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REGULAR PAPER

A Sim-to-real Practical Approach to Teach Robotics into K-12: A Case Study of Simulators, Educational and DIY Robotics in Competition-based Learning

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Abstract
Simulators in robotics are well-known tools for the development of new applications and training and integration of systems for remote operation or supervision. Therefore, robotics is one of the most used practices in science, technology, engineering, and mathematics-based educational frameworks, and, with COVID-19, simulators have become increasingly important. This study shows specific benefits achieved for K-12 students in an individualized family service plan/resource teachers for the gifted model based on a review. A simulator is typically adopted for undergraduates students to increase their ability to make technical-based decisions and move smoothly between the real and virtual worlds, with a strong emphasis on the feedback from both. It enables students to develop abilities to build robots without needing commercial kits. In a sim-to-real approach, early simulation allows improved team integration and reduced reliance on skills, equalizing the abilities of students, regardless of their backgrounds. Simultaneously, simulation encourages students to work harder in real implementation by equalizing their class level, resulting in competition-based learning.

Keywords Sim-to-real robotics · Educational robotics · Competition-based learning · DIY educational robots · K-12 robotics education

1 Introduction

The world has changed significantly with the emergence of new technologies. To succeed in a new information-based, technologically focused, and globalized society, students need to focus on developing 21^{st} century skills. In the last decade, the importance and focus of educational goals such as creativity, critical thinking, problem-solving ability, and collaboration has been increasingly emphasized in educational research [1]. The 21^{st} century society demands people capable of finding the best solutions in a constantly evolving context. This requires people to know their environments, appropriate methodologies, and how to deal with very different devices, tools, and applications [2, 3].

Robotics education has proved to be a powerful tool to stimulate computational thinking and problem-solving ability. Students acquire hands-on experiences for understanding technological and mechatronics systems, adapting to constant fast changes driven by complex environments, and utilizing knowledge to solve problems in real scenarios [4, 5].

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Physics simulators enable the vast majority of industrial, educational, and research robotics applications. They offer faster and lesser costly platforms than the real world, which is particularly important for learning without downgrading or breaking physical platforms. Moreover, they can prevent risks to operators, improve the use of available equipment, and help students learn and test theoretical complex topics [6–9].

Tools for remote learning are in significant demand; in 2015, approximately 14% university students in the United States used distance education courses exclusively [10]. Students engage in remote learning for medical, geographic, and economic reasons. Distance learners are susceptible to foregoing peer-mediated learning; however, effective social interaction during learning leads to better critical thinking and long-term retention of information [11]. Therefore, blended learning is an integrated approach with equalized remote and face-to-face learning [12].

Educational robotics (ER) competitions are excellent tools for the development of new solutions and innovations and pushing the state of the art. They also motivate students to learn various fields of science, technology, engineering, and mathematics (STEM) as well as encourage them to pursue engineering careers [13–15].

The global pandemic of 2020 led to the challenge of using ER competitions in remote teaching using simulators to meet the K-12 learning objectives [16]. After the pandemic phase, the learning aim became using the experience with a virtual environment and integration with a previous experience in the real world to establish a sim-to-real approach.

This study addressed the following problem. How to teach robotics in a mechatronics technical course by a sim-to-real approach using available inexpensive tools? The chosen solution was to use CoppeliaSim simulator as a teaching and development tool to explain the use of programming, build a robot in a virtual environment, and subsequently apply the project to develop a physical prototype.

The main objective of this study was to extend a previous investigation [17] with a teaching program in which students first learn how to develop a robot in a virtual environment, CoppeliaSim, and subsequently build one with similar characteristics in real conditions. Specifically, we systematically reviewed ERs and simulators for robotics. A comprehensive analysis of how robots developed in an individualized family service plan/resource teachers for the gifted (IFSP/RGT) model and the methods to evolve a new sim-to-real approach was conducted. Finally, the impact of the above teaching methodology on students in a current IFSP/RGT course of 2022 on mechatronics was examined.

2 Development

In this section, a review of ER for robotics simulation (RS) and details to established projects and their aspects are presented. For the first year (for 14–15 year-old students) of the mechatronics technical course, a mini sumo robot was chosen owing to its simple architecture. For the second year (for 15–16 year-old students), a line follower that repeats several aspects of the mini sumo robot and adds complexity to control the entire system was selected.

CoppeliaSim was the selected simulator owing to the following characteristics. First, it is free to use in education. It is a platform based in a distributed control architecture, in which each part can be individually controlled by an embedded code, a plugin, a robot operating system node, a remote application programming Interface client, or a custom solution. CoppeliaSim is a versatile simulator for all knowledge levels. Controllers can be written in C/C++, Python, Java, Lua, MATLAB, and Octave. In this study, the robots were coded in Lua and Python. Case facilitators offered small pieces of a code and stimulated students to understand and edit it.

2.1 Systematic Review of ER and RS

This study aimed to at searching research papers focused on ER and RS. To achieve a solid literature review, the SCOPUS database was searched based on keywords and a specific publishing period. The keywords were "educational robotics" and "robotic simulation," and the publishing period was 2018–2022.

The search produced a set of 335 documents. The documents were organized by relevance, and the most relevant 50 articles were screened. Subsequently, 16 articles were excluded because they could not be fully accessed or were irrelevant. Finally, we analyzed 34 documents; this process is shown in Fig. 1. Subsequently, these 34 texts were comprehensively read to understand a broader scenario of the issue being scoped.

