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Express report

A Robot-Sumo student competition at UNICAL as a learning-by-doing strategy for STEM education

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Abstract: The continuous growth of STEM (Science, Technology, Engineering and Mathematics) education has set intense pressure on well-established engineering subjects, with a trend of replacing them with less demanding theoretical contents. This paper describes a recent activity with bachelor students to stimulate STEM education via a Robot-Sumo Competition. Students are grouped in teams to design, build and program their robot sumo robots. This course was implemented for the first time at University of Calabria (UNICAL). As a first attempt has been made with six teams each made of six students. Some seminars are delivered to the students to let them understand the assignment and its basic requirements. Then, they are expected to start developing a concept design and competition strategy. Then, they work on a 3D CAD modelling to design their own robot, whose main components will be later 3D printed and assembled. In parallel, the team selects the required sensors and electronic components as based on an Arduino architecture. The robots are completed and programmed for the competition where teams fight to find the most competitive solutions. The competition proves to be highly effective to learn multiple skills with a very practical and stimulating approach.

Keywords: teaching strategies, learning-by-doing, robot competitions

1. Introduction

The wide growth of scientific knowledge over the last decades has resulted in an intense pressure on traditional engineering curricula where novel approaches are needed to stimulate STEM education. Scientific community is proposing the introduction of novel teaching approaches, which might be beneficial for stimulating the interest at fundamental content while avoiding under coverage of most recent achievements in the field. Namely, one can consider "learning-by-doing" approaches, which can stimulate autonomous learning by the students as well as demonstrating the practical usefulness of a solid theoretic background. Experiential education is aiming to apply classroom learning, theories, and experiences to professional settings. These teaching approaches are usually linked to a postgraduate curriculum and include reading reference sources, drafting a report, critical thinking, and, especially, a real-world problem solving while applying concepts from the classroom, [1–7].

There are several educational robotics competitions based on teaching experiences with university students as well as the robotic organizations [1,2] focused on methodological aspects both from an educational and a technological/engineering viewpoint. Also, this kind of competition aiding the development of such skills as teamwork, leadership, presentation, and communication [3]. Literature shows how 'the interaction between the robot and the real-world information observed by the sensor' is important for training students in laboratory research. The development of the mobile robot for the Tsukuba Challenge was used to train students in [4]. Similarly, RoboSim [5] is a simulator which complements the control scheme for the hardware robots. RoboSim was used to design the challenges for the 2016 RoboPlay Challenge Competition. The code which is used to control the robots is unchanged between the hardware and virtual robots making the transition to hardware robots simple. The use of competitions to accelerate robotics research and promote science, technology, engineering, and mathematics (STEM) education has been used as a learning method in various situations as outlined for example in [6,7]. Robotics is particularly suited to innovation through competitions. Case studies include robot football, the UAV challenge, and the DARPA (Defense Advanced Research Projects Agency) grand challenges. An innovative program with Lego Mindstorms was designed to interest girls in science, technology, engineering, and mathematics (STEM) careers [8]. The competition was part of the IEEE Western Canadian Robot Games. At times, graduate engineering students mentor female students enrolled in the program to gauge the attitude of female students towards STEM careers. Students were free to build any robot they saw fit using parts from a Mindstorm kit. The Penn State Abington campus has integrated several mobile robot design competitions [9] into project-based design activities. Robot competitions support a wide range of educational outcomes in a variety of courses. They are cost-effective and promote interest in science and technology careers in K-12 students. Specific competitions’ formats can be particularly suited for engaging students such as, for example robot-sumo competitions.

2. Robot-sumo competitions

2.1. Th Robot-sumo competition and rules

Two robots compete in a head-to-head match following the basic system of traditional human sumo matches. Robots are allowed no weapons, and are not allowed to flip each other, [10]. The sole purpose is a pushing match between the two robots to force the other from the arena. Multiple weight classes and control systems are allowed (autonomous compete against autonomous and R/C against R/C - they are separate classes and do not compete against each other). A match is fought between two teams, each team having one or more contestants. Only one team member may approach the ring; other team members must watch from the audience. In accordance with the game rules, each team competes on a Dohyo (sumo ring) with a robot that they have constructed themselves to the specifications in 4.1. The match starts at the judge's command and continuous until a contestant earns two Yuhkoh points. The judge determines the winner of the match. The main rules are the following:

(1) One match shall consist of 3 rounds, within a total time of 3 minutes, unless extended by the

judges.

