

Integration of arduino UNO in physics experiments: developing experiments and analyzing teacher competency

Dody Rahayu Prasetyo^{1*}, Nisa Safira,² Silvia Rahma Amalia³

Program Studi Tadris IPA, Institut Agama Islam Negeri Kudus, Kudus, Indonesia

**Correspondence: dody@iainkudus.ac.id*

Abstract

Keywords:

Skills in science;
Experiments;
Arduino UNO;

The purposes of this research are to develop Arduino Uno-based physics experiments, and to analyze the skills of prospective science teachers in using them. This research is a descriptive study consisting of four stages: (1) design, (2) production, (3) evaluation, and (4) implementation. The research data were obtained using questionnaires for tool validation, practicum guidelines, and observation sheets to assess science teachers' skills in conducting Arduino-based science experiments. The questionnaire and observation data were analyzed descriptively. The research results show that: (1) the average validation results for the tools, practicum guidelines, and observation sheets were 0.62, 0.84, and 0.83, categorized as "moderate," "very valid," and "extremely valid," respectively, indicating that the developed Arduino-based physics experiment instruments are feasible for use and (2) the students' average practical skills score was 2.76, categorized as "medium," with the lowest achievement in the "troubleshooting" aspect. Although there are challenges in learning with Arduino Uno, there is still a significant opportunity for it to become a valuable alternative as technology continues to rapidly develop.

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Introduction

One of the effective learning media for explaining abstract and complex scientific concepts is the use of practicum tools. Practical activities in science learning serve as an alternative method to train students' science process skills in schools. Therefore, it is essential for science teachers to have the ability to design and develop experimental activities. Laboratory practice is highly suitable for helping students apply scientific concepts and deepen their understanding through hands-on learning. To fully grasp scientific content, students must master science process skills, as science is not merely the accumulation of knowledge but also emphasizes the process of discovery (Agustina et al., 2021).

Recently, the integration of Arduino into science education has become a compelling topic of discussion. Arduino, a type of microcontroller, is a device capable of independently controlling components within an electronic circuit. A common project involving Arduino includes automatic light control, where the device can be programmed to adjust light intensity as needed. Thus, science teachers are expected to be capable of conducting experiments that incorporate current technology such as Arduino. In this study, practical skills are defined as

students' abilities to develop intellectual and psychomotor competencies through laboratory activities. The skill categories are adapted from Kumar, which include procedural skills, manipulative skills, observation skills, drawing skills, interpretation skills, and reporting skills (Raj et al., 2021). Several Arduino-based learning media have already been developed and applied in educational settings. These include efforts to enhance STEM literacy (Hidayati et al., 2023), improve physics teaching practices (Fatmaryanti et al., 2024), support project-based learning, and enable students to measure CO₂ levels (Pino et al., 2019). Meanwhile, some Arduino-based learning media are still at the design or prototype stage and have not yet been fully implemented in classrooms. These include materials such as circular motion (Azizahwati et al., 2019), technology in physics (Chaudry, 2020), free-fall motion (Kause, 2019), Hooke's law (Masyruhan et al., 2020), physics experiment tools (Organtini, 2021), the relationship between temperature and resistance (Sari & Kirindi, 2019), and automatic light controllers in electrical circuit (Basori et al., 2024).

In addition, Arduino has also been applied in various appropriate technology innovations, such as greenhouse technology (Zhu et al., 2022), solar energy measurement (Khasanov et al., 2021), automatic plant sprinklers (Rohim & Hartanti, 2022), water pH monitoring (Yakin et al., 2021), and soil humidity measurement (Yusuf et al., 2023). Field observations have identified several issues: physics experiments in the IAIN Kudus laboratory still utilize incomplete Arduino-based practicum tools, leading to low accuracy; some partner schools in science education have already begun using Arduino-based experiments; some science education students face difficulties with electricity-related practical work; and the development of Arduino-based science experiments remains limited. Therefore, it is essential to develop comprehensive Arduino-based physics experiments and to analyze the practical skills of prospective science teachers after they engage with these tools.