After defining the relevant set of papers, the main aim of each of them was summarized. Furthermore, different documents were compared, revealing possible relations. All different papers could be examined from the following specific perspectives: teaching robotics with STEM, robotics for industrial applications, robotics for medical applications, and robotics for competitions.

Teaching robotics with STEM focuses on introducing a practical approach in this area. One method is using simulators with highly realistic environments [18–21]. This will enable schools to teach robotics at low costs and with high fidelity to real robots, empowering classes and utilizing real robots more efficiently for academic purposes [22–26].

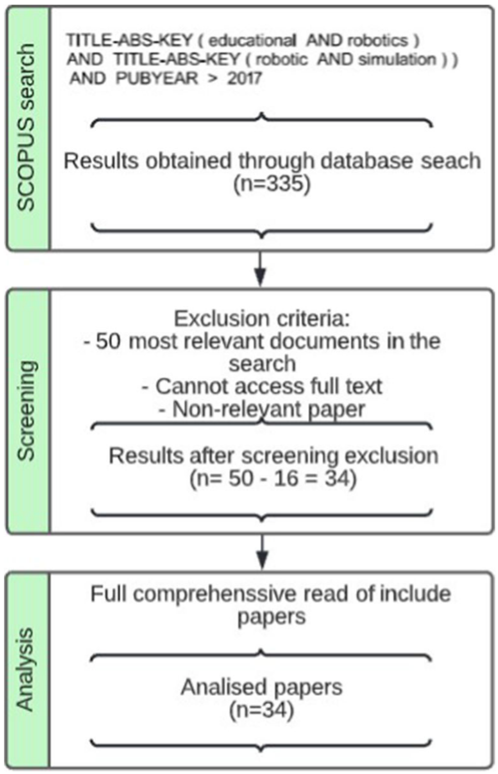


Fig. 1 Process to include documents in the systematic review

In addition, several of the selected studies were focused on K-12 [21, 23, 27–31] and undergraduate [24, 26, 32, 33] students. Some studies were aimed at using commercial robotics kits, such as Lego Mindstorms [31, 33–36], and a few, similar to this paper, were on using project and development of a robot as part of the learning loop for improvement. Such a process cyclically makes better robots and improves learning based on the use of a simulator to enhance a real prototype [22, 37, 38].

Another critical issue is the technical difficulty due to the high processing requirement of some simulators [18, 31, 39]. Furthermore, we searched for specific aspects, such as coding. New ways to learn to write programs can help K-12 and undergraduate students [19, 28, 33, 39–41]. Teaching robot kinematics is as difficult as teaching coding. Therefore, offering new tools can help students to learn more [20, 24, 26, 32, 35].

Owing to the high versatility of a simulator, special needs of students can be explored. Adapting high-cost robots can be difficult and highly expensive; however, new scenarios can be studied using simulations to fulfill these needs [38].

Using simulators to develop a real application of a robot can improve learning, and with this approach, laboratories can produce more efficient real robots and applications [25, 29, 32, 33, 35–37, 42]. The COVID-19 pandemic led to a time of remote learning, wherein teachers needed to adapt to enable students to still apply their studies to a real environment [18, 30, 41, 43].

Industrial applications are broader than simply manufacturing. They include training new professionals and improving capabilities [27], development of new uses or robots [44–46], and planning and implementation in manufacturing [22, 47].

In a particular scenario, robots are steadily entering medical applications. One factor is the emphasis on simulation before real scenario experiences for surgical residents [47]. Owing to the high cost of surgical robots, developing a training path to utilize real robots more efficiently [48] and find new applications for the same robots in a hospital is advantageous [49].

Not only learning, competitions are also important in an academic environment. These challenges are such that students apply several capabilities in a specific task [34, 50]. Considering the high cost of development of robots, using simulators can help develop robots and lead to a learn–apply–improve loop [31, 39, 51].

The selected documents showed the importance of simulators in educational, industrial, medical, and competition areas. This can be understood from Table 1. Furthermore, the aim to use only simulation or evolve to real applications can also be observed.

The majority of applications are in STEM education. STEM is an acronym for Science, Technology, Engineering, and Mathematics. This concept may vary depending on the source and the understanding of the stakeholders. Generally, STEM in education refers to using a practical approach to substitute a regular lecture-based curriculum with a project-based one [52].

Another scoping based on this review was the analysis of the purpose of using simulators instead of physical equipment. This study showed the importance of simulators

Table 1 Analysis between goal and application of selected projects

	Only simulated environment	Simulated-to-real
Teach robotics or STEM related	[18–20, 22, 38],	[25, 35, 37],
	[23, 24, 28, 39],	[33, 36, 41],
	[21, 26, 30, 31]	[29, 42]
Industrial training/ applications	[20, 24, 27],	[22, 44, 47],
	[40, 45, 46]	[32, 43]
Medical training/ application	[47]	[48, 49]
Robotics challenges/ competitions	[18, 39, 51],	
	[30, 31, 50]	[34]

Table 2 Reasons to use simulation instead of physical equipment

	Teach robotics or STEM related	Other application
Cost reduction replacing physical equipment with simulation	[25, 28, 37],	[22, 47, 51],
	[26, 31, 35], [36, 41, 42]	[40, 48, 50], [46, 49]
Simulation aiding design	[18, 20, 21, 24], [29, 30, 36]	[22, 44, 51], [31, 45, 46]
Simulation improving real robot usage	[19, 23, 28, 38],	
	[21, 29, 33]	[27, 32, 43]
Robots training for challenges/competitions	[30, 34, 39]	[50, 51]

with or without physical equipment in making education and training more efficient. This can be inferred from Table 2. As summarized, many reasons have led to the relevance of simulation. The most significant objectives achieved by simulating physical models are the cost reduction and the increased efficiency of real equipment after their improved design.