(2) The team who wins two rounds or receives two "Yuhkoh" points first, within the time limit, shall win the match. A team receives a "Yuhkoh" point when they win a round. If the time limit is reached before one team can get two "Yuhkoh" points, and one of the teams has received one Yuhkoh point, the team with one Yuhkoh point shall win.

(3) When the match is not won by either team within the time limit, an extended match may be fought, during which the team who receives the first Yuhkoh point shall win. Alternatively, the winner/loser of the match may be decided by judges, by means of lots, or by a rematch.

(4) One Yuhkoh point shall be given to the winner when the judges' decision was called for or lots were employed.

A Yuhkoh point shall be given to team that legally forces the body of the opposing robot to touch the space outside the ring, which includes the side of the ring itself.

2.2. Requirements for the dohyo and the robots

The dohyo interior is defined as the playing surface surrounded by and including the border line. Anywhere outside this area is called the dohyo exterior. The ring shall be circular in shape and of the appropriate dimensions for the given size class like reported in Table 1.

A robot must fit within a square tube of the appropriate dimensions for the given class. A robot may expand in size after a match begins, but must not physically separate into pieces, and must remain a single centralized robot. Robots violating these restrictions shall lose the match. Screws, nuts, and other robot parts with a total mass of less than 5 grams falling off from a robot's body shall not cause the loss of match. The dimensions and weight of the robots must be in the in the constraints of the given class, as reported in the Table 2.

Table 1. Ring dimensions

Class	Height	Diameter
Mega/Humanoid	5.00 cm	154.0 cm
Mini/Lego	2.50 cm	77.0 cm
Micro	1.25 cm	38.5 cm
Nano	0.625 cm	19.25 cm

Table 2. Robots’ maximum dimensions and weight

Class	Height	Width	Length	Weight
Mega Sumo – Auton, R/C, Network	unlimited	20.0 cm	20.0 cm	3000 g
Humanoid - R/C	50.0 cm	20.0 cm	20.0 cm	3000 g
Lego	unlimited	15.0 cm	15.0 cm	1000 g
Mini	unlimited	10.0 cm	10.0 cm	500 g
Micro	5.0 cm	5.0 cm	5.0 cm	100 g
Nano	2.5 cm	2.5 cm	2.5 cm	25 g

3. The proposed teaching activities

The purpose of this initiative was to experiment with a new teaching methodology, evaluating the skills of bachelor's degree students when faced with a multidisciplinary problem. Through a mechatronics project, it was possible to assess the skills acquired by students in the bachelor's degree program. The development of a multidisciplinary project, integrating cross-disciplinary knowledge and practical experience, led students to a greater awareness of their skills. The project will cover all its fundamental stages not just by using directly commercial robotics kits. Instead, by proposing modification and integration of components and the programming of control software. The course is open to a limited number of 30–40 students in groups of a maximum of 5 students, giving priority to those who have obtained the highest number of CFUs. The project is characterized by its strong interdisciplinary character, combining aspects of mechanical component selection (motors, gearboxes, sensors), aspects of CAD design/rapid prototyping and aspects of electronics, control, and programming. The activities were self-directed by the students, with weekly discussions with tutors and lecturers. seminars were organized by the lecturers on specific aspects. reference manuals, tutorials, video lectures, necessary for autonomous learning, were provided. The assessment method for passing the course is based on the writing of a report, the construction of a working robotic prototype and subsequent participation in the competition.

3.1. Classes

The activities were conducted in presence by the students, according to a well-defined structure of theoretical and practical lessons and group activities. The lessons included an initial two-month period, on a weekly basis, in which theoretical lessons and specific seminars were held. The theoretical lessons were conducted by teachers with specific competences in the different disciplines necessary for the implementation of the project. The theoretical courses began with a review of the basic concepts of mechanics and applied mechanics already studied in other courses, and then moved on to an in-depth study of robotics. An initial overview of existing robots for industrial and non-industrial applications enabled the students to understand the main components to be implemented in their project. The students were able to interface with this new world by discovering different movement systems, types of actuators and sensors. This was followed by electronics lessons that allowed the students to evaluate and know how to choose the correct sensor and/or actuator, exploring the main technical characteristics and operating principles of each. As each group began to conceptualize their robot, theoretical-practical lessons followed in which they were given the necessary tools to start developing and evaluating their ideas.