Method

The stages of the research adapted from the findings of Plomp (Firdaus et al., 2023) and shown in Figure 1. This study employed a descriptive research design consisting of four main stages: (1) design, (2) production, (3) evaluation, and (4) implementation.

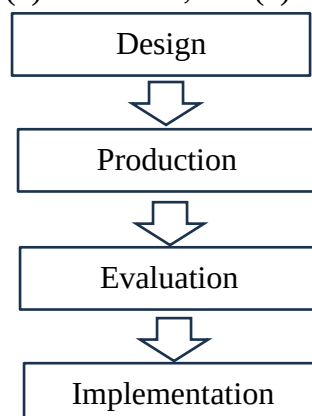


Figure 1. Stages Study Descriptive

The design stage involved two key steps: a needs analysis and the design of the practicum device. The needs analysis was carried out through discussions regarding the

availability and capability of physics practicum tools currently owned by the Physics Laboratory at IAIN Kudus. The design of the hardware device was based on a three-block system: input, process, and output. The input system included ultrasonic sensors, infrared sensors, and push buttons. The data processing system was controlled by an Arduino, which functioned as the main controller. In addition, the software for the practicum device was developed using the C++ programming language and compiled through the Arduino Integrated Development Environment (IDE). The mechanical design was created to serve as a visual interface to support the functionality of the hardware. The production stage focused on testing the electronic system and the performance of the practicum tool. This was done to assess its accuracy and effectiveness in conducting data acquisition during experiments. The evaluation stage involved validation of three components: the practicum tool, the practicum guidebook, and the practicum observation sheet. The evaluation used a 4-point Likert scale questionnaire, ranging from "strongly disagree" (1) to "strongly agree" (4), along with written comments from expert validators. The assessment criteria for the practicum tool and its guidebook included: (a) information clarity, (b) compatibility with the guidebook instructions, and (c) functionality and performance of the tool. Meanwhile, the guidebook was also assessed in terms of (a) structural completeness and (b) language and presentation quality. The validation aspects referred to the standard guidelines established by the Directorate of Senior High School Development (Dewi et al., 2021). Intervals and categories Index Aiken Validity shown in Table 1.

Table 1. Intervals and Categories Index Aiken Validity

Interval	Category
≤ 0.4	Less
$0.4 < V \leq 0.8$	Currently
< 0.8	Very valid

Stage Implementation, This is the last stage in research. Prospective teachers do Arduino practicum. Their skill measured by 2 independent observers. Category skills, observed aspects, and descriptions performance participant shown in Table 2.

Table 2. Categories Skills, Observed Aspects, and Performance Description on the Observation Sheet

Category Skills	Observed Aspects	Participant Performance Description
Skills Procedural	Preparation of Tools and Materials	Prepare and assemble all tools and materials with Correct
Skills Procedural	Assembly Series	Make the circuit on the breadboard is appropriate with the given scheme
Skills manipulative	Arduino Operation	Connecting Arduino to computer, upload the code, and run the program with correct
Skills draw	Basic Programming	Writing and running code
Skills observation interpret	Sensor Programming	Read sensor data and display results in serial monitor

Category Skills	Observed Aspects	Participant Performance Description
Skills interpret	Troubleshooting	Able to identify and fix error in series or code
Skills Presentation	Ethics and Cooperation	Work independent and show attitude proactive as well as cooperative in team

Results and Discussion

Instrument Experiment

The experimental instruments used include practicum tools, practicum guidelines, and observation sheets. The tools developed to support physics experiments using the Arduino platform. Three types of practicum tools were designed: 1) Free Fall Motion (FFM), 2) Uniform Linear Motion (ULM), and 3) Propagation Speed of Sound (PSS) in air. These were developed because such tools utilizing Arduino were not yet available in the Physics Laboratory at IAIN Kudus.

