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Paradox of Precision: Challenges with ESP32 Accuracy in Physics Educational Tools

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ABSTRACTS

This study explored the development of a low-cost educational tool using the ESP32 development board to teach principles of acceleration measurement. Designed to provide hands-on learning opportunities, the device aimed to deliver accurate and affordable data collection for students and educators. While the ESP32's high precision met expectations for accuracy, it introduced unforeseen challenges in real-world applications. The device's sensitivity amplified environmental noise and data variability, complicating its use as an intuitive teaching tool. These difficulties highlighted a common paradox in educational technology: excessive accuracy can hinder practical learning experiences by overwhelming users with overly complex data. This study emphasizes the need for a balance between precision and usability when designing teaching tools, particularly in educational settings where simplicity and clarity are essential. The findings offer valuable insights for improving low-cost experimental kits in physics education and enhancing their effectiveness in classroom and hands-on learning environments.

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1. INTRODUCTION

Effective physics education requires a balanced approach that incorporates both theoretical understanding and practical application through experiments. To provide better performance in the teaching of physics, it is strongly recommended that teachers boost their teaching performance using experimental devices (Millar, 2004; White, 1996). Experimental studies are a cornerstone of physics education as they provide hands-on experience and a tangible understanding of theoretical concepts. When compared to alternative science teaching and learning activities, students found practical work to be reasonably beneficial and entertaining (Abrahams & Millar, 2008). Additionally, engaging in experiments helps develop students' psychomotor abilities, which are critical for their overall learning and skill development in scientific inquiry. It was found that the students who took the experiment did better than students who did not. It is convenient to say that experimental studies in physics are really important (Cox & Junkin III, 2002; Wieman & Holmes, 2015). Even in the view of Albert Einstein as a theorist expert, one could prove his theory wrong if a single experiment disproves it.

Providing the experimental kit in the school can be costly and not affordable for many schools, especially in rural areas. In that case, it is necessary to create a simple, low-cost, yet effective experiment kit to facilitate experimental learning at school (Pajpach et al., 2022; Turner & Parisi, 2008). This solution is expected to provide better learning for students even with a limited budget. It is also noted that the experimental kit is simple to accommodate needs so the kit should be easy to use and produce.

In our paper, we build a low-cost experimental kit using an ESP32 developing board. It is a microcontroller with programming ability and flexibility. It also has a better memory and is cheaper than similar microcontrollers with the same features. This experimental kit is intended to be used by the low-budget high school or at home. It has gained the attention of many educators and has been seen as the future (low-cost) DIY experiment. We review the pros and cons of using ESP32, especially in Newton's slaw experiment.

2. METHODS

In our experimental kit, we set up a simple kit with several devices that can be assembled or disassembled depending on the experiment. It is important to note that our experimental kit must be cheap enough and affordable for any school. Also, as we used ESP32. The user can modify this device independently. Our experiment kit consists of a total of 7 devices (see Figure 1)

(i) ESP32 (see **Figure 1a**)
(ii) Digital scales (see **Figure 1b**)
(iii) Load wheels (see **Figure 1c**)
(iv) Mini rolling ruler (optional in our case) (see **Figure 1d**)
(v) Pulley (see **Figure 1e**)
(vi) Nylon thread (see **Figure 1**f)
(vii) Table clamp (see **Figure 1g**).

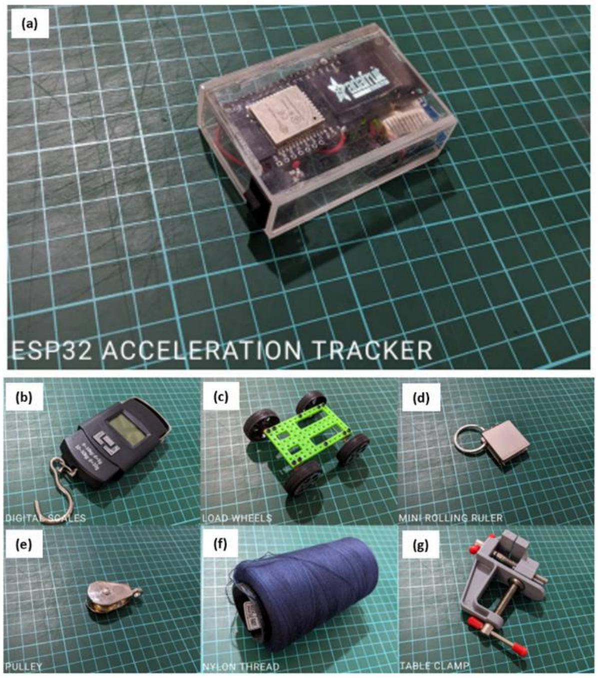

Figure 1. (a) ESP32, "wrapped" by acrylic to attach it by ease in load wheels, (b) digital scales, (c) load wheels, (d) rolling ruler, (e) pulley, (f) nylon thread, and (g) Table Clamp