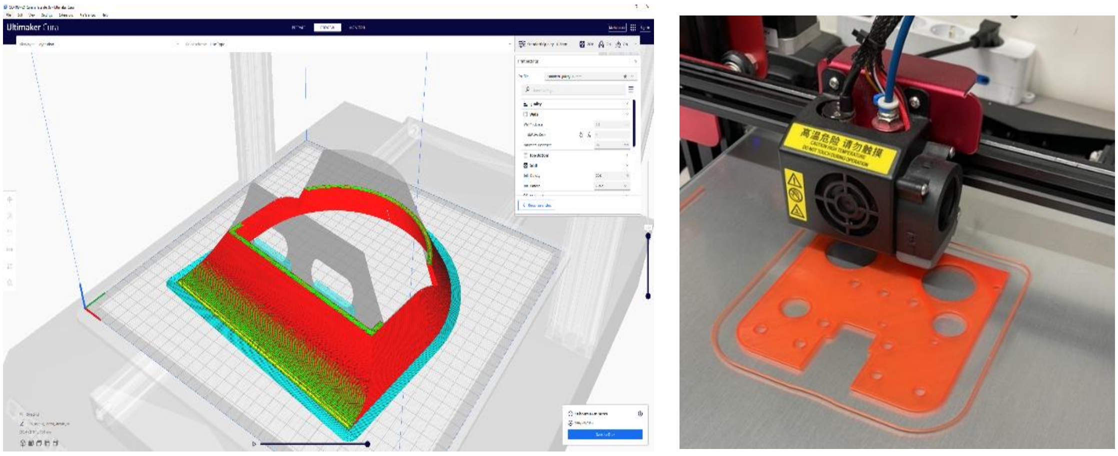

Figure 1. Some pictures taken during the 3D printing classes and practices

The lessons covered the use of CAD and numerical software, for the creation of virtual models and related simulations; electronics lessons, in which the main techniques for interfacing sensors and controllers were illustrated; and practical lessons on the construction of prototype circuits. In order to enable the students to work independently, practical lessons on the use of the 3D printer were organized. The lessons were held by tutors who developed examples of 3D printed objects (Figure 1) in class with the students. In this way, it was possible to bring out in class the difficulties involved in the printing process, such as positioning on the printing plate, orientation of the parts, use of supports, levelling the print bed, process temperatures and the use of slicing software. The students were able to put themselves to the test in the classroom by developing their CAD models with the tutors in order to proceed independently with the printing of prototypes. The last part of the theoretical lessons covered controller programming techniques, such as ARDUINO, and object-oriented programming to develop their own algorithms.

3.2. Practical experience

In parallel with the theoretical lessons, practical lessons were held in the laboratory. During these lessons, students learnt how to use the equipment required to build a robot Figure 2. Lectures were held on the soldering of electrical circuits, in which the students were presented with small, gradually more complex exercises in which they made prototype boards or parts of them. during these exercises, the students were shown the component to be made and each of them, in turn, replicated the proposed exercise. Activities were conducted on the assembly of mechanical components and the use of measuring instruments, during which the students assembled their artefacts, correcting printing errors and understanding the importance of mechanical couplings. Through an iterative process of 'trial and error', the students were able to improve their prototypes. Teams also implemented their own programming codes such as the example in Appendix 1.

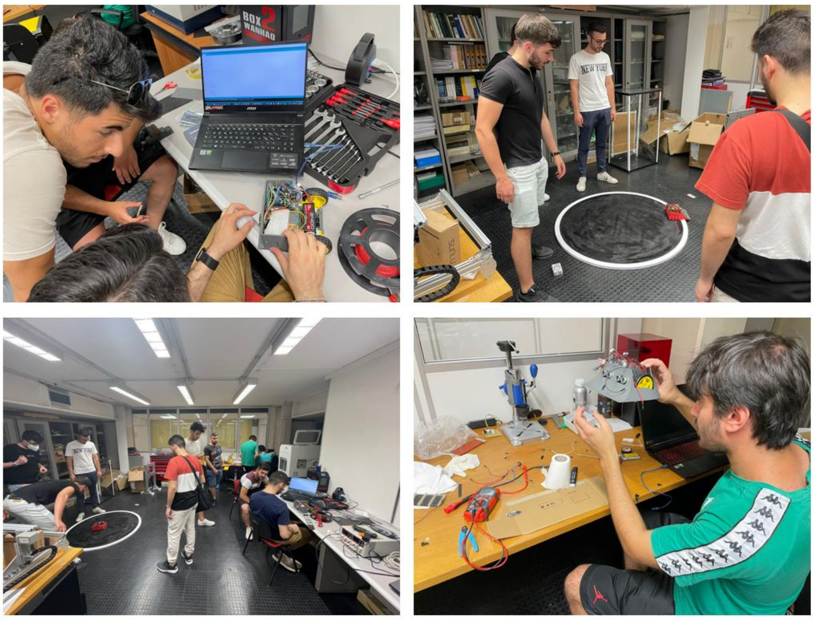

Figure 2. Some pictures taken during the assembly and testing phase of the Sumo Robots