The development process started by identifying the intended learning objectives, which are presented together with the relevant mathematical equations in Table 3. These objectives were derived based on the researchers' experience and references. Winingsih et al. (2023) found that student still struggle with understanding free fall motion, particularly the concepts of velocity, time, and gravitational acceleration. Similarly, Amiruddin et al. (2025) reported students difficulties in comprehending uniform linear motion, and Batlolona & Jamaludin (2024) found student misconceptions in understanding the speed of sound wave propagation.

Table 3. Learning Objectives in Activities Practicum

Practicum	Learning objectives	Mathematical Equations
Free Fall Motion (FFM)	Determining gravitational acceleration Determining object velocity Understand the relationship between mass, time, velocity, and gravity	$g = \frac{2h}{t^2}$ $v = gt$
Speed of Sound (PSS)	Calculate the speed of sound in air	$v = \frac{2s}{t}$
Uniform Linear Motion (ULM)	Measure constant linear velocity	$v = \frac{s}{t}$

Arduino consists of from 3 systems namely 1) software, 2) hardware, and 3) the connectivity of software and hardware. The software used is Arduino IDE application that can downloaded for free. How to use it is with enter languages programming. Here is picture languages programming for practicum 1) movement fall free (Figure 1), 2) uniform linear motion (Figure 2), and 3) fast propagation sound in the air (Figure 3).

```

gerak_jatuh_bebas.ino
1  const int sensor1 = 2;
2  const int sensor2 = 7;
3  double start;
4  double finish;
5  double waktu_jatuh_bebas;
6  double h = 1.04;
7  double g, v;
8  int activate = 0;
9
10 void setup() {
11   pinMode(sensor1, INPUT);
12   pinMode(sensor2, INPUT);
13   Serial.begin(9600); // Inisialisasi komunikasi serial
14   Serial.println("PRAKTIKUM GERAK JATUH BEBAS");
15   delay(2000);
16 }
17
18 void loop() {
19   if (digitalRead(sensor1) == LOW) {
20     start = millis();
21     activate = 0;
22   }
23
24   if (digitalRead(sensor2) == LOW && activate == 0) {
25     finish = millis();
26     waktu_jatuh_bebas = (finish - start) / 1000;
27     g = 2 * h / pow(waktu_jatuh_bebas, 2);
28     v = g * waktu_jatuh_bebas;
29
30     Serial.print("Waktu jatuh bebas (s): ");
31     Serial.println(waktu_jatuh_bebas);
32     Serial.print("Percepatan gravitasi (m/s^2): ");
33     Serial.println(g);
34     Serial.print("Kecepatan (m/s): ");
35     Serial.println(v);
36
37     activate = 1;
38   }
39 }

```

Figure 1. FFM Practicum Programming Language

```

29
30
31 if (digitalRead(sensor2) == LOW && activate == 1) {
32   finish = millis();
33   waktu1 = (finish - start) / 1000.0;
34
35   v1 = s / waktu1;
36
37   Serial.print("Waktu Sensor 1 ke 2 (s): ");
38   Serial.println(waktu1);
39
40   Serial.print("Kecepatan GLB (m/s) Sensor 1 ke 2: ");
41   Serial.println(v1);
42
43   activate = 2; // Siap untuk pengukuran berikutnya
44   delay(500); // Tunggu 1 detik sebelum melakukan p
45 }
46
47 // Sensor 3 ke 4
48 if (digitalRead(sensor3) == LOW && activate == 2) {
49   start = millis();
50   activate = 3;
51 }
52
53 if (digitalRead(sensor4) == LOW && activate == 3) {
54   finish = millis();
55   waktu2 = (finish - start) / 1000.0;
56
57   v2 = s / waktu2;
58
59   Serial.print("Waktu Sensor 3 ke 4 (s): ");
60   Serial.println(waktu2);
61
62   Serial.print("Kecepatan GLB (m/s) Sensor 3 ke 4: ");
63   Serial.println(v2);
64
65   // Tampilkan hasil akhir kecepatan dari semua sensor
66   Serial.println("Hasil Akhir Kecepatan:");
67   Serial.print("Kecepatan Sensor 1 ke 2 (m/s): ");
68   Serial.println(v1);
69   Serial.print("Kecepatan Sensor 3 ke 4 (m/s): ");
70   Serial.println(v2);
71
72   activate = 0; // Reset aktivasi untuk pengukuran sel
73   delay(2000); // Tunggu 2 detik sebelum melakukan per
74 }

