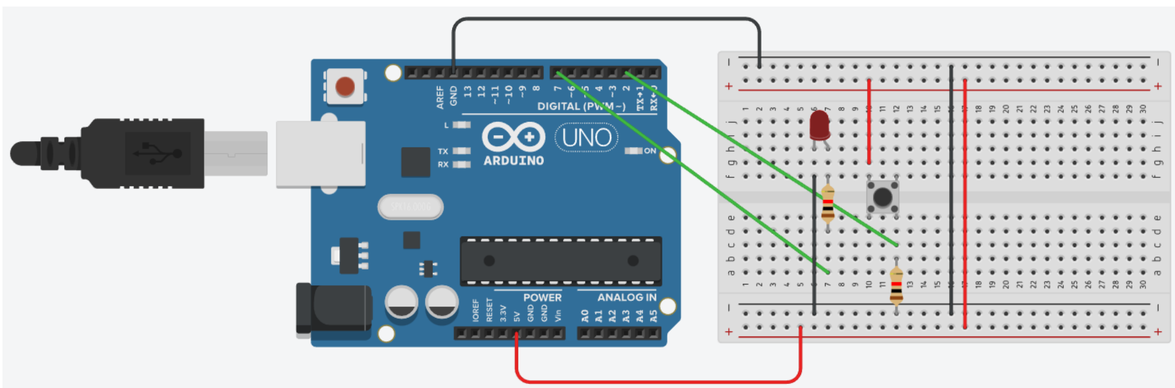
course progressed with intermediate Arduino and Tinkercad (3 sessions). The course ended with a final presentation to share the results with the community. Students who took part in the session had no knowledge of programming and much fewer electronics and associated physical principles. Their prior academic record at those institutions was above average (6.0 on a scale of 1.0 to 7.0). Consequently, the workshop's objectives appear a touch too ambitious. Participants were nonetheless encouraged to participate physically and primarily for the live results while utilizing the Arduino simulation in TinkerCAD. The first two workshop sessions taught students about the Arduino inputs and outputs (structure). Authors experimented using a real battery and Arduino to turn on and off a light (Fig. 1 and 2a), and implementing a semaphore (Fig. 2b). The Arduino loop cycle, in which this code is continually executed, was grasped by the students. Students studied more about conditional structures, variables, and sensors in the next three sessions.

This project proved that by using Arduino, people could effectively educate and develop students' programming and problem-solving skills. This page displays the primary school test scores from various Chilean primary schools, a nation that is still growing. These findings may inspire other institutions and countries to do comparative research to enhance and develop these skills in elementary school children. The researchers of this project want to conduct a more extended experiment with younger primary school pupils to help them develop their programming and problem-solving skills.