4. Competition and experience at University of Calabria

The official rules described in 2.1 were not followed for the proposed competition, because the focus was more on the educational and playful experience involving the students.

4.1. Adopted rules

For our competition, we chose to make robots that were the size of a MEGA SUMO with a maximum weight of 500 g (maximum weight of the MINI SUMO). the Dohyo also has different dimensions from the official ones, with a size of 120 cm along the diagonal and a height of 2.5 cm. The white line delimiting the edge is 4 cm thick. Robots may not have armed appendages to break the opponent, but may have mobile appendages to lift, tip or move the opponent. At the start of the fight, robots with mobile appendages must have a maximum base size of 20 cm x 20 cm. The competition takes place in two rounds. In each round each competitor fights in turn with all the others; for each round won, the team wins a point. The point is awarded to the robot that manages to push its opponent out of the ring.

4.2. The case of study at University of Calabria

Six teams, each consisting of six students, participated in the competition with a total of 37 students. The students divided the tasks independently in order to conduct the tasks as well as possible. In the group, the tasks were divided as follows: students responsible for the implementation of the CAD models, students responsible for the implementation and assembly of the components, students responsible for the implementation of the printed circuit boards and students responsible for the implementation of the control software. Each team was given the same components to build their own robot, and then chose themselves which components to use based on the notions acquired during the theoretical and practical lessons. This freedom of choice was decisive for the results obtained from this workshop, which enabled unexpected results to be achieved thanks to the students' imagination.

4.3. Prototypes

All teams were provided with controllers (ARDUINO mega, UNO and nano), line sensors, ultrasonic proximity sensors and DC motors with wheels. Each team chose to integrate these components synergistically with the structure; in other words, the students chose the form and functionality of their robot according to the competition strategy.

Figure 3 shows the robot of team 1 in which two-wheel motors, an Arduino UNO, a single line sensor on the front of the robot and an ultrasonic sensor were used.

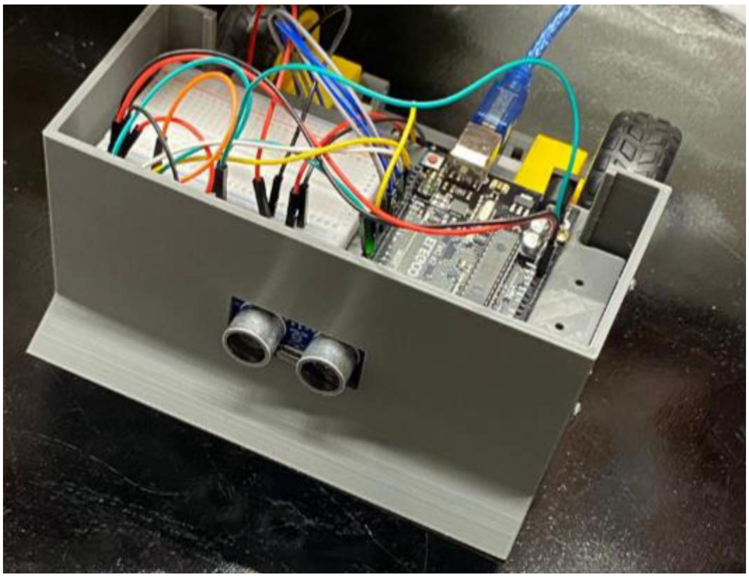

Figure 3. Robot of Team 1, called SQUARE

Group 2 created a robot with a special shape, with a movable central harpoon to lift the opposing robot, as can be seen in Figure 4. This robot is also equipped with a line sensor and an ultrasonic sensor.