In addition, based on Table 3, COVID-19 is not the most important factor for the development and use of an increased number of simulated systems. Even considering the major relevance of simulators during remote classes, it was not the cause of the daily increased use of simulators in academia for classes and research. This suggests that we should only highlight the importance and increment in the usage of simulators.

During the COVID-19 pandemic, simulators gained increased prominence and helped schools and companies in continuing to develop applications and train efficiently people for current and future challenges.

Table 3 Reason to develop or use simulators considering the pandemic of COVID-19 as an important factor

	COVID-19 motivation (remote interaction)	Simulation empowering learning/design
Teach robotics or STEM related	[18, 30, 36],	[19, 23, 28, 37, 38],
	[41]	[20, 24–26, 35], [21, 29, 31, 33, 42]
Industrial training/ applications	[32, 43]	[22, 27, 44],
		[40, 45, 46]
Medical training/ application	[51]	[47–49]
Robotics challenges/ competitions		[34, 39, 50]

2.2 Autonomous Robots

Autonomous robots are machines with certain intelligence and a capacity to execute specific tasks without needing external control. The autonomy required in a robot of this model is achieved using sensors that are distributed along the chassis of the prototype and varying the distribution according to the application for which the machine is designed. Applications of this type range from domestic to industrial to examples of planetary exploration.

In the domestic context, the use of autonomous vacuum cleaners that help in cleaning a house, built to recognize and avoid obstacles, is well known. In the same context, autonomous cars are already a reality. In the industry, in general, robots perform highly diverse tasks, e.g., welding operations in a car assembly plant, automated guided vehicles through corridors without human interference, carrying products in factories or logistics centers, and maintaining warehouse organization.

In the context of ER, models such as service, rescue, line follower, and sumo robots are used to explain theoretical concepts in practical projects. Among these, two were used in this study. Autonomous sumo robots are inspired by Japanese sumo competitions, wherein two robots equipped with sensors capable of identifying the opponent autonomously participate in a dispute aimed at pushing the opponent out of the combat arena. Another frequently used robot as a robotics teaching tool is a line follower, which runs on a track based on sensors to complete a lap in a circuit made from a guide line in the shortest time.

2.3 "Autonomous Sumo Robot" Project

As mentioned before, an autonomous sumo robot has the objective of pushing an opponent out of the combat area. Thus, building a robot that has a combination of strength and good traction of the wheels, fast and efficient detection of the opponent, and ramp that can destabilize and push an opponent is necessary. First, adjusting the project according to the specifications of a competition is required, because sumo robot competitions are categorized according to the weight and size of the robot. For instance, one category is autonomous sumo robots with a weight limit of 500 g and maximum dimensions of 100 mm (L) 100 mm (W) with an unlimited height.

Second, parts must be selected according to the limits of the project and the ramp should be adjusted to ensure its closeness to the ground, as can be seen in Fig. 2, and with an inclination that can lift an opponent to decrease its traction. Third, the strategies that the robot will adopt when it detects

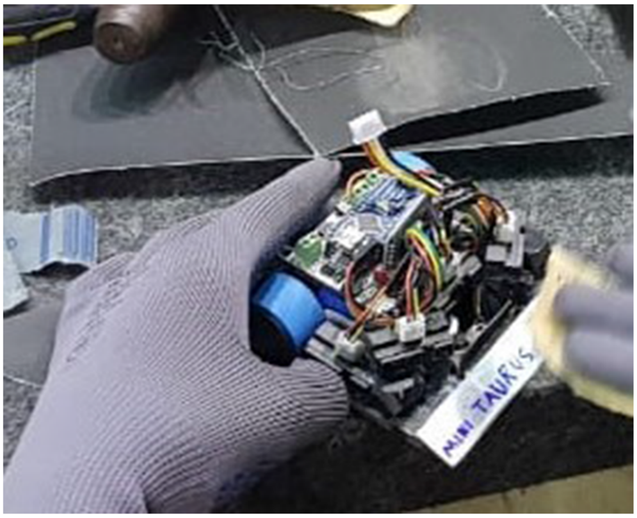


Fig. 2 Sumo robot developed by IFSP/RGT students being prepared for combat

an opponent are configured. The configuration is based on the distance sensors that a designer chooses as the sensor model for the best results for the robot. There is no limit on sensors, and the most common configuration is of three sensors.

The definition of the attack strategy can be adjusted in each round, and the same robot can have several combinations. There is no standard starting position in the fights of autonomous sumo robots. A robot can be lined up face to face or in any position and orientation, depending on the strategy developed by the designer.

For ease of understanding, a simple sumo robot strategy is presented in Fig. 3; it has a combination of three sensors (Sen*), where Sen1, 2, and 3 are the left, center, and right sensors, respectively. In Fig. 4 shown three examples of sensor detection.

In the first example, the detection of the opponent is only by Sen1 (combination "100" in the table), in which the robot is triggered for an extreme left attack that makes it move quickly to the left to face the opponent. In the second, Sen1 and Sen2 detect the opponent ("110" in the table), and the robot performs a left attack. In the third example, Sen1–3 detect the opponent, i.e., combination "111." In this case, frontal attack occurs, in which the robot applies full power to displace the opponent. In all these combinations and considering the extreme right attack ("001") and the right attack ("011"), the analysis is based on which sensor has the shortest distance, aiming to find the opponent and pushing it out of the combat area.

