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Bipedal robot center of pressure feedback simulation for center of mass learning

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ABSTRACT

This research aims to create a walking bipedal robot with center of pressure feedback simulation for the center of mass learning, describe its feasibility for learning, describe students' motivation to learn, and describe students' science literacy after using it. The research method used ADDIE (analysis, design, development, implementation, and evaluation). The research data was obtained using a motivation scale questionnaire, science literacy scale, and feasibility scale. The research sample was 48 people; after the research obtained, the simulation of bipedal robot pressure center feedback for center of mass learning can be implemented with the principle of the robot's center of mass detected on the sole of the robot's foot equipped with a force sensitive resistor (FSR) sensor, the position of the center of mass is visible on the monitor screen as a center of mass learning, so that it can motivate students to learn and improve students' science literacy. This can be seen from the feasibility scale score, motivation scale, and science literacy scale of 4.133, 4.072, and 4.067 (scale 1 to 5), respectively, in the "good" category.

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1. INTRODUCTION

The results of junior high school science learning in Bengkulu province in the 2017/2018 academic year are the lowest among the 4 national exams carried out due to the teaching methods of teachers who still need to be standardized. The decline can be seen in the UN learning outcomes, which decreased by 2.91 from the previous year, namely 57.15 in 2016/2017 to 54.24 in 2017/2018. In the 2018/2019 school year, it decreased again by 11.46 from 54.24 to 42.78 [1], [2]. The teacher's teaching method needs to be standardized because it causes low literacy and motivation of students in learning science; therefore, it is necessary to take concrete actions so that students' science literacy and learning motivation increase. One of the activities that can be done is to utilize the role of robotics in science learning.

Curriculum 2013 emphasizes student activeness in constructing their knowledge according to the paradigm of constructivist theory developed. Teachers must be able to create fun learning so that students do not feel forced to find their own knowledge. The learning process will be successful if a teacher can apply learning approaches and methods that are mastered and relevant to the theory or concept being taught [3]. The implementation of science learning in high schools and junior high schools is usually complemented by electronics skills (physical science), which can be carried out in intracurricular, co-curricular, extracurricular or self-study activities at home [4], [5]. Therefore, robotics activities can play a role in science learning in extracurricular, co-curricular, and intracurricular activities.

Robotics is a branch of technology that deals with robot design, construction, operation, structural disposition, manufacture, and application. International Federation of Robotics, European Robotics Research Network defines a robot as an automatically controlled, reprogrammable, multipurpose, programmable manipulator in three or more axes, which may be fixed in place or mobile for use in industrial automation applications [6]. A bipedal robot is a robot that moves and manages balance using two legs, and this robot moves like a human. In movement, a method is needed to facilitate the movement of the robot's legs [7].

One of the settings for robot movement is called controlling the walking stability of bipedal robots. Controlling a bipedal robot is a challenging task due to the large number of degrees of freedom involved and the nonlinear and difficult-to-stabilize dynamics [8], [9]. The structure of bipedal robots is one of the most flexible forms of walking robots. Bipedal robots have the same working mechanism as humans and can walk in environments of uneven terrain, slopes, stairs, and obstacles [10]–[14]. Bipedal stability during walking motion is an important factor in preventing the robot from falling and causing harm to humans or itself. The zero moment point (ZMP) method is often used as a stability criterion for bipedal walking robots [15]–[21]. One way is to use force sensors placed under the feet. A method that can be done using a Fuzzy control scheme, the controlled variable is to coordinate the rod compensation only in the sagittal plane, used to move the measured ZMP to the desired ZMP, which is obtained from the force sensor placed on the robot's leg. A cooperative control scheme to achieve a lateral balance of a biped robot in the coronal plane was conducted and tested under disturbed conditions, such as changes in floor inclination and external forces applied to the body [22].

The main control system is responsible for commanding the leg servomotors and two proportional Fuzzy controllers, one for each leg, which calculate the center of pressure (CoP) under each leg and generate control actions to move the hip-ankle servomotor to return the CoP to a stable region. The ZMP was analyzed from a human walker wearing robot feet as shoes [23]. Some researchers proposed a flexible shoe system for bipedal robots to optimize the energy consumption of lateral plane motion [24]. Suwanratchatamanee *et al.* [25] proposed a haptic sensing foot system for humanoid robots. They investigated two different types of applications: one is an active touch sensing technique to recognize the slope of the ground in contact. The other is balancing the robot body on one leg for human-robot interaction.

Fuzzy controllers can be used to realize biped walking on slopes with desired ZMP trajectories [26]. Dynamic balance control (DBC), which includes a Kalman filter (KF) and a fuzzy motion controller (FMC), is also designed to keep the body in balance and make the biped walk following the desired ZMP reference. In addition, the KF is used to estimate the state of the system and reduce the effects caused by noise [27]. The CoP located at a position under the sole should affect the stability of bipedal walking. Therefore, the study of the CoP region of a bipedal robot remaining stable is a challenge. Stable walking on a bipedal robot can be realized by balancing two types of forces. One is the resultant of gravitational and inertial forces generated by the motion of the robot. The other force is the floor or ground reaction force acting on both legs of the robot. In this paper, we develop bipedal robot walking stability in the second perspective. We call the point associated with the contact force CoP.