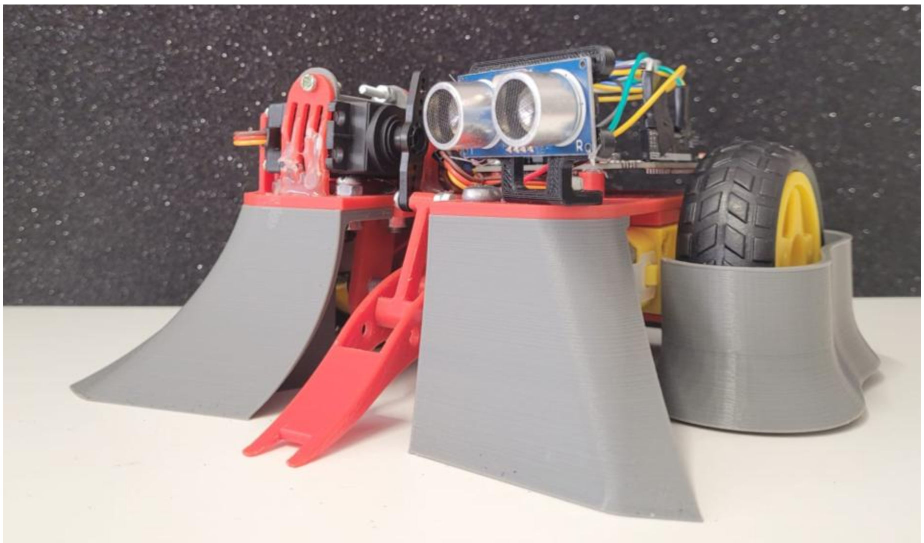

Figure 4. Robot of Team 2, called RHINO

Figure 5 shows the robot of team 3 in which two-wheel motors, an Arduino UNO, two-line sensors on the front (left and right) of the robot and an ultrasonic sensor were used.

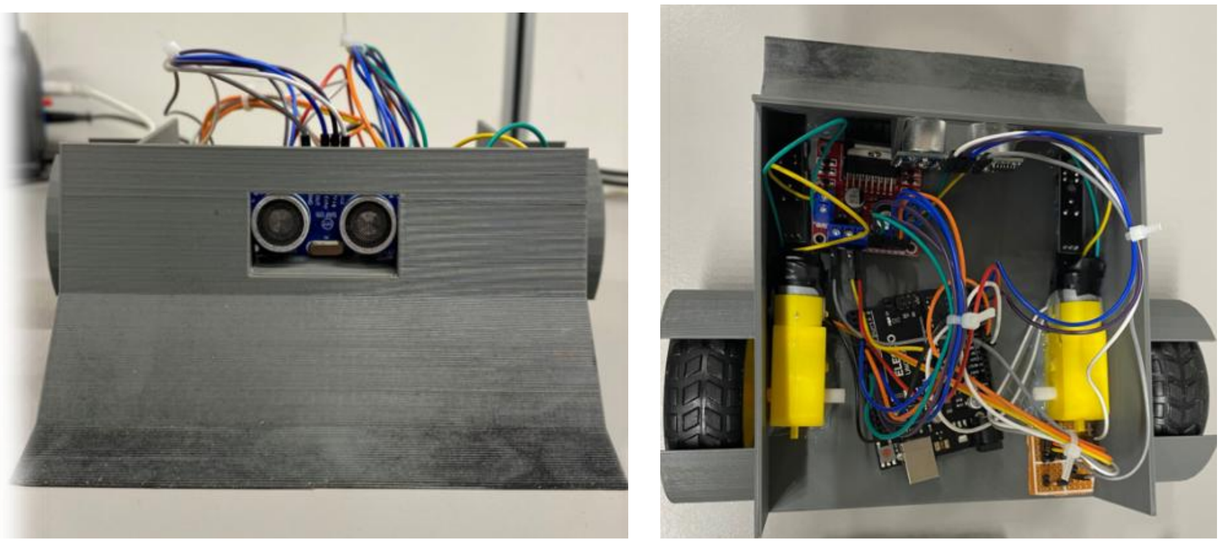

Figure 5. Robot of Team 3, called J3RR1

Figure 6 shows the robot of team 4 in which two-wheel motors, an Arduino UNO, and an ultrasonic sensor were used. No line sensors were installed because this team works a lot on the game strategy.