In the control loop, the table output is updated, and subsequently, the motors are activated for robot action. It is worth mentioning that strategies can be changed in the breaks between rounds, to adapt to the behavior of the opponent.

It is also noted that, several skills are developed, from analyzing the theoretical concepts addressed in the classrooms to the selection of the components that will be used in the project. These consider the weight, size, and mainly the ability to win over the opponent. Furthermore, the many strategies in each round make a student understand the operation of the robot and create combinations that can remove the opponent from the combat area.

2.4 "Line Follower Robot" Project

There are various autonomous robot projects with attractive features for use in ER and STEM applications. One project is a line follower robot. With an architecture of three wheels: two for powering the rear and one to freely move (spherical) frontal. It also has 3–5 sensors that are fixed in the front part of the chassis toward the ground, to recognize the contrast between white and black. Thus, they can follow a white guide line (path) demarcated on a black floor mat. Figure 5 shows a line follower robot developed by students of a mechatronics technical course at a high school level at IFSP campus Registro – SP. This was part of a project discipline in the school curriculum.

The control logic applied in this project is based on the construction of a lookup table of the possible positions that the set of front sensors can sense in relation to the line. Values are assigned to all positions (Errors). Assume that for a robot with five frontal sensors, the digital output is "1" for black and "0" for white. Figure 6 shows all the possibilities of errors from the sensor readings, and Fig. 7 shows the arrangement of the sensors in relation to the guide line.

Moreover, a PID controller is implemented to keep the robot following the guide line, performing the necessary

Lookup Table

Sen1	Sen2	Sen3	Output
0	0	0	-
0	1	0	FA
0	0	1	ERA
0	1	1	RA
1	1	1	FA
1	1	0	LA
1	0	0	ELA

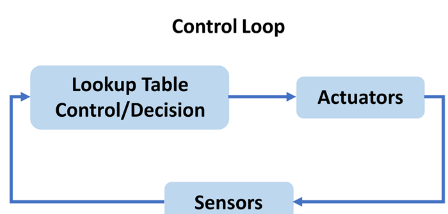


Fig. 3 Control lookup table and control loop for sumo robot

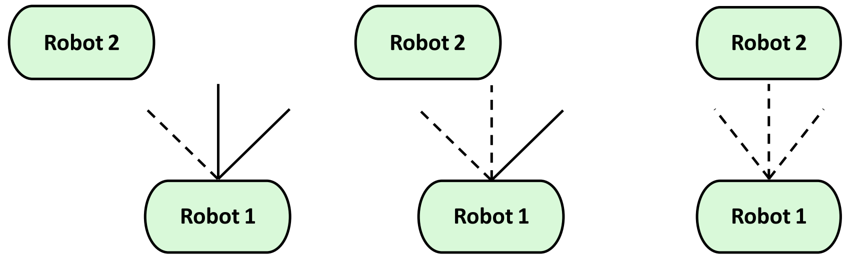


Fig. 4 Attack strategy for sumo robot

corrections when the error is different from zero. The negative and positive values assigned to the errors indicate the direction the robot is deviating from the line. If the robot is escaping to the left side, the error is positive, whereas if it escapes to the right side, the error is negative. Based on these errors, the controller acts by increasing or decreasing the rotation of the driving wheels, to always keep the robot on the line and smooth the movement. Figure 6 shows the control loop used in the project.

Examples of the characteristics that can be explored in the technical knowledge field are computational thinking, concepts of electronics and electrical circuits, application and characterization of sensors (reading, difference between analog and digital sensors), development and application of programming logic mechanical projects and construction practice, in addition to the integration of mechanical, electronic, and programming projects. These characteristics are becoming increasingly necessary for the development of a modern professional.

3 Discussion and Results

3.1 Highlights of Differences Between Projects in Real and Simulated Environments

The construction of a robot as a teaching tool is interesting and contributes in many ways to the development of the involved students. Educational projects involving robotics typically had a practical, hands-on, and do-it-yourself approach. Owing to the COVID-19 pandemic and the need to find alternatives to continue robotics studies even at a remote distance, the use of robotic simulators such as CoppeliaSim software has increased. Moreover, this currently presents another possibility of application of robotics.

Both physical and simulated robots present key factors that help understanding an ER project as well as add capabilities owing to the involvement of several areas.

Among the wide variety of educational projects involving robotics, two projects that were conducted in practical and simulated modalities were a part of this study, allowing noting the differences between real and simulated environments. During the pre-pandemic period, students of the abovementioned mechatronics technical course at the high school level in the IFSP/RGT model built autonomous sumo and line follower robots projects in PJI1 and PJI2 (projecto integrador, i.e., integrator project) subjects. However, with the COVID-19 pandemic, these projects had to be adapted and conducted by a remote and simulated environment approach [17]. From these experiences, conducting an analysis by evaluating the two approaches (practical and simulated) became possible, highlighting the qualities and differences observed in the execution of these two projects. Figure 8 shows an info graphic presenting the main points of focus in line follower and autonomous sumo robot type projects applied to high-school technical students. The only project restriction is the maximum external dimensions; thus, students have the freedom to design the shape and distance between all components of the robots.