```

Figure 2. ULM Practicum Programming Language

```

jarak.ino
4
5 // Pin untuk sensor ultrasonik
6 const int trigPin = 9;
7 const int echoPin = 10;
8
9 // Variabel untuk menyimpan durasi dan jarak
10 long duration;
11 int distance;
12
13 void setup() {
14   // Inisialisasi komunikasi serial
15   Serial.begin(9600);
16
17   // Inisialisasi pin
18   pinMode(trigPin, OUTPUT);
19   pinMode(echoPin, INPUT);
20
21   delay(1000);
22
23   // Tampilkan pesan
24 }
25
26 void loop() {
27   // Bersihkan trigPin dengan membuatnya LOW
28   digitalWrite(trigPin, LOW);
29   delayMicroseconds(2);
30
31   // Set trigPin HIGH selama 10 mikrodetik
32   digitalWrite(trigPin, HIGH);
33   delayMicroseconds(10);
34   digitalWrite(trigPin, LOW);
35
36   // Baca echoPin dan hitung waktu perjalanan
37   duration = pulseIn(echoPin, HIGH);
38
39   // Hitung jarak dalam cm
40   distance = duration * 0.034 / 2;
41
42   // Tampilkan jarak di Serial Monitor
43   Serial.print("Duration: ");
44   Serial.print(duration);
45   Serial.print("microseconds, Distance: ");
46   Serial.print(distance);
47   Serial.println("cm ");
48 }

```

Figure 3. SPA Practicum Programming Language

Next steps is designing scheme arduino. Schematics For third practical work shown in Figure 4-6.

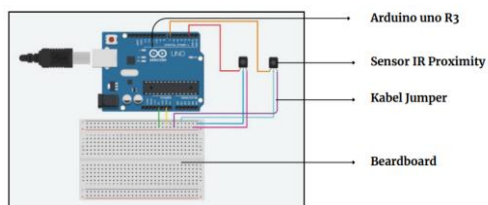


Figure 4 Arduino Schematic for FFM Practicum

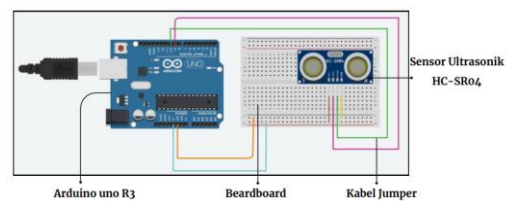


Figure 5 Arduino Schematic for SPA Practicum

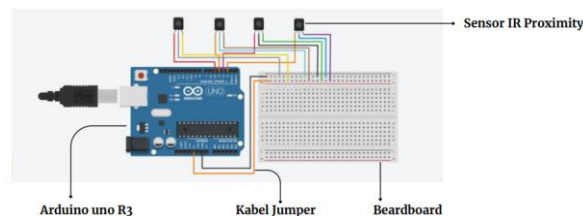


Figure 6 Arduino Schematic for ULM Practicum

For hardware is shown in Figure 7-9. The main hardware used for third practical work are 1) laptop, 2) Arduino UNO, 3) breadboard, and 4) jumper cables. While additional hardware sfor FFM practicum are 1) two IR sensors and 2) five mass variations. The practical activity on fast

propagation sound utilized an HC-SR04 ultrasonic sensor, while the activity on ULM employed four IR proximity sensors and toy cars moving at a constant speed