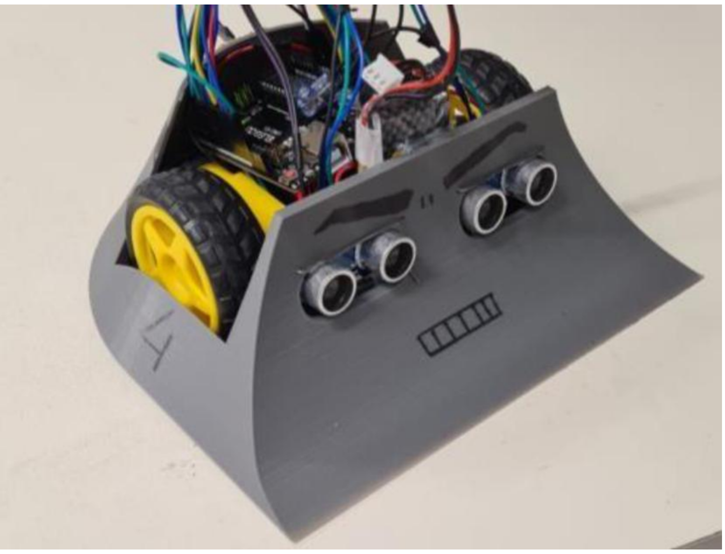

Figure 6. Robot of Team 4, called JACKIE CHAN

Figure 7 shows the robot of team 5 in which four-wheel motors, an Arduino UNO, four-line sensors and an ultrasonic sensor were used. This was the unique robot with four wheels in the competition.

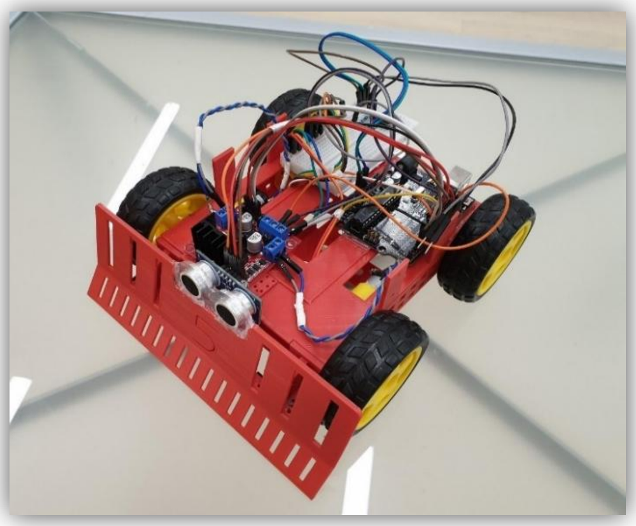

Figure 7. Robot of Team 5, called BONAROBOT

Figure 8 shows the robot of team 6 in which two-wheel motors, an Arduino UNO, one-line sensors and an ultrasonic sensor were used. This was the unique robot with metal plate in the competition.

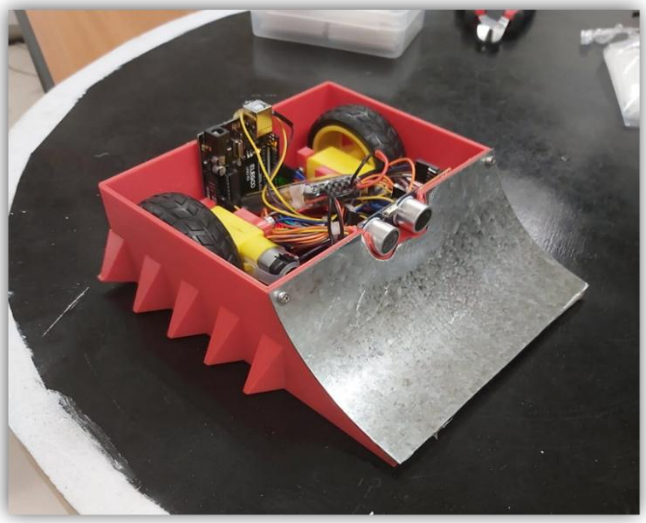

Figure 8. Robot of Team 6, called DUNEBUGGY

After the construction of the prototypes, it was on to the competition. Figure 9 shows some phases of the clash between the various teams. The competition took place in a university lecture hall, with an audience and live streaming on the university channel. At the end of the competition, there was an award ceremony for the top three, and a final discussion on the entire project and evaluation by the course participants (Figure 10). The winning team was Team 4, who exploited the shape and correct weight balance of their robot. Their ingenuity in using a simple competition strategy proved effective. Their robot did not use sensors to recognize the edge of the ring but based its logic on the main rule to win consisting in throwing the opponent out of the ring. Their game plan therefore consisted of spinning the robot on itself until it detected the opponent, only then would it charge and push him out of the ring.