The cost of all devices is about 30 US$, which can be considered much cheaper than a similar kit in the online store (which is almost 1000 US$). The main device on our kit is the ESP32 development board. We covered the ESP32 with acrylic to ensure that it can be attached easily with load wheels.

We must confirm that the wheels' weight is much smaller than the ESP32. It is to ensure that the torque produced by the wheels is negligible (mwheels = 8 g), compared to the total mass of ESP32 with load wheels (mESP32+load = 85 g). For uniform motion and uniformly accelerated motion experiments, the pulley must be slippery enough not to spin. Because if it spins, then the torque will affect the acceleration reading by the ESP32. In addition, if the pulley is rolling, it is indicated that there is a torque.

In this part, we showed the result on our setup device. First, we considered the Atwood machine (See **Figure 2).** This setup provided the experiments of Newton's 2nd law, uniform motion, and uniformly accelerated motion.

Figure 2. Atwood machine system.

In this setup, we attached the ESP32 to the load wheels. Initially, on the surface of the table, we used a system that needed to be very slippery. However, such a condition is nearly impossible to provide, or at least it is more costly. Thus, we used the wheels (mwheels = 8 g) with a mass that is very small compared to the combined load and ESP32 (mESP32+load = 85 g). Thus, the torque provided by the wheels is not so significant.

The light nylon thread attached the ESP32 to the pulley. The pulley itself needed to be slippery enough. We added a bit of oil. After being oiled, it was not rotated while it was working, which means the pulley could be used. We avoided the pulley rotating to prevent its torque from perturbing the system so much. At the end of the thread, we added various weights. The table clamp was placed at the end of the table where the pulley was attached. Lastly, the mini rolling ruler was used in case we wanted to add a specific distance in our measurement. However, the last item was optional, since in this paper we did not specify the measurement of the certain distance.

During the experiment, we released the ESP32 and it started to move with a certain acceleration through the pulley. It is important to note, that the setup could not neglect:

(i) The friction of the wheels and the surface of the table.
(ii) The torque by the wheels.
(iii) The pulley's mass.

3. RESULTS AND DISCUSSION

As a starting point, we showed how the ESP32 works in our setup experiment. In **Figure 3**, when the ESP32 was switched 'ON', it was immediately shown a 'Start' word on the screen. After 1 s later, ESP32 started to take data for every 0.05 s until 1 s, meaning 1 s of preparation and 1 more s for data collection. It is important to note that ESP32 in our experiment is equipped with an MPU-6050 module sensor as an accelerometer. We obtained 20 data on the last 1-s interval (1 data for each 0,05 s). The example of the reading on ESP32 is shown in **Figure 4**.