The center of mass is a point on the object that contains the mass of all particles that make up the object and is considered centered at that point. If there are two objects with m1 = mass of particle 1, m2 = mass of particle 2. Both particles are on the x-axis. Particle 1 is x1 away from the y-axis, and particle 2 is x2 away from the y-axis. The center of mass is abbreviated as PM. Both particles lie on the x-axis; hence, the center of mass of both particles is written xPM.

$$xPM = \frac{(m_1 x_1 + m_2 x_2)}{(m_1 + m_2)} \tag{1}$$

Many studies have investigated the effects of ER on STEM performance. Kandlhofer *et al.* [28] used 179 students from nine elementary schools as subjects to find that, based on student gender, age, and background, there was no significant difference in learning outcomes of "robot assembly and programming". In a study with a research method in the form of a quasi-experimental design using a sample of 148 students, with an average age of 14.9, a very strong relationship was found significantly between the significant intervention effects on math and scientific inquiry, teamwork, social skills on technical skills and soft skills/social aspects [29].

The results of another study showed that the use of the Nao robot was able to generate positive interactions, children enjoyed interacting with the robot, and children's pleasure in "playing" with the robot was maintained over time. The results of this study indicate that storytelling robots successfully promote children's emotional engagement in the learning process. Children's emotional responses correlated with the dynamic content in the story text. In addition, the findings showed that children's IL scores were greater when they listened to the Ugly Duckling story than when they heard the Pluto story [30]. Educational robotics activities with children (from 3 to 19 years old) with a diagnosis of neurodevelopmental disorder, when children have the opportunity to program the behavior of a real robot. Most of the experiences showed improvements in participants' performance or abilities, their engagement and involvement, and communication/interaction with peers during the robotics sessions; mixed results were obtained, calling for the need to design the objectives and related activities of each experience carefully [31].

Another study reported that Turkish high school students' attitudes towards robotics and STEM were examined in terms of gender and robotics experience, using a sample of 240 high school students (98 girls and 142 boys; grades 5 to 7). The results showed that students' attitudes toward robotics and STEM were positive. Gender did not affect STEM attitudes. However, in terms of robotics attitudes, female students had significantly less desire and confidence to learn robotics than male students. The students were also significantly less likely to play with robots they designed themselves [32].

The application of Spiderino's robot swarm platform through workshops conducted in the classroom will evaluate whether these workshops have a positive effect on students personally and increase their interest in STEM subjects, especially computer science, through quantitative student and qualitative teacher approach instruments. The results showed overwhelming acceptance of using the robot swarm platform as an effective educational tool, easy to use, entertaining, and increasing motivation to complete tasks during observations of interactions between students and robots [33]. An understanding of student perceptions of edu-robotics and task-centered STEM learning through quantitative and qualitative data sources. Theoretically, this research extends the application of the teacher centered learning approach based on mastery learning theory to hands-on STEM learning on edu-robotics. Practically, this research can help students and educators understand how to conduct task-centered STEM teaching and learning activities in edu-robotics [34].

To complement the above findings, researchers need to conduct similar research related to the role of robots in learning, especially the relationship between bipedal robots and the center of mass. The title of this research is "Bipedal robot center of pressure feedback simulation for center of mass learning." For this reason, the problem is formulated as follows: i) Can the bipedal robot pressure center feedback simulation for center of mass learning be implemented? ii) Is it feasible to use it to learn about the center of mass? iii) Can it motivate students to learn? iv) Can it improve students' science literacy?

In order to find solutions to the above problems and answer the objectives of this research, it is necessary to carry out activities with the following stages/algorithm: i) create a bipedal robot pressure center feedback simulation program for mass center learning, ii) test the feasibility of the bipedal robot pressure center feedback simulation program for mass center learning, iii) test the increase in student learning motivation, and iv) test the increase in student science literacy after learning using the bipedal robot pressure center feedback simulation media for mass center learning.

2. METHOD

A research method is needed to achieve the research objectives. The method used is a type of research and development with the ADDIE development model, which is a generic learning design model that provides an organized process in the form of simulated learning materials that can be used, both in face-to-face and online learning. In this method, there are five stages: i) analysis, ii) design, iii) development, iv) implementation, and v) evaluation. The sample as the research subject used was 48 people from undergraduate students of Physics and postgraduate students of Science Education FKIP UNIB Bengkulu in the academic year 2023/2024.