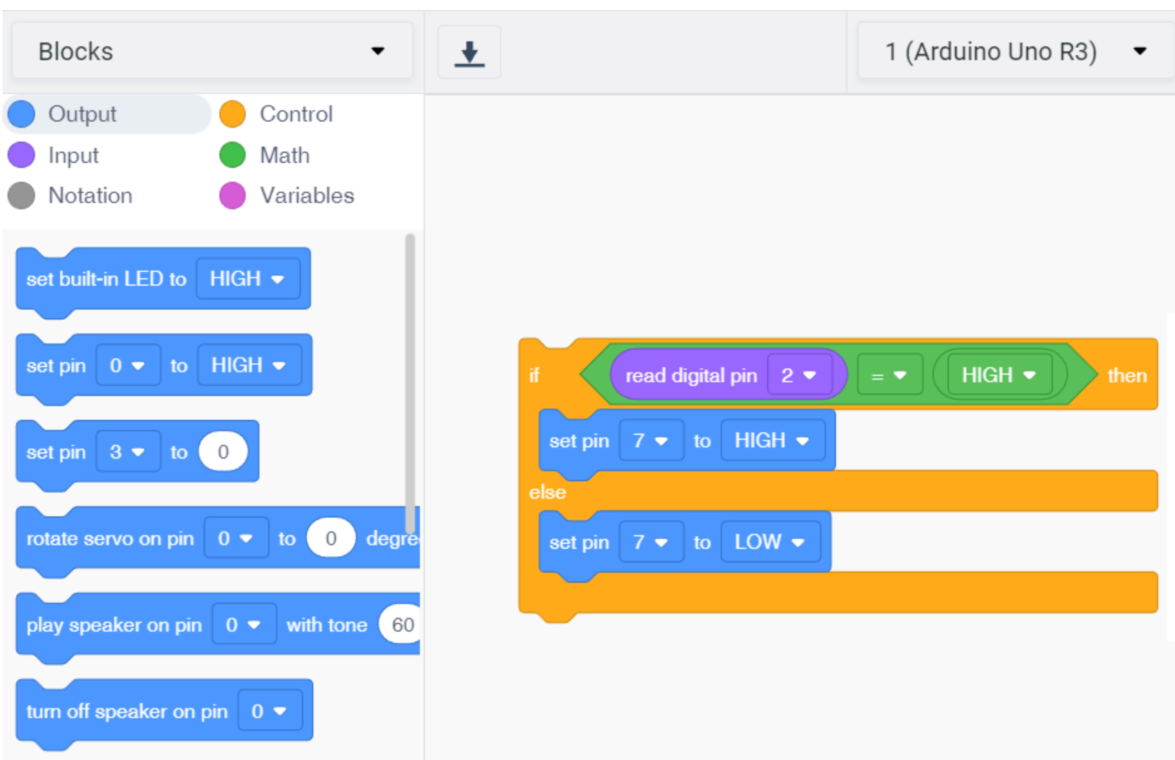
IV. Succulent Student Experiments

Students were considerably more enthusiastic about studying electronics using Arduino after learning about using TinkerCAD to build circuits and its block-structured programming environment. A TinkerCAD method to turn on a red led when pushing a button and turn it off in another situation is shown in Fig. 3.

The circuit is shown in part a of this solution, and part b shows the block-structured code. Students go through the key concepts of the Arduino loop cycle once again to determine whether or not the button is pushed to turn on and off the red LED accordingly. Students were, therefore, able to distinguish between input and output signals. In the fourth lesson, students received examples of how variables are used in human life (for example, to record a friend's phone number) and on the Arduino (e.g., to know what the previous button pressed was for a circuit with a set of buttons). Students also knew about a few distinctions between digital and analog signals using sensors. In this lesson, the authors created a TinkerCAD solution with the primary objective of turning on the red light when the temperature exceeds a particular value (Fig. 4 illustrates the circuit and the block-structured code). The block-structured code defines the maximum temperature using the MaxTemp variable (35 Celsius). In another instance, the red led is switched on and off when the read temperature, using a mathematical calculation, exceeds that maximum value. This TinkerCAD exercise was completed by seven students, while the remaining two were assisted. Thus, all pupils could understand how their first sensor system worked. As a motivation for using an ultrasonic sensor to calculate the distance of an object concerning the sensor position and turn on a led concerning the current distance of that object, the authors went over the main steps of the previous TinkerCAD temperature systems in the final session of the workshop. There are three variables for the detected value (distance), the lowest distance