In a practical robotics project, using components is required, whereas in a simulated environment, they are expendable. Some examples are controller boards

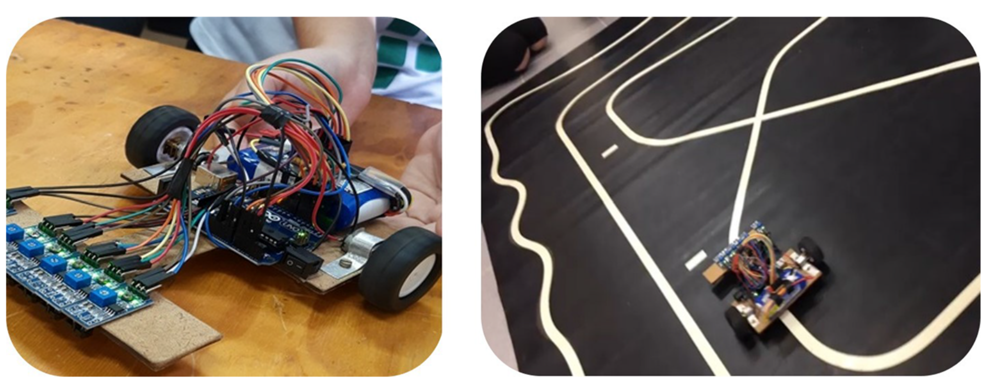
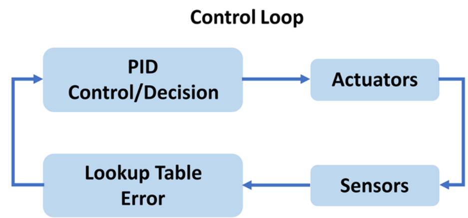


Fig. 5 Example of a line follower robot built by students of the IFSP/RGT mechatronics' technical course

Fig. 6 Lookup table for sensors and error output and the control loop of line-follower robot

Lookup Table

Sen1	Sen2	Sen3	Sen4	Sen5	Error
0	1	1	1	1	-4
0	0	1	1	1	-3
1	0	1	1	1	-2
1	0	0	1	1	-1
1	1	0	1	1	0
1	1	0	0	1	1
1	1	1	0	1	2
1	1	1	0	0	3
1	1	1	1	0	4



(generally Arduino), batteries, and wiring necessary to interconnect components. This expendability becomes eases the development of the project. Factors that involve the construction of structures for assembly components on the chassis, such as a sensor, in a virtual environment become much simpler than in a real situation.

Constructive characteristics include the estimation by weight of the robot, spacing between sensors and its relation to the guide line, distance between the driving and driven wheels, alignment and symmetry of the components, diameter of the driving wheels and its impact, and efficient distribution of the components in the robot chassis to obtain a balanced center of mass. These are issues that in a practical environment, students can frequently only understand based on the complete form when the robot is completed and finally placed on the test track. The latter presents problems, raising questions and underestimation of phenomena and the methods to overcome them.

For instance, when students run the first tests and the robot does not perform a smooth path, it makes them search for a solution to this problem. This, improves their understanding of the importance of the spacing between the front sensors or of adjusting the distance between the sensors and the ground. Factors such as the influence of the ambient light that mislead sensors and the need for calibration of the sensors are experiences that are observable only in practical applications.

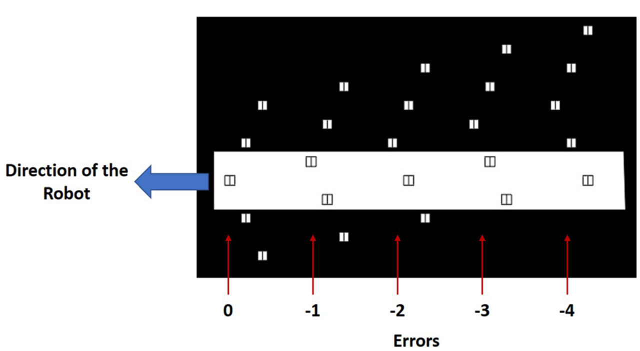


Fig. 7 Sensors' position in white guide line

In a simulated environment, this understanding occurs relatively rapidly, because a simulator promotes a much faster and easier construction process than an actual robot development. Students after a short period of dedication to the project assembly, experiment and test a virtual model with dynamic characteristics similar to those of a real model. A real model takes a much longer to build, and any change, e.g., changing the sensor positioning, increases the time of the mechanical construction of the project.

In addition, in both projects, it was notably easier for a student to assimilate the operating logic of the robot, when it is first presented in a virtual environment. In the line-follower robot projects, which included a PID controller, even in an introductory-level application, issues such as the gain and adjustable parameters of the controller, were understood better and faster with simulation.

Moreover, a simulated environment is more accessible and easier to understand than a real environment owing to the ease that a simulator offers in construction, which consequently accelerates the robot test stages. In addition, simulators offer rapid changes can be made in the structure of a chassis, positioning of sensors, and type of sensor for another.

However, in a virtual assembly environment, other factors become challenging, such as the ability to acquire a complete understanding and command of the Cartesian space, widely used in the assembly and positioning stages of components. Furthermore, understanding the hierarchy of components present in a robot and construction and modification of solids and their physical characteristics, such as weight, type of material, and format are difficult. Additionally, in some cases, performing 3D component import operations using another software correctly is problematic. Figures 9 and 10 show how the skills acquired by working in a simulation environment are integrated and a sequence of video tutorials explaining the assembly of each model step-by-step, respectively.