2.1. Analysis

The analysis was conducted using direct experimental research, aiming to simulate the CoP using foot pad sensors and controlling the walking stability of bipedal robots. After direct experimentation, educational research followed. Simulation of CoP using foot pad sensors and controlling walking stability of bipedal robots, used as media and teaching materials in learning the center of mass so that learning effectiveness is achieved. Educational research was conducted among S1 Physics and S2 Science education students at FKIP UNIB Bengkulu. In contrast, the study of the bipedal robot center of pressure feedback simulation was conducted at UGM Vocational School Yogyakarta and S2 Science FKIP UNIB Bengkulu from May to September 2023.

2.2. Design

2.2.1. Walking bipedal robot pressure center feedback simulation

The tools used in this simulation consisted of a robot, a computer, a flat, tilted table with a flat floor, a ladder, and MATLAB software. The robot above the various situations is connected directly to a computer that has loaded a simulation program written using MATLAB software. Furthermore, various robot maneuvers are carried out so that the change in the pressure point on the monitor screen can be seen when there is a change in the pressure on the robot's foot.

2.3. Development

Simulation is a way of duplicating or describing a natural system's characteristics, features, and appearance [35]. The simulation method moves an actual situation into the learning space because of the difficulty of practicing a real problem. In this paper, we used a bipedal robot; where 12 DOF joints are desired for two legs, 4 DOF joints are desired for two arms, and 2 DOF joints are desired for the head. The height and the total weight including the batteries are 380 mm and 2900 grams, respectively. The mechanical structure is shown in Figure 1.

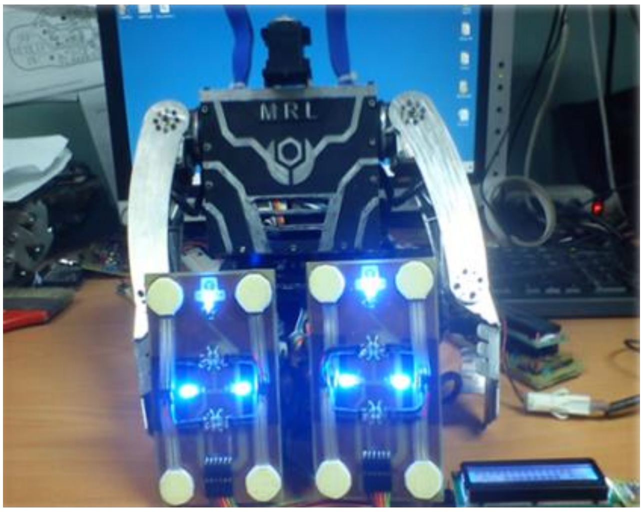


Figure 1. Physical of the bipedal robot’s platform [36]

2.3.1. Determining center of pressure (CoP) using foot pad sensor

We can calculate the resultant force by using the center of area (CoA) technique. In this paper, we developed four force sensitive resistor (FSR) sensors which were attached to the sole of the foot. There are two step calculations to know the CoP position, which is related to the gait phases, i.e., single support phase (SSP) and double support phase (DSP). Figure 2 shows the CoP position when the bipedal robot is on the SSP. The coordinates A, B, C, D are described by P_A (x_{PA}, y_{PA}), P_B (x_{PB}, y_{PB}), P_C (x_{PC}, y_{PC}) and P_D (x_{PD}, y_{PD}). So, we can calculate the CoP position as follows for SSP phase as indicated in (2) and (3).

$$x_{CoP} = \frac{f_A x_{PA} + f_B x_{PB} + f_C x_{PC} + f_D x_{PD}}{f_A + f_B + f_C + f_D} \tag{2}$$

$$y_{CoP} = \frac{f_A y_{PA} + f_B y_{PB} + f_C y_{PC} + f_D y_{PD}}{f_A + f_B + f_C + f_D} \tag{3}$$

where f_A, f_B, f_C, f_D, are the force at A, B, C, D point achieved through FSR sensors and explained in (4) to (7).