Figure 9. Some photos taken during the competition

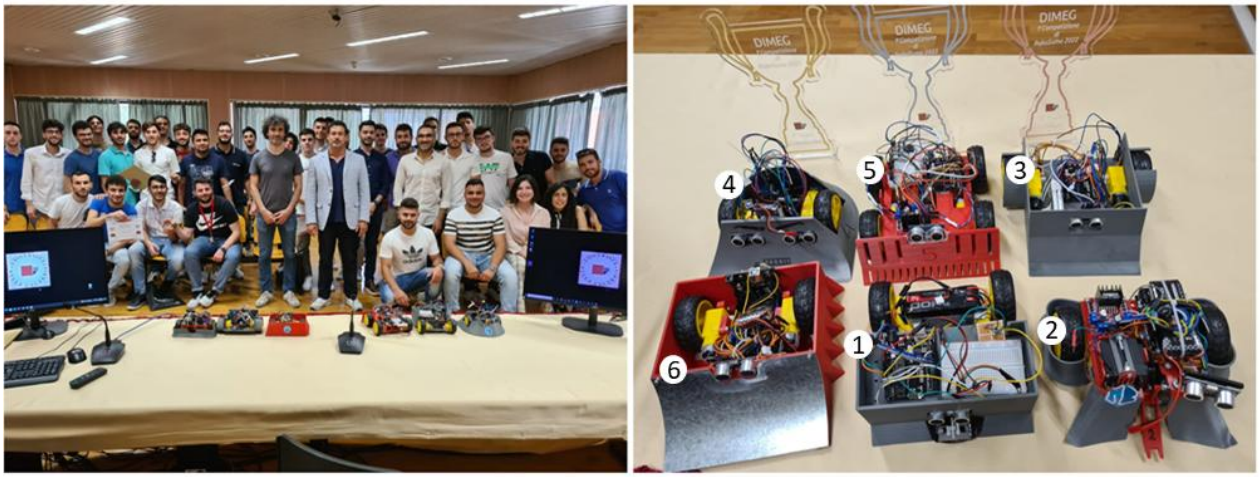

Figure 10. Photos taken during the final stage of the awards ceremony. 1: SQUARE, 2: RHINO, 3: J3RR1, 4: JACKIE CHAN, 5: BONAROBOT, 6: DUNEBUGGY

5. Discussion

Thanks to this multidisciplinary course, the students were able to deal with different areas of mechatronic engineering, understanding the interconnection between the various sectors and the all-round interdisciplinary design. This initiative demonstrates the usefulness for the students to improve their basic skills, related to their course of study, but also to develop soft skills such as teamwork, correct communication of information, the value of being part of a team and the healthy competition that will have to accompany them throughout their profession to improve themselves in the face of each new challenge. This multidisciplinary experience allowed the students to understand how a project should be approached, considering also various practical aspects that are commonly neglected during bachelor engineering studies. "Learning by doing" is not only a learning paradigm, but also a way to engage the students who demonstrate that they really learn the concepts, as they learn to solve concrete problems and search for the information, they need to develop their prototypes. The real excitement comes when they finally see their prototypes working and competing in the ring winning battles. This initiative brought the desired results and the students saw a new way of learning concepts, not by sitting in a classroom but by doing it with their own hands. Another important concept that the students learnt is that sometimes the simplest solution is also the strongest and allows you to win. The excellent experience will be repeated in the years to come.

5.1. Limits of this study

The limitations of this teaching methodology experiment are the lack of a quantitative assessment of the achieved level of knowledge. The pass/fail level was estimated as based on the quality and performance of the robot during the competition. The students did not individually develop the same skills since this is a teamwork in which everyone contributed according to their aptitudes.

5.2. Future improving of this learning-by-doing strategy

In future years, the competition will be offered again, and some changes will be proposed. First, we consider opening to a wider range of students (bachelor, master, or even high school students) with different categories and levels of complexity. To make sure that all students participate in the work and learn basic skills, hands-on classes will be held to individually assemble standard components. The competition will also be offered to other undergraduate courses with different backgrounds to allow for the integration of skills related to other specific STEM fields.

6. Conclusions

This paper describes a learning by doing experience that has been developed at DIMEG, University of Calabria, Italy, as based on a specifically developed Robot-Sumo competition. This initiative demonstrates the usefulness of this specific learning-by-doing format as an excellent mean to engage students while letting them learn a wide range of hard and soft skills. Given the success of the initiative, it will be implemented as part of regular courses, and we hope to also invite teams from outside our institution further developments and challenges.