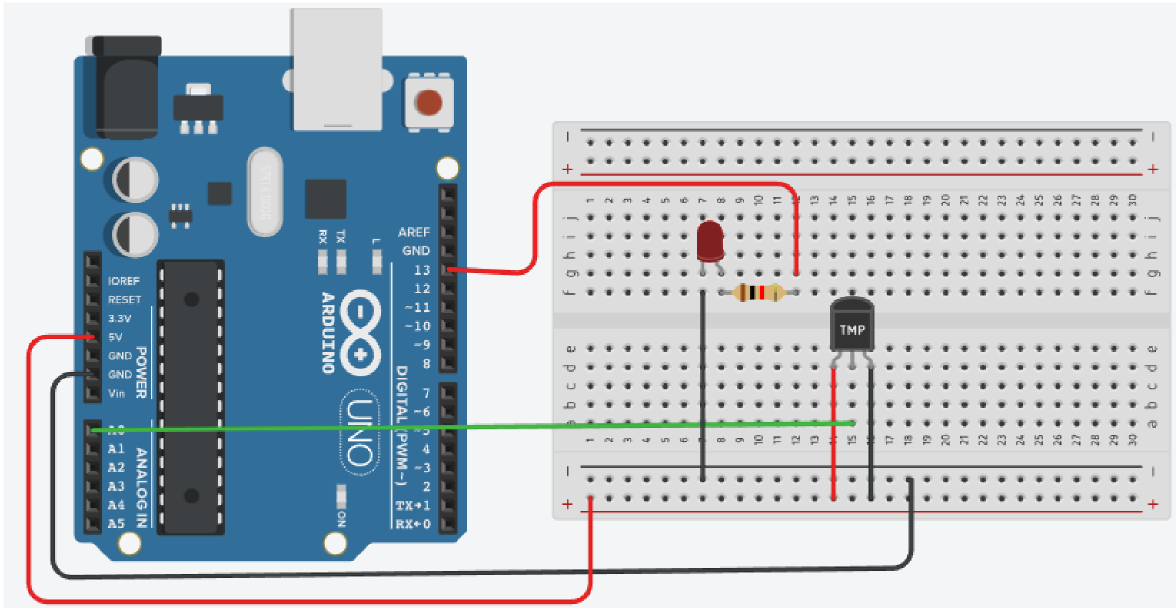


(a) TinkerCAD Circuit Solution for Turning on the Led when a Button is Pressed.

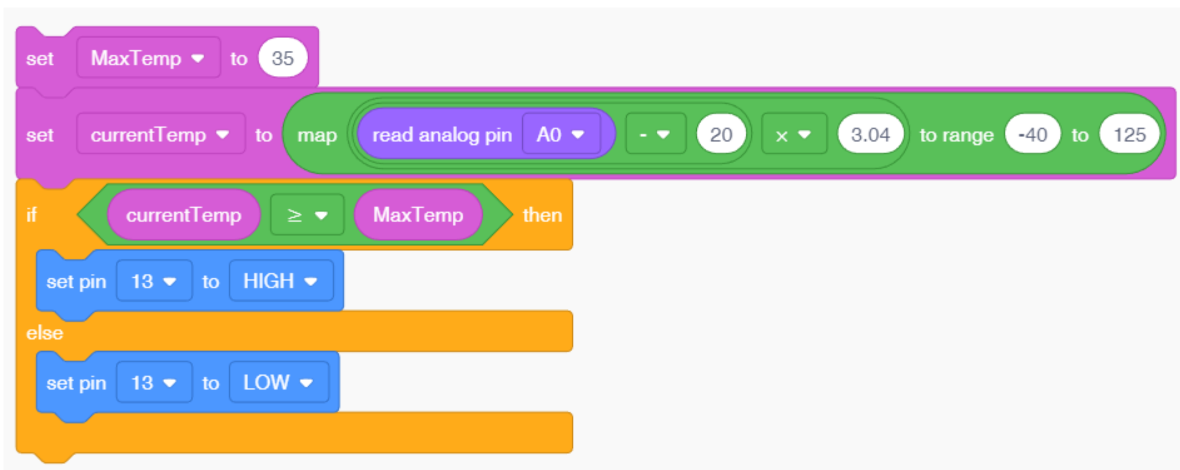


(b) TinkerCAD Code Solution for Turning on the Led when a Button is Pressed.

Fig. 3. TinkerCAD Solution for Turning on the Led when a Button is Pressed.



(a) TinkerCAD Circuit for Reading a Temperature Sensor and Activating a Light.



(b) TinkerCAD Block-Structured Code for Reading a Temperature Sensor and Activating a Light when the Temperature Rises over a Certain Threshold, Called MaxTemp.

Fig. 4. Using TinkerCAD for Reading a Temperature Sensor and Activating a Light when the Temperature Rises over a Certain Threshold, Called MaxTemp.

allowed (minDistance), and the maximum distance allowed (maxDistance) in the block-structured code. The authors are grateful for the circuit's red, yellow, and green-led instances that can be turned on individually. If the distance is less than the minimum distance, the red led turns on; if it is between the minimum and maximum distance, the yellow led turns on; and if it is more than the maximum distance, the green led turns on. Some of the experimental findings that students obtained during the last three workshop sessions are summarized in Fig. 3 and 4.

V. Academic Progress

According to their primary school records, students who participated in the workshop demonstrated improved academic performance from their prior academic performance, particularly in the math and science classes. The authors understand that these pupils might significantly benefit from courses where developing algorithmic thinking and problem-solving skills is relevant. The following lines provide further information about such upgrades.