$$x_{PA} = FL - dxA;\ y_{PA} = FW - dyA \tag{4}$$

$$x_{PB} = FL - dxB; y_{PB} = dyB \tag{5}$$

$$x_{PC} = dxC;\ y_{PC} = FW - dxC \tag{6}$$

$$x_{PD} = dxD; y_{PD} = dxD \tag{7}$$

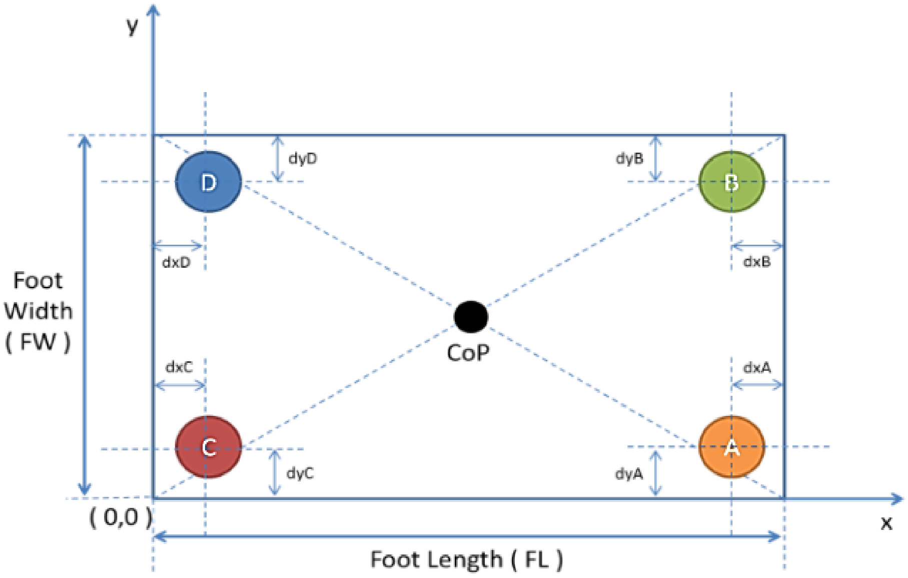


Figure 2. CoP position when the bipedal robot on SSP phases

2.4. Implementation

The implementation of this research in the field of education is carried out during face-to-face learning in the class of undergraduate Physics students and graduate students of Science Education FKIP UNIB for the topic of the role of robots in learning. Simulation of feedback pressure center bipedal robot walking is used as media and teaching material for the concept of center of mass. The research design used is presented in Table 1. The research subjects the undergraduate students of physics and master students of science education FKIP UNIB Bengkulu, the academic year 2023/2024, as many as 48 people.

Table 1. Research design

Behavior	Questionnaire		
X	Q_1	Q_2	Q_3

X: Walking bipedal robot pressure center feedback simulation program
Q_1: Motivation scale
Q_2: science literacy scale
Q_3: feasibility scale

2.4.1. Data collection

The questionnaire given to the sample consists of three types: the learning motivation scale, the student science literacy scale, and the feasibility scale of the bipedal robot pressure center feedback simulation as a mass center learning media. The three types of scales were distributed to all samples for study. Each sample/research subject was required to provide qualitative and quantitative assessments through questionnaires regarding the role of the bipedal robot pressure center feedback simulation program in increasing student motivation and science literacy and to determine the feasibility of the bipedal robot pressure center feedback simulation as a learning medium. The motivation and science literacy questionnaires each amounted to 40 statements, while to determine the feasibility of 15 items, in each statement, there are 5 choices with the following conditions as described in Table 2.

Table 2. Selection criteria and score on the questionnaire

No	Optional	Scores	Categories
1	Strongly agree	5	A
2	Agree	4	B
3	Quite agree	3	C
4	Disagree	2	D
5	Strongly disagree	1	E

2.4.2. Processing data

Questionnaires will be used to reveal data on motivation, student science literacy, and the feasibility of simulating feedback pressure centers of bipedal robots as learning media in the form of statements containing five choices. The data obtained through the motivation scale questionnaire, science literacy scale, and the feasibility scale of the bipedal robot pressure center feedback simulation as a learning media are then processed based on the criteria as shown in Table 3.

2.4.3. Data analysis

The data obtained through the data collection tool is then processed, and the processed data results are analyzed to determine the motivation and science literacy of students as well as the feasibility of the bipedal robot pressure center feedback simulation program as a center of mass learning media. For the analysis results to be reliable, a criterion is used, as shown in Table 4.

Table 3. Scoring criteria on the motivation scale, science literacy and feasibility of the simulation program

No	Categories	Quality	Scores
1	A	Very good	5
2	B	Good	4
3	C	Moderate	3
4	D	Less	2
5	E	Poor	1

Table 4. Criteria for scoring the motivation scale, science literacy and feasibility of the simulation program

No	Criteria	Quality	Categories
1	4.50 – 5.00	A	Very good
2	3.51 – 4.50	B	Good
3	2.51 – 3.50	C	Moderate
4	1.51 – 2.50	D	Less
5	< 1.5	E	Poor

3. RESULTS AND DISCUSSION

3.1. CoP Position

In order to verify the CoP equations on SSP and DSP, simulation by using MATLAB was applied before implementing it on the bipedal robot. Two condition simulations (SSP or DSP) are shown in Figure 3. In this simulation, the force value begins from 0 (indicating no pressure) until 255 (indicating high pressure).