Figure 7. FFM Practicum Hardware



Figure 8. SPA Practicum Hardware



Figure 9. ULM Practicum Hardware

After the software and hardware are ready, then done checking whether the hardware and software are connected or not yet. If not yet connected, done checking to series. This stage requires accuracy. Based on field observations, several factors were identified that contributed to the disconnection between the software and hardware components. These included: (1) improper installation of jumper cables, (2) malfunctioning jumper cables that required replacement, and (3) an unresponsive USB connection between the computer and the Arduino UNO. Once the connection is established, the next step is to test the system by moving an object. This step is carried out to ensure: (1) whether the sensor functions properly, and (2) whether the displayed data aligns with the expected physics concepts. Based on the trials conducted: (1) in the FFM practicum, the sensor was unable to detect the object's position once it reached the lower end, (2) in the ULM practicum, the speeds recorded by the four sensors did not indicate a constant velocity, and (3) in the SPA practicum, the measured speed of sound was consistent with the theoretical value of 340 m/s.

From repeated trials, several inhibiting factors in the FFM practicum were identified, including the small size of the object and the limited range of the sensor, which prevented the sensor from detecting the object's presence. As a solution, the object was wrapped in a small cardboard box to increase its size, enabling detection by the sensor. In the ULM practicum, the inhibiting factors included a non-horizontal trajectory and the small size of the toy car wheels.

To address these issues, water was used as a level indicator to ensure the track was horizontal, and lubricant was applied to the toy car wheels. After these adjustments, the system was retested, and the resulting practical data aligned with the theoretical framework

In the testing process of this Arduino practicum, troubleshooting skills are essential. This is related to the software, hardware, and their connectivity. Based on the research results, troubleshooting identified two main causes: *communication errors* and *sensing errors*. *Communication errors*, occurred when software and hardware are not connected. *Sensing errors*, occurred when the sensor is not can detect movement objects. This is also in accordance with discovered by Zhong & Si (2021) . While that, they grouping *troubleshooting* into 4 types of errors, namely: 1) *Communication errors*, 2) *Control errors*, 3) *Sensing errors*, and 4) *System errors*. Examples Arduino IDE output results after overcome existing problems shown in the output of Figure 10.

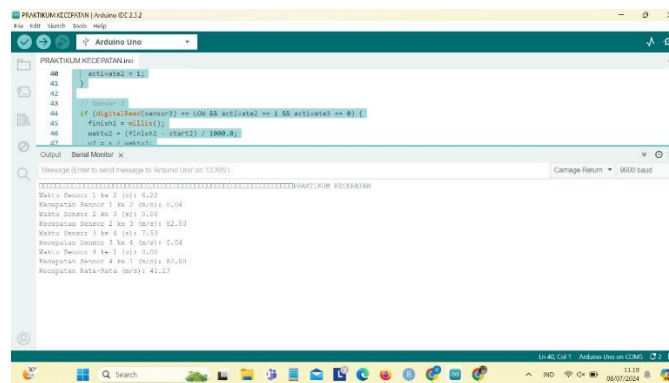


Figure 10. Output in the ULM Lab

After the practical work tools were refined, the Arduino practical work guidelines were created using the *Canva app*. The guidelines are shown in Figures 11-15.