When only a simulator is used in an ER project, all issues related to the handling of tools, understanding of the importance of developing a good project for subsequent execution; experience of working with sensors, actuators

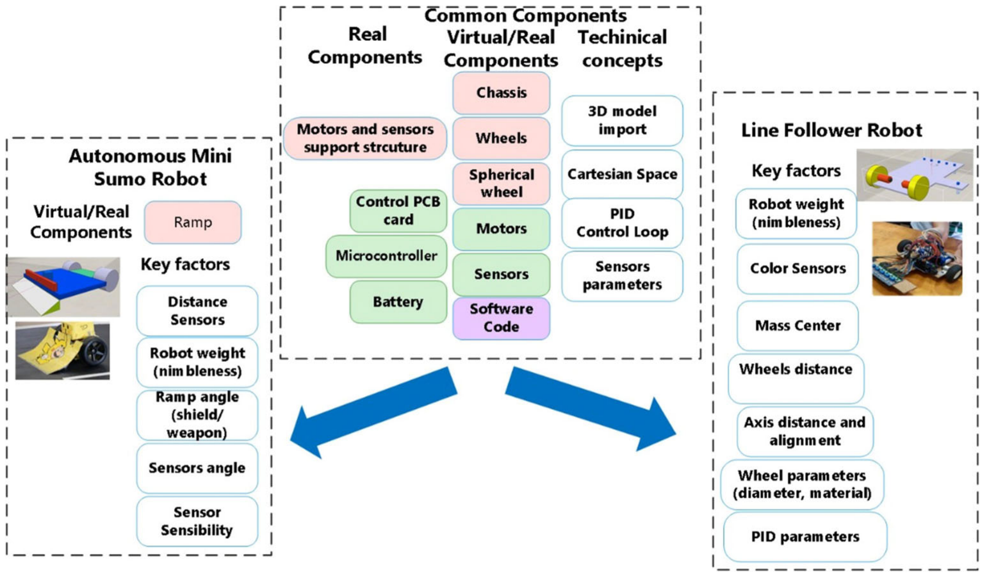


Fig. 8 The main points of attention that involve both projects

and real control boards; all involved features and difficulties; and opportunity to develop a physical model, which is high relevant in robotics, are neglected or poorly explored.

Furthermore, the analyzed experiences, in which the two methodologies of ER—real and simulated—were conducted separately, suggest that a well-managed integration of the two techniques in a constant-feedback loop with understanding of their importance in the teaching–learning process of students can be the key approach to achieve better results in projects and practices with ER. This is shown in Fig. 11.

3.2 Evidences of learning in 2022

After applying an ER project with simulators thrice, students are considered to become central in their own learning paths. Professor turn mediators, empowering discovery [53] and collaborative and competition-based

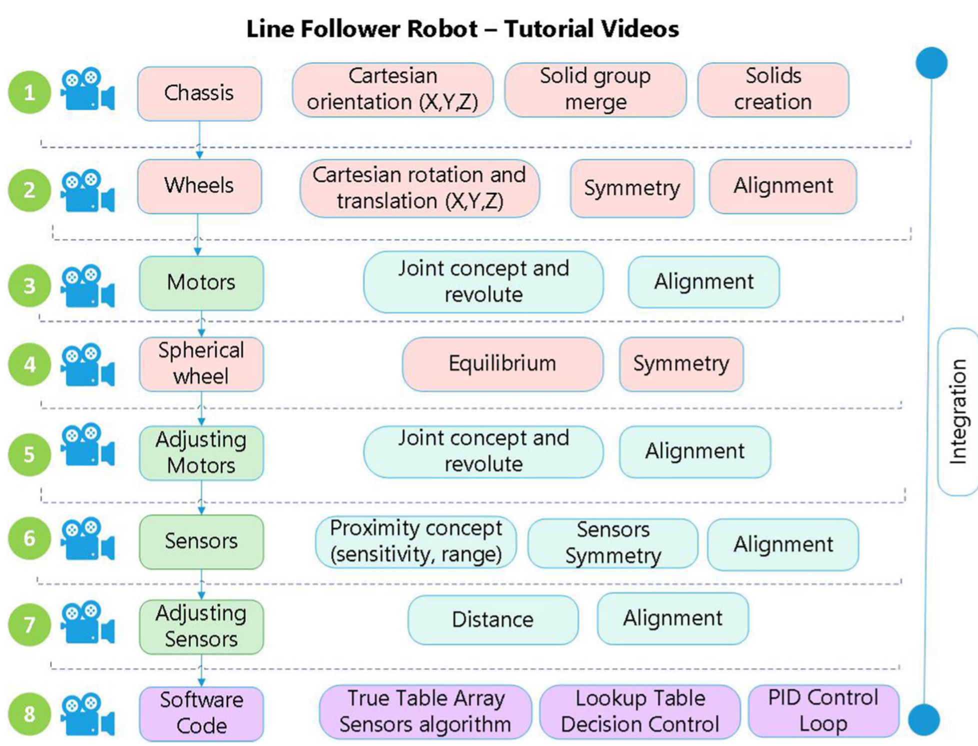


Fig. 9 Skills related to the use of the simulator in the construction of a line follower robot and division of video tutorial