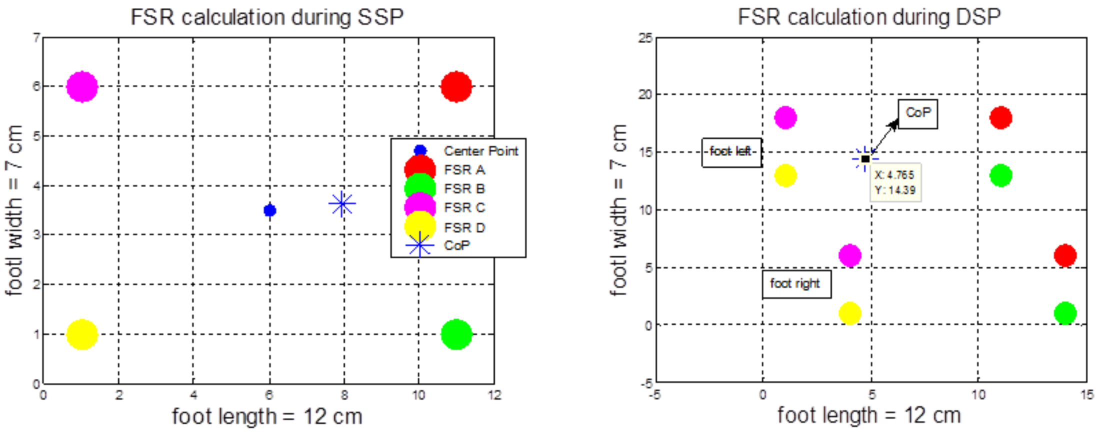
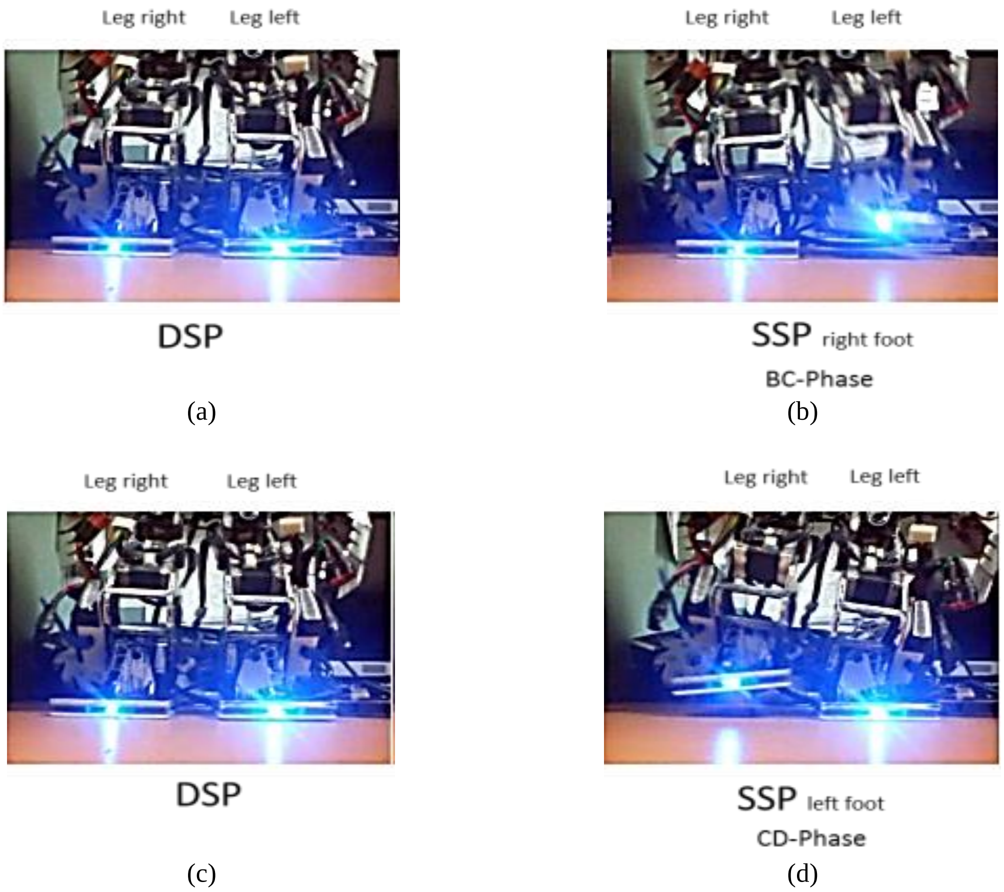


Figure 3. CoP position during (a) SSP with fA=192, fB=128, fC=50, fD=90 and (b) DSP with displacement=3 cm, fA1=125, fB1=56, fC1=238, fD1=43, fA2=0, fB2=0, fC2=12, fD2=80

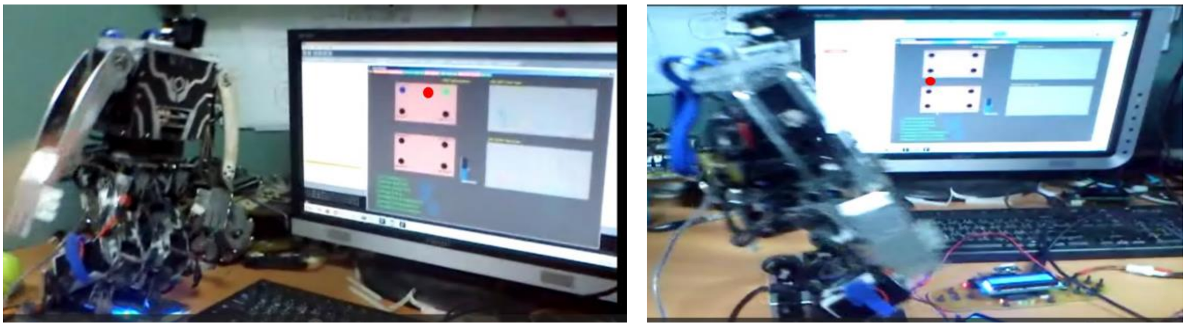
When the bipedal robot moves, the CoP trajectory is used to evaluate the CoP position which is still inside of the CoP margin stability range or inside of the support polygon as shown in Figure 4. For analyzing the result, a single walking cycle was divided into four parts: Figure 4(a) to (d) show that phase A-B is the first lifting of the right leg, phase B-C is SSP on the right foot, phase C-D is SSP on the left foot, and the D-E phase is SSP on the right foot, respectively. This process will be repeated.