A. *Improved Math Test Results*

The primary academic gains made by pupils in the math class are shown in Table I. Authors may acknowledge that pupils improved their scores by 9.21% on average. All of the pupils also scored close to their post-test records. Because algorithmic and problem-solving skills are closely related to logical and mathematical reasoning, these results are expected to rise.

TABLE I. MATH COURSE ACADEMIC RESULT - CHILEAN SCORE RECORDS FROM 1.0 TO 7.0

# Students | School	Academic Performance		
	Previous record	*Post record*	*Improvement*
3 | School A	5.8	6.3	8.62%
3 | School B	5.6	6.1	8.92%
2 | School C	5.7	6.2	8.77%
1 | School D	5.5	6.1	10.53

TABLE II. SCIENCE COURSE ACADEMIC RESULT: CHILEAN SCORE RECORDS FROM 1.0 TO 7.0

# Students | School	Academic Performance		
	Previous record	*Post record*	*Improvement*
3 | School A	6.0	6.4	6.66%
3 | School B	6.1	6.4	4.92%
2 | School C	5.8	6.2	6.90%
1 | School D	5.9	6.3	6.78

B. An improvement in science test results

The primary academic gains made by pupils in the science class are shown in Table II. Authors may acknowledge that pupils improved their scores by, on average, 6.32%. Regarding the arithmetic course, every student received a post-record score close to the maximum. Authors could say that algorithmic and problem-solving skills help students improve in science, even though this improvement is not as significant as in math.

VI. RELATED WORK

Research about developing programming and problem-solving competencies in university students and children exists. Lineros et al. [20] present positive experiences developing electronic and computing architecture competencies using Arduino. Vidal et al. [21] highlight experiments in the same academic experience at the Viña del Mar University. The work of Vidal et al. [10] shows positive experiences with school children in Viña del Mar, Chile, using Scratch and Arduino to develop programming and electronic competencies. Tupac et al. [22] describe positive experiences and results using Arduino in a first programming course with university students in Huancayo, Perú. Tupac et al. [23] highlight results and academic performance regarding previous experiences in Huancayo, Perú, even more during the pandemic time applying online education.

Regarding programming competencies in university students, Ortega et al. [24] and Vidal et al. [25] remark on the usefulness of Python for developing multiprogramming and web development competencies, respectively, not necessarily for computer science students. Likewise, Vidal et al. [26] describe the positive results and experience developing multiprogramming and programming competencies applying Python in two majors with the different primary focus, computer engineering, and business administration. Even though those works are not related to Arduino, they also demonstrate confidence in applying high-level programming languages to develop programming and problem-solving competencies.

VII. CONCLUSIONS

This project proved that by using Arduino, people could effectively educate and develop students' programming and problem-solving skills. This page displays the primary school test scores from various Chilean primary schools, a nation that is still growing. These findings may inspire other institutions and governments to do comparative research to enhance and develop these skills in elementary school children. The people doing this research want to do a more extended experiment with younger kids in primary school to help them learn how to code and solve problems.

TinkerCAD's online functionality goes hand in hand with the global education trend. For example, the universities of the authors of this work are currently offering programs applying partially or fully to that system. Hence, TinkerCAD can be part of those programs for developing programming, circuit design, and problem-solving competencies.

VIII. FUTURE WORK

This research invites us to investigate the usefulness of Arduino and TinkerCAD for first-year primary school and first-year university students to develop programming, circuit design, and problem-solving competencies. That is a current project in the universities of the authors. They expect to publish the obtained results.

The authors will also investigate Arduino and TinkerCAD's impact on developing programming, circuit design, and problem-solving competencies in kindergarten children. The block-based programming language seems attractive, and appreciating results after coding seems useful for learning purposes. Nowadays, children are born in a computer and information world that invite them to use and learn about technology.

The block-based language of TinkerCAD for developing programming, electronics, and problem-solving competencies also motivates researchers to apply tools in videogame development, such as Unity [27] and Unreal Engine [28]. Videogames attract children, teens, and adults; their development can motivate them to develop programming and problem-solving competencies.

The main issue of this work was the requirement for internet connection and computer availability, although it seems an irrelevant problem nowadays.

ACKNOWLEDGMENT

The authors would like to thank the positive experience developing programming and electronics competencies in primary school children. Educating children represents a marvelous task overall for university professors. After that, the authors want to continue applying this teaching-learning experience in their Chilean cities, specifically in Viña del Mar, Santiago, and Talca.

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