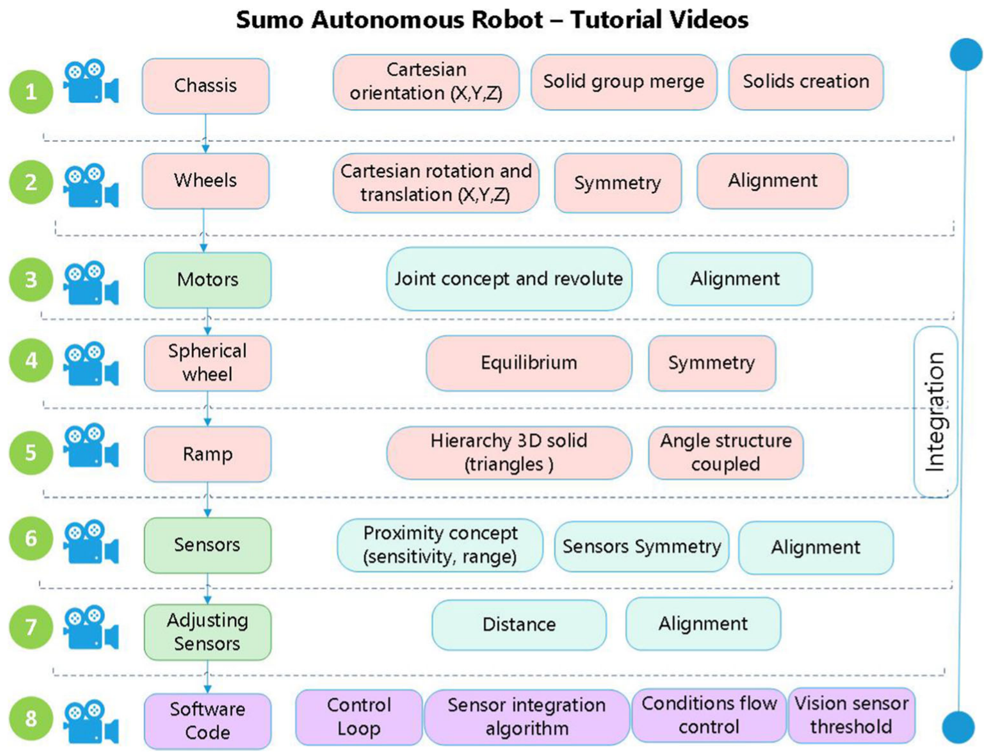


Fig. 10 Skills related to the use of the simulator in the construction of a sumo robot and division of video tutorial

learning [54]. This section presents evidences based on the participation of students in subjects PJI1 (sumo) and PJI2 (line-follower) and 12th grade students in 2022.

Students who studied for two years using the methodology of using simulators to learn robotics reached a conclusion during a capstone project meeting. The best strategy for approaching a project should start with simulations and then shift to building prototypes. Furthermore, after each change in the project, they should return to the simulation and test it. Thus, they can reduce the time dedicated to the project, minimizing possible problems due to lack of planning.

Another evidence observed was that during classes, one student faced problems with his robot in CoppeliaSim. It was not moving appropriately, and the team searched for a possible problem in the model. After a brief discussion with the mediator of the project (professor), they foresaw

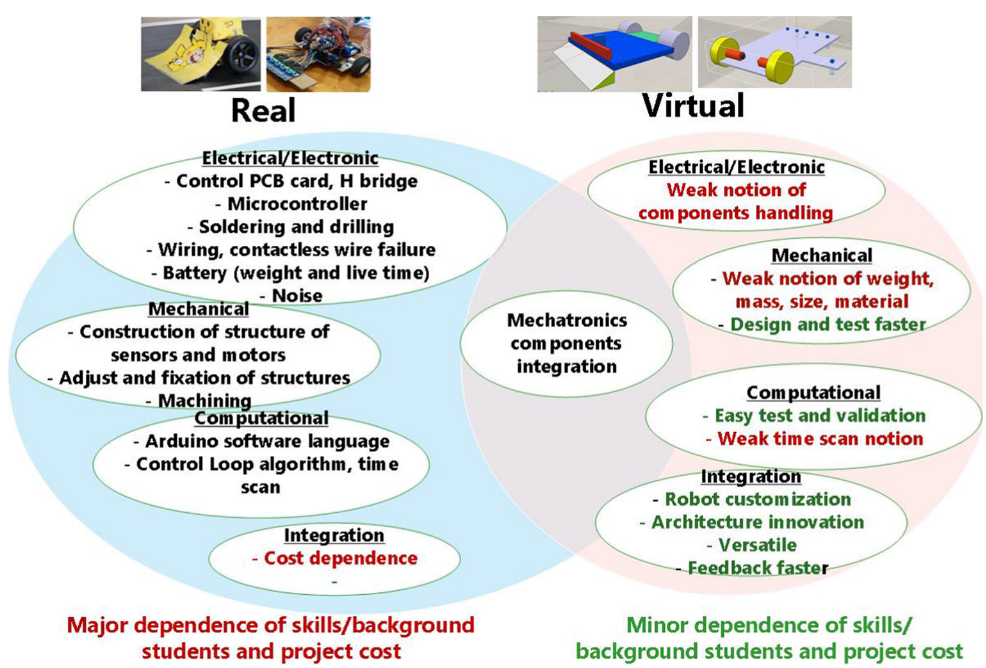


Fig. 11 Comparison between real and virtual robot development platforms

that the lack of a spherical wheel made the robot harder to slide on the floor. Students of 14–15 years are not used to friction concepts, and this should be considered during a project. However, they reached this concept by induction and internalized it after a practical approach and discovery learning process [53, 54].