Figure 5 shows the red dot on the monitor screen, showing that the robot's center of mass is on the robot's left leg due to the thrust force from the robot's right side so that the robot merges to the left. In Figure 6, the red dot on the monitor screen shows the robot's center of mass at the back of the two legs due to the thrust force from the front of the robot.



(a) (b) (c) (d)

Figure 4. The video captures during the robot's walking at (a) phase A-B, (b) phase B-C, (c) phase C-D, and (d) phase D-E



(a) (b)

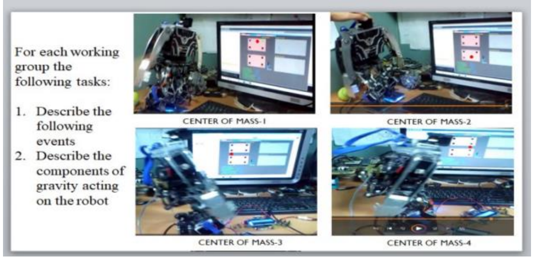
Figure 5. The video capture of the robot's center of mass (a) on the left side of the robot's foot and (b) at the back of the robot's two feet

3.2. Research implementation

This research was conducted at the Master of Science and Bachelor of Physics FKIP UNIB Bengkulu and the Department of Electronics and Computers SMK UGM Yogyakarta in 2023. This study aims to determine the effect of learning with bipedal robot pressure center feedback simulation on the central concept of mass learning on aspects of learning motivation, science literacy and feasibility of bipedal robot pressure center feedback simulation for physics learning. It was tested using a motivation scale questionnaire, science literacy scale and feasibility scale to describe the effect. The motivation and science literacy scales totaled 40 statements, while the feasibility scale totaled 15.

The research subjects were first semester students of Master of Science Education who took the Trending Topics in Education (Robotics) course and 5th semester Physics Education undergraduate students, as many as 26 people who took the Application of Technology in Physics Education (Robotics) course. The lecture materials in these two study programs are relatively the same, so their knowledge about the role of robots in education and learning is assumed to be homogeneous. At the same time, the making of the bipedal robot pressure center feedback simulation program was carried out at the Learning Laboratory of JPMIPA FKIP UNIB. Research subject activities during learning, students were divided into four groups, each working on the tasks CENTER OF MASS-1, CENTER OF MASS-2, CENTER OF MASS-3, and CENTER OF MASS-4, as shown in Figures 6 and 7.

Figure 6. Students discussing in their groups



For each working group the following tasks:

1. Describe the following events
2. Describe the components of gravity acting on the robot

Figure 7. Bipedal robot simulation display for 4 maneuvers

After learning, a questionnaire was given to the research subjects, including a motivation questionnaire, science literacy questionnaire, and feasibility questionnaire for the bipedal robot pressure center feedback simulation as a learning media; the questionnaire results can be seen in Table 5.

Table 5. Recapitulation of motivation, literacy and feasibility scores

No	Motivation	Literacy	Feasibility	No	Motivation	Literacy	Feasibility
1	3.58	4.03	3.98	25	3.58	4.03	4.48
2	3.58	3.95	3.98	26	3.58	3.95	4,00
3	4.03	3.98	3.95	27	4.03	3.98	4.48
4	3.95	3.88	3.98	28	3.95	3.88	4,00
5	3.98	3.95	3.88	29	3.98	3.95	3.88
6	3.88	4.08	3.95	30	3.88	4.08	4.3
7	3.95	4.58	3.98	31	3.95	4.58	3.9
8	4.08	3.93	4.33	32	4.08	4.03	3.95
9	4.58	4.23	3.95	33	4.58	3.95	4.48
10	3.93	4.23	3.98	34	3.93	3.98	4,00
11	4.23	4.08	3.88	35	4.23	3.88	4.48
12	4.23	3.65	3.95	36	4.23	3.95	4,00
13	4.08	4.48	4.08	37	4.08	4.48	4.48
14	4.65	4,00	4.58	38	3.65	4,00	4,00
15	4.48	3.88	3.93	39	4.48	4.48	4.48
16	4,00	4.3	4.23	40	4,00	4,00	4,00
17	3.88	3.9	4.23	41	4.48	3.88	3.88
18	4.3	3.98	4.08	42	4,00	4.3	4.3
19	3.9	3.88	3.65	43	3.88	3.9	3.9
20	3.95	3.95	4.48	44	4.3	3.95	4.48
21	4.48	3.98	4,00	45	3.9	4.48	4,00
22	4,00	3.88	4,28	46	3.95	4,00	4.48
23	3.88	3.95	4.3	47	4.48	4.48	4,00
24	4.3	3.98	3.9	48	4,00	4,00	3.88
Summary					175.1	174.92	157.08
Average					4.072	4.067	4.133
Standard deviation					0.287	0.229	0.258