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Conflict of interest

Authors declare no conflict of interest.

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Appendix 1 – A programming example made by the teams for the competition at UNICAL

```
#include <NewPing.h>
int motorRforward = 7;
int motorRreverse = 6;
int motorLforward = 9;
int motorLreverse = 8;
int ENA = 5;
int ENB = 10;
int lettura;
#define trigpin A2
#define echopin A3
#define sensorR A0
int valueR = 0;
int WhiteLine=0;
const int buttonPin = 2;
int buttonState = 0;
 NewPing sonar (trigpin, echopin);
 void setup() {
  pinMode (ENA, OUTPUT);
  pinMode (ENB, OUTPUT);
  pinMode (sensorR,INPUT);//left sensor infr
  pinMode (motorRforward, OUTPUT);//left motor
  pinMode (motorRreverse, OUTPUT);
  pinMode (motorLforward, OUTPUT);//right motor
  pinMode (motorLreverse, OUTPUT);
  pinMode(buttonPin, INPUT);
  Serial.begin(9600);
  while(buttonState == 0){
    Stop();
    if (digitalRead(buttonPin) == HIGH){
      buttonState=1;
```

```
//-----------------------------------------------
void BACKWARD(int Speed){
  analogWrite (ENA, Speed);
  analogWrite (ENB, Speed);
  digitalWrite(motorRforward,HIGH);
  digitalWrite(motorRreverse,LOW);
  digitalWrite(motorLforward,LOW);
  digitalWrite(motorLreverse,HIGH);
}
void FORWARD (int Speed){
  analogWrite (ENA, Speed);
  analogWrite (ENB, Speed);
  digitalWrite(motorRforward,LOW);
  digitalWrite(motorRreverse,HIGH);
  digitalWrite(motorLforward,HIGH);
  digitalWrite(motorLreverse,LOW);
}
void LEFT (int Speed){
  analogWrite (ENA, Speed);
  analogWrite (ENB, Speed);
  digitalWrite(motorRforward,HIGH);
  digitalWrite(motorRreverse,LOW);
  digitalWrite(motorLforward,HIGH);
  digitalWrite(motorLreverse,LOW);
}
void RIGHT(int Speed){
  analogWrite (ENA, Speed);
  analogWrite (ENB, Speed);
  digitalWrite(motorRforward,LOW);
  digitalWrite(motorRreverse,HIGH);
```

```
      delay(5000);
    }   }  }
void loop() {
  lettura = sonar.ping_cm();
  //Serial.println(read);
  valueR = digitalRead(sensorR);
  FORWARD(150);
  if (valueR == WhiteLine){
    Stop();
    delay(20);
    BACKWARD(200);
    delay(500);
    switch(random(0,2)){
       case 1:
        RIGHT(170);
        delay(1000);
        break;
       default:
        LEFT(170);
        delay(1000);         }    }
  if (read<30){
    Fight();        }     }
```

```
  digitalWrite(motorLforward,LOW);
  digitalWrite(motorLreverse,HIGH);
}
void Stop(){
  analogWrite (ENA, 0);
  analogWrite (ENB, 0);
  digitalWrite(motorRforward,HIGH);
  digitalWrite(motorRreverse,LOW);
  digitalWrite(motorLforward,LOW);
  digitalWrite(motorLreverse,HIGH);
}
void Fight(){
  while(sonar.ping_cm()<30){
    FORWARD(255);
    if (digitalRead(sensorR) == WhiteLine){
      Stop();
      break;
    }
  }
}
```

Author’s biography

Giuseppe Carbone is Associate Professor at DIMEG, University of Calabria, Italy since 2018. Since 2020 he is Chair of the IFToMM TC on Robotics and Mechatronics and His research interests cover aspects of Mechanics of Manipulation and Grasp, Mechanics of Robots, Mechanics of Machinery with more than 400 published papers. Among others, he currently serves as Editor-in-Chief of Robotica (Cambridge Univ. Press), Section Editor in Chief of Machines and Robotics (MDPI), Technical Editor of IEEE/ASME Transaction on Mechatronics, Member of the Board of Directors for the Society of Bionics and Biomechanics, Treasurer of the IFToMM Italy Society, Vice-president of the Italian Institute of Robotics, and Intelligent Machines (I-RIM). Senior member IEEE.

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