We also observed that students in the second year of the project helped by simulators in developing the second model (line follower) asked questions about design earlier. In the projects, they installed 3–5 sensors in front of a car to detect the line in the control loop. Typically, students discuss the distance between sensors after practical tests; however, this time because they already had experience in loop control in the mini sumo model, they understood the importance of analyzing this problem and how to overcome it. They started to discuss how far sensors should be placed from the line and each other. Even though they were not very experienced in designing robots, they tackled by themselves a critical aspect of this project. The mediators presented the challenges and practical experiences from past projects, and some teams could make in first test whole track afterwards.

During the COVID-19 pandemic time of remote classes, students faced several interpersonal challenges and difficulties in sharing tasks as a team. They frequently asked to change members of the groups or to work by themselves. In 2022, we conducted a Myers–Briggs-type indicator personality test, and built teams based on its results. We observed a drop of more than 95% problems in relationships, and the groups were accepted well by students, indicating good teamwork in the majority of cases.

As revealed by past experiences, earlier students could not participate in robotics competitions or events owing to the high costs involved in building a prototype. Moreover, during a project, mistakes occurred and they had to buy broken and burnt components frequently. With this new approach of simulated projects and competitions, they became more motivated to participate and confident in spending lower resources to start a project and particularly in the assembly of a real model for a competition.

4 Conclusion

The developed approach showed evidence of enhanced student interest and achievement of integration of concepts of robotics. Various learning approaches such as discovery, collaborative, problem solving, project-based, competition-based can be integrated.

In a virtual environment, the immediate responses, visualization, and feedback increase interest. It encourages a student to build a robot in the real world with more interest, persistence, and responsiveness.

Clearly, correct combination of the two approaches of studying robotics (practical and simulated), leading to understanding the limits of each student and how students interact, can be an excellent method to achieve improved results in ER projects. Thus, the strong interaction between real and virtual environments and the feedback of this loop can enrich teaching and engage students more.

The use of robotics simulators for the development of works with students in [17] showed that such tools can significantly enhance the quality of teaching, save time and, reinforce concepts that are highly complex in real projects. Furthermore, they can reduce costs and democratize ER teaching.

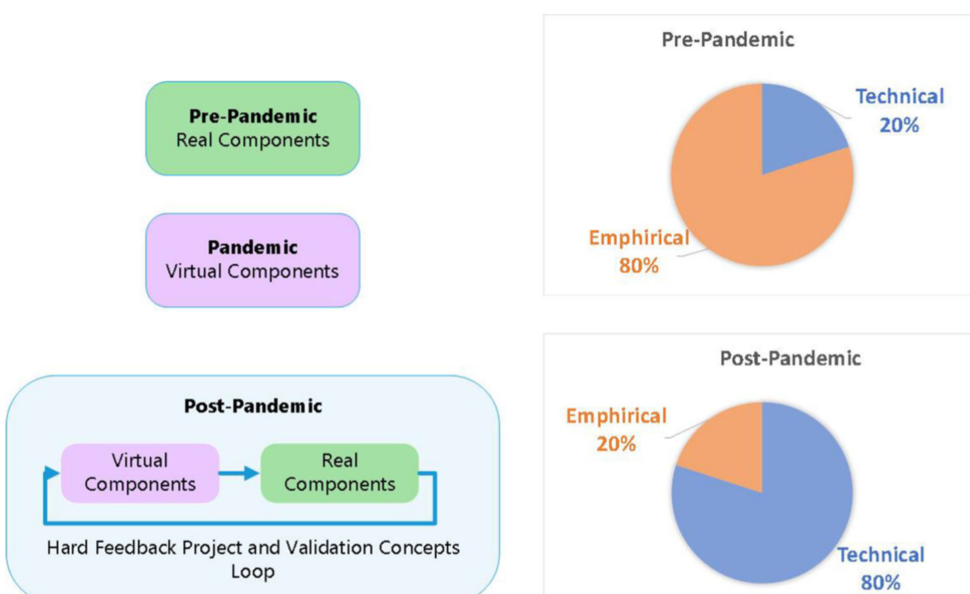


Fig. 12 Strong feedback between virtual and real approach. Impact on the emphasis from empirical to technical

Specific benefits were achieved for K-12 students. Based on the review, a simulator is typically adopted for undergraduates students to increase their ability to make technical-based decisions and move smoothly between the real and virtual worlds, with a strong emphasis on the feedback from both (Fig. 12). Such students can develop abilities to build robots by themselves without needing commercial kits. In a sim-to-real approach, early simulation allows better team integration and reduced reliance on skills while encouraging students to work harder in real implementation by equalizing the class level.

A simulation approach decreases the dependence on the skills and knowledge background of students, and thus, when adopted at the beginning, this approach equalizes the technical level of the students, standardizing them. The effects of the costs and resources to be spent by students are also minimized.

Not providing commercial kits for the construction of robots at the beginning of a project requires increased effort and dedication. However, it allows the development of more skills in the construction process and endows greater flexibility, creativity, and ability to make technical decisions. A mechatronics course provide all equipment, tools, and laboratories to a student to build a robot.

In this study, a significant change in decision-making was observed: design definitions that were once more by trial and error and in empirical form, were made using technical criteria discovered, learned, and validated by simulation. This led students to use the plan, execute, test, and validate cycle by realizing more consistently of its importance in project development.

The reported observations were made by the professors and staff involved during the project. One suggestion for future research is to develop a criterion to analytically compare the evolution of this methodology. Because it is tested with students, increasing the understanding of how these tools affect learning and help create stronger skills while showing the difficulty of cycle reformulation and improvement is possible.

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Declarations

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