Table 6 shows that the validity index of the motivation scale, science literacy scale, and feasibility scale has a value of r = 0.475, 0.385, and 0.415 > 0.2353, meaning that the motivation scale, science literacy scale, and feasibility scale are declared valid. The reliability index of the motivation scale, science literacy, and feasibility have a value of r = 0.465, 0.395, and 0.425> 0.2353, meaning that the motivation scale, science literacy scale, and feasibility scale are declared reliable. While the standard deviation is calculated using (8).

$$s = \sqrt{\frac{\sum_{n=1}^{\infty}(x_i - x)^2}{n-1}} \tag{8}$$

Table 6. Questionnaire reliability and validity test

No	Scale type	Reliability	Validity
1	Motivational scale	0.465	0.475
2	Science literacy scale	0.395	0.385
3	Feasibility Scale	0.425	0.415

Based on calculations using SPSS, the average score of the motivation questionnaire, science literacy, and the average score of the feasibility questionnaire were 4.072, 4.067, and 4.133, respectively. The standard deviations for motivation, literacy, and feasibility were 0.287, 0.229, and 0.258, respectively. The results showed that the bipedal robot pressure center feedback simulation for center of mass learning can motivate learning, improve science literacy and is feasible to use; this can be seen from the motivation score, science literacy and feasibility scores of 4.072, 4.067 and 4.133 which are in the good category.

The comfort and ease of use of the bipedal robot pressure center feedback simulation-based learning program helps students feel at home, and this pleasant atmosphere adds to students' enthusiasm for learning. In addition, the display presented by the bipedal robot pressure center feedback simulation-based learning program allows the types of student intelligence to be accommodated to grow and develop optimally. Many types of student intelligence can be adjusted and realized in the bipedal robot pressure center feedback simulation-based mass center learning program, including logical, mathematical, visual, verbal and other intelligence. However, the existing form of the physics learning program based on the bipedal robot pressure center feedback simulation cannot be strictly reserved for certain types of intelligence; that is, one form of simulation program can accommodate various kinds of intelligence because there are no clear boundaries about the type of intelligence of a person. A person can have multiple kinds of intelligence, but only some types of intelligence are prominent in that person. Still, only a few, and in each person, the type of intelligence that stands out is different. The bipedal robot pressure center feedback simulation learning program on the center of mass material can be implemented quickly, efficiently, effectively, individually, and cheaply.

Learning becomes feasible and motivated and improves science literacy when using the bipedal robot pressure center feedback simulation learning program due to the interactive multimedia system so that almost all five senses are involved in absorbing and constructing knowledge. Learning using the bipedal robot pressure center feedback simulation allows students to learn freely, can be done anytime and anywhere, and is equipped with animations and simulations that motivate students to learn.

This finding aligns with other findings that use the concept of robot simulation in learning in various countries, including increased knowledge in diabetic children who use robots compared to those who do not use robots as a control group. This study showed that the robot was more fun, improved outcomes, and was more motivating. Audio/video recordings showed that children with robots were more serious, social, and positive in terms of engagement [37]. Robots are essential tools in production automation, with advantages and disadvantages [38]. A study entitled "Robots will support you as a companion and perhaps as a friend" found that students' insight into the world of robots is improving, ranging from conventional industrial robots and cooperative robots through various mobile robots to humanoid robots [39].

Chevalier *et al.* [40] found that robots immensely helped students' interactivity and interest in learning in the classroom. In the case of an engineering course in a master's study program, we present how the course has evolved in recent years to its current format. We have organized lectures and laboratory practices to achieve an appropriate balance between traditional and contemporary inductive learning and teaching methodologies. We present the application of various inductive teaching methodologies, such as simulation challenges, individual projects, multi-team projects, and competition challenges. Some example projects from the course are given in robot simulation [41].

Comparing an online workshop with an onsite workshop, the simulated online workshop not only opened up opportunities for participants to become familiar with robotic systems in a context without access to a physical laboratory but also allowed participants to explore the challenges and limitations of the system and new struggles for material handling by robots could be discovered. These findings reflect the achievement of the learning objectives and provide new insights worth considering in the study of robot assembly design. The results of the field workshop showed that all focus groups designed tools for assembling robots. The lack of access to laboratory facilities and resources forced them to focus on redesigning the toy car, which was entirely in line with the learning objectives.