Figure 11 Guidelines Practicum



Figure 12 Component Compiler

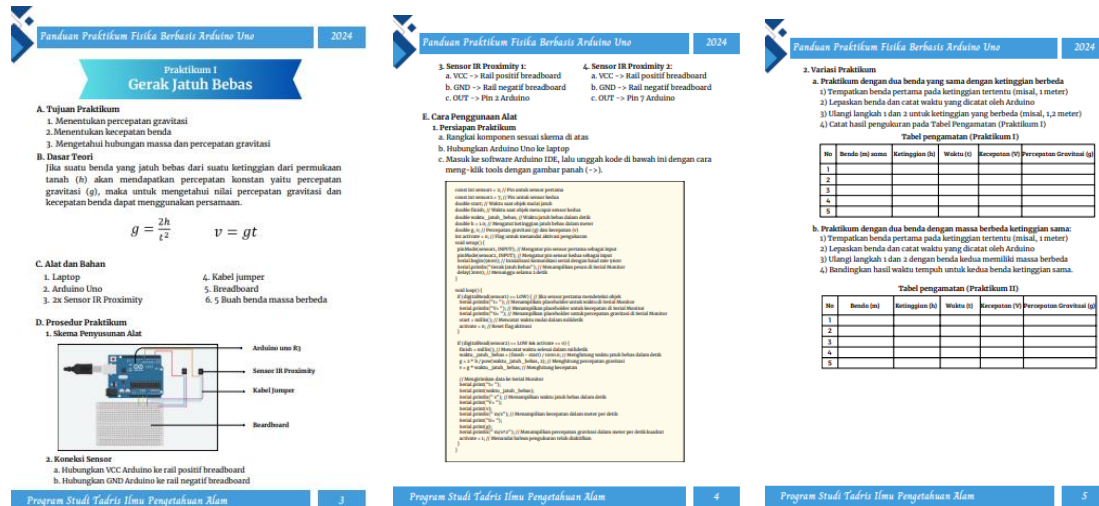


Figure 13 ULM Practicum Guide (I)

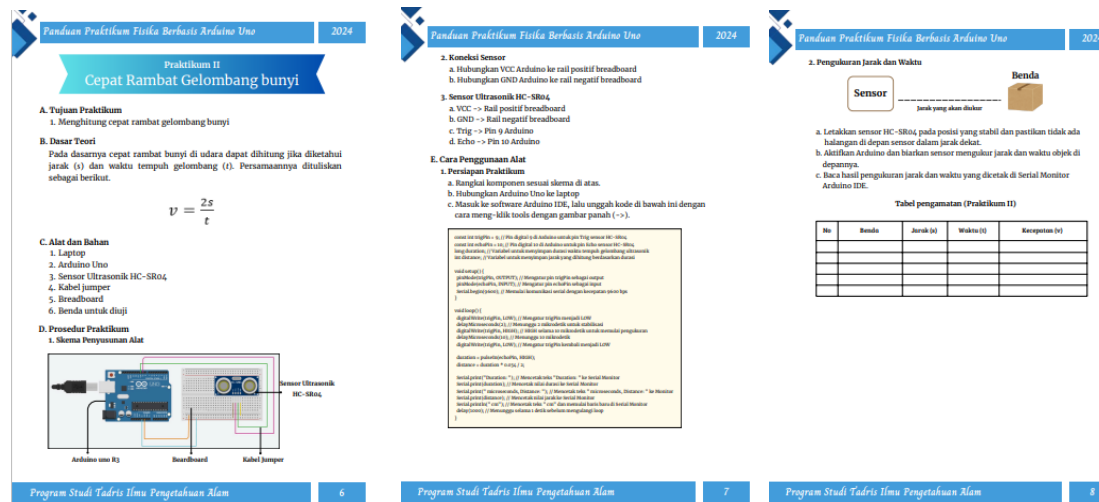


Figure 14 SPA Practicum Guide (II)