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Start
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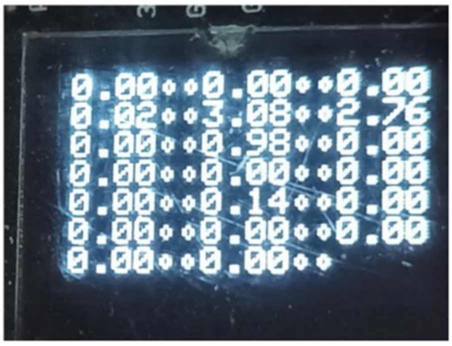
Figure 3. When ESP32 is switched "ON", showing the "Start" word in 1-s intervals before using.



```
0.00◦◦0.00◦◦0.00
0.02◦◦3.08◦◦2.76
0.00◦◦0.98◦◦0.00
0.00◦◦0.00◦◦0.00
0.00◦◦0.14◦◦0.00
0.00◦◦0.00◦◦0.00
0.00◦◦0.00◦◦
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Figure 4. The example of the ESP32 reading, reading the acceleration of the device. The unit of the reading is in m/s^2. In this experiment, we used m = 85 g.

In our experiment, we used 4 different mass variations as a weight to pull the ESP32 (15, 20, 34, and 49 g). **Table 1** shows the 20 readings by the ESP32 in ones.

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Table 1. The Reading table from ESP32. m corresponds to the mass of the object (in grams), a1 ~ a20 corresponds to the acceleration reading by ESP32 (in m/s^2)

No	m	a1~a11	a12	a13	a14	a15	a16	a17~a20
1	15	0	0	1.55	0.9	1.95	1.77	0
2	20	0	0	0	1.73	0	0	0
3	34	0	1.57	2.29	1.93	0	0	0
4	49	0	0.27	0	2.74	2.92	0	0

Table 1 shows the system's acceleration from ESP32. One should have noted that there should be a friction system. However, as our concern is only the performance of the ESP32, it is already implied in the reading. As we used the acceleration reading of ESP32, during the 20 reading points, their variation of results is depicted in **Table 1**. Theoretically, it should show a single-valued acceleration result.

For m = 15, the acceleration reading varied from 0.9 to 1.95 m/s^2. The uncertainty is more than 100%, which is truly a disaster. The first zero values in the early time could be due to the late release of the device by hand and the inertia of the system. On the contrary, the last zero values indicate the weight already reached the floor, which means no acceleration is affected on the ESP32.

For m = 20 g, it showed only a single value, which corresponds to t = 0.7 s. We understood the reason for the zero values in the early and late times. However, as the following experiments showed several results, it was dubious as an experiment. We could not confirm why ESP32 only showed a single value at t = 0.7 s. When we tried the experiment once more, it showed several values. But, we wanted to keep this result as it is peculiar and interesting to be discussed.

For m = 34 g, there were only 3 data shown but their accuracy was also dubious. They range from 1.57 to 2.29 m/s^2. Again, the deviation was almost 100%.

Lastly, for m = 49 g, there was a zero value at t = 0.65 s. As it showed 0.27 m/s^2, the data was 2.74 m/s^2, the zero in between was rather strange. However, we could imply that it should be zero, but it was the reading of 2.74 m/s^2. This could be from the 'outside' system disturbance. During the experiment, small contributions such as thread spinning, pulley sudden stop, slippery surface, etc could affect the experimental result. If we ignored this reading, the data showed a coherent result of 2.74 and 2.92 m/s^2. The actual acceleration should be around those values. However, two data are statistically a bad idea.

Different methods might be used such as giving the more distance of load wheels to the pulley, adding more mass to the load, increasing the height of the weight, and programming ESP32 to take several data. However, the longer the trajectory of the load wheels correlated the higher the final velocity. As the load wheels (equipped with ESP32) were not heavy, their trajectory would be more chaotic. This is in line with what we confirmed in our experiment previously. Thus, we put the proper distance during the experiment to avoid such an issue. In addition, we might modify the experiment to get a better result by adding more improvements to the devices. However, it will be more costly and it is less intended for home-experiment or schools with a low budget.

It is important to state the pros and cons of ESP32 for experimental devices, especially if it is intended to be used as a low-cost experiment kit. The pros in our experimental kit are the lower cost, simplicity, and upgradable mechanism through the ESP32 programming and the supporting device. The cons in our experimental kit are that ESP32 itself is extremely sensitive and shows the undesired result as shown in **Table 1**. Thus, teachers who use ESP32 in their lessons need to be careful. They need to understand physics more deeply. Teacher which lack of understanding physics may be confused if using ESP32, especially if they use acceleration in their data collection for this experiment. They should use 'time' in their data collection and calculate the acceleration or friction indirectly from mathematical calculation.

4. CONCLUSION

This study highlights the challenges of using highly accurate devices, like the ESP32 development board, in educational settings. While the tool provided precise acceleration measurements, its sensitivity amplified noise and data variability, complicating its usability as a teaching resource. The findings emphasize the importance of balancing accuracy and simplicity in educational tools to ensure they are effective and accessible for learners. Overly complex data can hinder understanding, reducing the tool's value in physics education. Future designs should prioritize usability alongside precision to create practical, learner-friendly tools that enhance engagement and comprehension in hands-on educational environments.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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