The value of supporting tools emerged at the testing stage, which was not feasible online, but the product redesign could be presented in a digital format. The online group also utilized digital tools better. In addition, more participants can attend online workshops simultaneously, whereas the number of participants for onsite workshops depends on physical conditions. Generally, the number of participants is limited for workshops that require access to robotic systems. Also, operating a remote automated system with only one camera is challenging. Playing like a robot helps to understand how mechanical systems work but cannot replace the experience of operating a real robot. In conclusion, this study presents an innovative approach to designing an online workshop on DRFA that does not require access to laboratory facilities. Learning is valuable both during the pandemic and post-pandemic, as the number of participants is not limited by physical conditions [42].

The results of 22 papers suggested several advantages of learning with e-learning robots. The measurement instruments contained in 22 papers are i) observation, ii) questionnaire, iii) artifact evaluation, iv) verbal interview, v) test/exam, vi) neuropsychological test battery, and vii) personal report. Generally, most studies use more than one method for evaluation. As these two approaches are still in the early stages of renewable energy research, comprehensive experiments should be conducted using these approaches in the future. Similarly, the performance of a group of students working with a swarm of robots to program collective behavior to achieve a common goal. Features such as low cost, customization possibilities, and ease of use make it suitable for schools.

Research using the Spiderino platform allows students to learn simple programming and apply that knowledge to many experiments. Its attractive appearance as a spider and its development from a toy to a robot provide excellent potential for Spiderino to be an educational tool [43]. A study found that computational practices and perspectives, examining programming processes, and analyzing qualitative data are recommended to be carried out by involving robots [40]. Another study exploring the extent to which children anthropomorphize social robots found that children generally anthropomorphize robots. However, children differ significantly in how much they do so. The results showed that children's tendency to anthropomorphize did not change considerably after the tutoring sessions. Still, analysis at the item level revealed a complex pattern of change, suggesting a shift in the overall tendency to view robots as more mechanical while at the same time attributing more cognitive abilities to robots. As an exploration, we found a weak but significant correlation between children's increased anthropomorphism and their word knowledge [44]. Training on manipulator control, which aims to improve competence in learning, is carried out using the robot application control method. Because ITMO University appreciates the opportunity to see how robotic systems work, students include several mechanical applications in their bachelor's and master's theses, as they are more demonstrative than simulations. The design of new tasks and their adaptation to laboratory equipment can be highlighted as a direction for further work [45].

Other findings regarding the role of robots in improving motivation and science literacy are as follows: Based on the article by Auddy *et al.* [46], it is concluded that continuous learning can be carried out with demonstration methods, and the nature of constant learning will be better if using robots. In the paper, continuous learning is adapted to the demonstration method, especially teaching domesticity with real robots. One solution to the many challenges that must be overcome in learning and the progress that must be achieved is learning with robots that can improve student learning outcomes in the aspect of science literacy and can be accepted and well-integrated in the context of its utilization, thus improving students' science literacy. Science literacy allows students to solve problems using a scientific approach [47].

Demonstrations using robots integrated with images that represent higher and richer dimensions and how to process images with powerful and real-time capabilities need to be further explored by considering the setting of making physical robots in the real world, which can increase student motivation in learning [48]. Exploration of the potential educational value of a form of robot-assisted educational activities in primary school children to explain the behavior of robots created in advance by the teacher plays a vital role in science education, especially in the aspect of participation in a collaborative process aimed at explaining the behavior of educational robots, providing opportunities for children to develop science, skills, research competencies and engage in cognitive meta-reflection as a fundamental issue surrounding scientific research methods [49]. Robots with variable morphology allow users to build, plan, and program different types of robotics artifacts. The constructivist approach promotes learning where the educator is not transferring information. Still, rather than a learning facilitator leading work groups, the learner increases their knowledge by manipulating and constructing physical objects.

Robotics, therefore, offers a unique educational influence, as it is a multi-disciplinary field involving many technical topics, including mathematics and physics, design and innovation, electronics, computer science and programming, and psychology. The results show that the pedagogical value of robots lies in getting students to work, identifying problems, and arguing that robots are a highly motivating technology because they are concrete, complex, and relate to deep human needs. Consequently, by building programs and coding, students can control the robot; students have a unique opportunity to tackle many central issues head-on, including the interaction between hardware and software, the complexity of space in terms of robot controller memory limitations, and time. Complexity regarding speed of action decisions can be resolved using robots [38].

4. CONCLUSION

Based on the findings in this research, it can be concluded that bipedal robot pressure center feedback simulation for center of mass learning can be implemented using the principle of the robot's center of mass detected on the soles of the robot's feet equipped with sensors, the amount of center of mass will be seen on the monitor screen with the help of an intelligent control system (fuzzy logic) written using MATLAB. Bipedal robot pressure center feedback simulation for mass center learning is feasible to use for learning the concept of the mass center, can motivate students to learn physics, and improve students' science literacy it can be seen from the feasibility scale score, motivation scale score, and science literacy scale score of 4.133, 4.072 and 4.067 respectively (on a scale of 1 to 5) are in the "good" category.

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