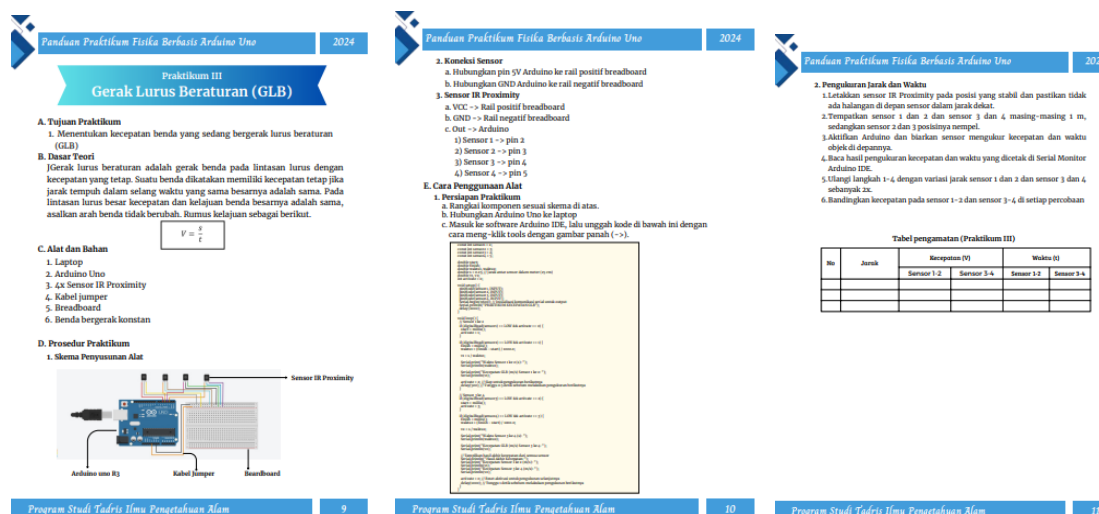


Figure 15 ULM Practicum Guide (III)

Tools, practicum guides, and observation sheets validated by experts. The validation results obtained were on average respectively: 0.62; 0.84; and 0.83 with categories “moderate”, “very valid”, and “very valid”. Details of the results validation tools, practicum guides, and observation sheet shown in Tables 4, 5, and 6. Revisions were made based on input from experts, as follows: 1) check the electronic components before use, 2) enlarge and clarify the schematic diagrams, and 3) correct any typos. Trial repeatedly and evaluated by experts is one of method for get tools and guidelines valid practicum (Herdayanti et al., 2020) .

Table 4. Validity of Practical Tools

Component	Average	Category
Tool Information	0.75	Currently
Compliance with Guidelines	0.61	Currently
Practicum		
Tool Function and Performance	0.52	Currently
Average Validity	0.62	Currently

Table 5. Validity Guidelines Practicum

Component	Average	Category
Structure and Completeness	0.94	Very valid
Guidelines		
Language and Presentation	0.73	Currently
Eligibility		
Average Validity	0.84	Very valid

Table 6. Validity of Observation Sheet

Component	Average	Category
Preparation of Tools and Materials	0.89	Very valid
Circuit Assembly	0.89	Very valid
Arduino Operation	0.89	Very valid
Basic Programming	0.89	Very valid
Sensor Programming	0.78	Currently
Troubleshooting	0.73	Currently
Ethics and Cooperation	0.75	Currently
Average Validity	0.83	Very valid

The development of the practicum did not take much time and was made very simple. In addition, testing was conducted, including experimental tests and expert validation. Along with the practicum tools, the guidelines and observation sheets were also validated. These stages must be completed to ensure that the tools and guidelines are appropriate for use in the practicum. (Rahmatullah & Suparno, 2020; Azizahwati et al., 2020; Herdayanti et al., 2020; Indrasari et al., 2021) .

Skills of Prospective Science Teachers

In the Arduino activity, the students' skills are measured based on seven aspects: 1) preparation of tools and materials (PTM), 2) circuit assembly (CA), 3) Arduino operation (AO), 4) basic programming (BP), 5) sensor programming (SP), 6) troubleshooting (T), and 7) ethics and cooperation (EC). The results of the average skill analysis are shown in Table 7 and Figure 16.

Table 7. Average Results of Students' Basic Skills

Student	Aspects observed							Total
	PTM	AC	AO	PB	SP	T	EC	
Average	2.93	2.97	2.93	2.93	2.97	1.79	2.83	2.76

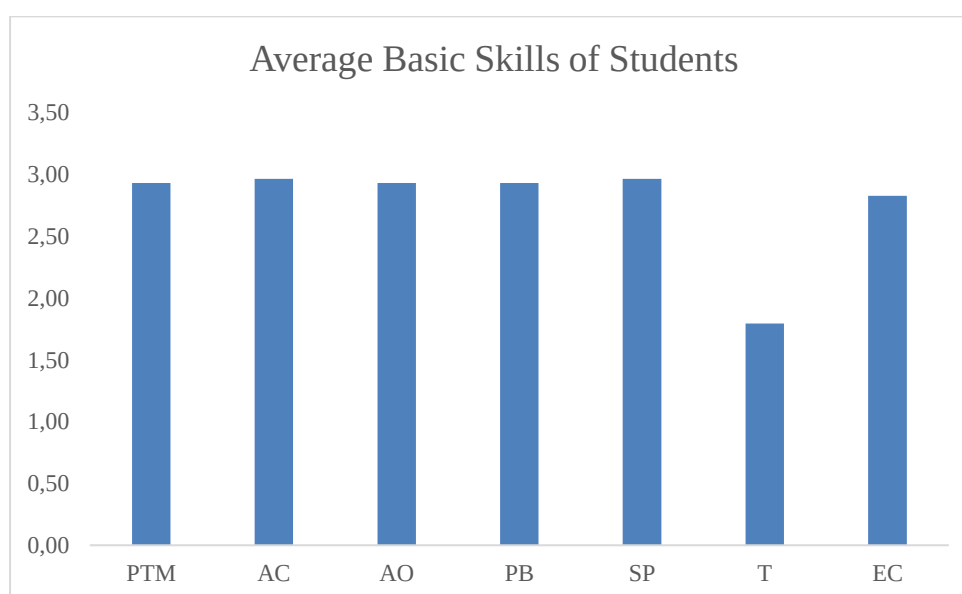


Figure 16. Basic Student Skills

The results indicate “moderate” performance, with troubleshooting receiving the lowest score. Many students are used to straightforward practicum procedures or cookbook experiments, which leave no room for failure or exploration of alternative solutions (Zhong & Si, 2021). This suggests that students lack sufficient practice in identifying and solving real-time problems. This finding has critical implications for science teacher education, highlighting the need for more structured guidance and practice in error detection and problem-solving strategies. Despite these challenges, the Arduino experience provided direct, hands-on learning. Students were not limited to theoretical understanding but were able to apply concepts to real-life applications. Although the students had no prior coursework in electronics, this did not pose a barrier.

One major challenge was limited knowledge in electronics programming. According to (Zhong & Si, 2021), such limitations can demotivate learners when facing hardware compatibility issues or complex debugging. However, behind this challenge, there are many interesting opportunities that can be achieved through Arduino learning. One of the biggest opportunities is the ability to enhance problem-solving skills. Through a hands-on approach,

students are encouraged to solve various technical problems, which involve critical thinking, analysis, and finding effective solutions. In addition, Arduino fosters innovation and creativity. With various sensors and actuators available, students can create unique devices, such as robots, home automation systems, or innovative IoT devices. In addition, Arduino also greatly supports STEM (Science, Technology, Engineering, and Mathematics) education (García-Tudela & Marín-Marín, 2023; Pabuçcu Akış, 2024)

Conclusion

The validation results for the Arduino-based physics practicum tools, practicum guidelines, and observation sheets yielded average scores of 0.62, 0.84, and 0.83, respectively, falling into the categories of 'moderate,' 'very valid,' and 'very valid.' These results suggest that the developed instruments are suitable for use in physics learning activities involving Arduino. The average score for students' basic practical skills was 2.76, categorized as 'moderate,' with the lowest performance observed in the 'troubleshooting' aspect. This finding highlights the need for more structured support and targeted training in diagnostic and problem-solving skills during laboratory activities. To address this, future iterations of the practicum could include more focused troubleshooting exercises and guidance to enhance students' competency in real-time problem resolution.

Credit Authorship Contribution Statement

Dody Rahayu Prasetyo: Conceptualization, Methodology, Software, Visualization, Formal analysis, Writing – original draft, Writing – review & editing. **Nisa Safira, Silvia Rahma Amalia:** Conceptualization, Formal analysis, Resources, Writing – review & editing, Supervision, Project administration.

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