Development of an Arduino Nano-Based Viscometer to Enhance Students' Physics Concept Understanding

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Abstract - *The understanding of the physics concept of viscosity is often hindered by its abstract nature and the limited availability of experimental tools in schools, leading to theoretical and suboptimal learning. Therefore, an innovative learning package needs to be developed to address these issues. This study aimed to develop this learning package and to test whether the resulting product is valid, practical, and effective for enhancing student's conceptual understanding. This study is a research and development adapting the procedural framework of the ADDIE model. The process involved 11th-grade SAINTEK students at SMAN 11 Mataram as trial subjects, with feasibility data collected through expert validation sheets, response questionnaires, and pretest-posttest questions for quantitative analysis. The data analysis indicated that the developed learning package consisting of an Arduino Nano-based viscometer, a teaching module, a student worksheet, and a test instrument achieved a very valid rating (average >89%), a very practical rating (92.00%), and was sufficiently effective with an average N-Gain score of 0.51 (medium category). Based on these results, it is concluded that the developed learning package is valid, practical, and sufficiently effective to be used for enhancing students' understanding of physics concepts.*

Keywords: *Arduino Nano; Conceptual Understanding; Learning Media; Research And Development; Viscometer*

INTRODUCTION

Physics is a science that explains natural phenomena, yet many of its concepts, such as fluid viscosity, are abstract and challenging for students to grasp (Purwanti, 2023; Rizaldi et al., 2020). According to Purwanti (2023), many students perceive physics as difficult precisely because of its abstract nature, which often leads to boredom when taught using conventional methods like lectures. This challenge is compounded by a significant gap in many schools: the lack of adequate and interactive experimental tools, which can be limited in number or too complex and time-consuming for effective classroom use (Ali et al., 2022; Dewa et al., 2025; Herwinarso et al., 2024; Tampenawas et al., 2025). This limitation often restricts the learning process to theoretical instruction (Supriyanto et al., 2024), hindering students' conceptual understanding.

This limitation particularly affects grade XI students, where abstract thinking and scientific skills should be honed through hands-on experiments. The importance of practical laboratory work for enhancing conceptual understanding is widely recognized, as it helps students link theory with phenomena observed in their surroundings (Tampenawas et al., 2025). Without it, students' grasp of concepts like viscosity remains suboptimal as they lack the tangible experience needed to connect theory with real-world phenomena. One crucial aspect that is often overlooked is the students' prior knowledge; without a proper assessment of their initial understanding, it becomes difficult to design effective learning experiences (Harjono et al., 2023).

To bridge this gap, technology integration offers a potent solution (Ali et al., 2022). The use of microcontrollers like Arduino offers a solution, as it can simplify experimental processes, reduce measurement uncertainty, and increase time efficiency (Herwinarso et al., 2024). This approach has been successfully applied in developing various digital practicum tools, such as for measuring gravitational acceleration (Maulani et al., 2022; Tampenawas et al., 2025), verifying Archimedes' Law with high precision (Isnaini et al., 2025), and analyzing uniformly accelerated linear motion (Maryani et al., 2023). Following this approach, this research introduces an innovative learning package centered around a low-cost, accessible Arduino Nano-based viscometer. The novelty of this study, compared to previous research such as that by Rahmani et al. (2022) and Doyan et al. (2023) which used Arduino Uno with different sensors, lies in the implementation of an inductive sensor (LJ12A3-4-Z/BX NPN) with Arduino Nano. This choice simplifies the device's hardware architecture, as the inductive sensor can detect the metallic object independently, eliminating the need for an external magnet. This innovation makes the device more compact, easier to assemble, and less prone to setup errors. This development aims to provide an affordable and effective experimental tool that not only deepens conceptual understanding but also aligns with the demands of the 4.0 Industrial Revolution by fostering students' STEM skills.

RESEARCH METHODS

This study employed a Research and Development (R&D) methodology, a common approach for developing and testing educational tools in physics (Tampenawas et al., 2025). The procedural framework was adapted from the ADDIE model, which consists of five phases: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The ADDIE model has been successfully used in similar studies to develop physics teaching aids, demonstrating its suitability for this type of research (Ewar et al., 2023; Sari et al., 2020, as cited in Purwanti, 2023). The research was conducted from February 2025 onwards at the Physics Laboratory of Universitas Mataram for development and at SMAN 11 Mataram for product implementation. The subjects for the limited trial were students of class XI SAINTEK.

The developed product was a complete learning package, including the Arduino Nano-based viscometer, a teaching module, a student worksheet (LKPD), and a conceptual understanding test instrument. Data were collected using validation sheets assessed by expert validators (university lecturers) and practitioner validators (senior physics teachers), a student response questionnaire to measure practicality, and pretest-posttest results to measure effectiveness.

Data analysis was performed quantitatively. Product validity was determined using a percentage formula based on Likert scale scores from validators, with reliability confirmed using the Percentage of Agreement (PA) formula, requiring a score $\geq 75\%$ to be deemed reliable. Product practicality was assessed through student response questionnaires, also analyzed using a percentage score. The effectiveness of the learning package in improving students' conceptual understanding was analyzed using the Normalized Gain (N-Gain) score, calculated from the pretest and posttest results.

RESULTS AND DISCUSSION

Results

The development process resulted in a functional learning package centered on a digital viscometer. The device utilizes an Arduino Nano microcontroller integrated with an inductive proximity sensor (LJ12A3-4-Z/BX NPN) to detect the metal ball's movement through the fluid. The final design of the developed tool is presented in Figure 1.

Figure 1. The Developed Arduino Nano-Based Viscometer

The device is designed to be compact and user-friendly, consisting of a vertical tube holder, the sensor array, and an LCD display to show the travel time and calculated viscosity immediately. This design specifically addresses the need for affordable and accessible laboratory tools in schools.

The development process resulted in a functional learning package. The feasibility of this package was evaluated through three main assessments: validity, practicality, and effectiveness.

1. Validity and Reliability: The entire learning package was validated by five experts. The main product, the viscometer, received an average validity score of 93.18% (Very Valid) with a reliability of 95.18%. The supporting materials, including the teaching module, student worksheet, and a test instrument, also achieved "Very Valid" ratings with scores of 93.00%, 93.00%, and 89.09% respectively, and were all deemed reliable.
2. Practicality: The practicality was assessed by the end-users (students) via a response questionnaire after the implementation phase. The product package obtained an overall practicality score of 92.00%, categorizing it as "Very Practical". This indicates that students found the viscometer and its supporting materials easy to use, the instructions clear, and the overall experience engaging.
3. Effectiveness: The effectiveness was measured by the improvement in students' conceptual understanding. The results, as shown in Table 1, indicate a significant increase from the average pretest score to the posttest score.

Table 1. Pretest, Posttest, and N-Gain Score Summary

Assessment	Average Score	N-Gain	Category
Pretest	60.65	0.51	Medium
Posttest	80.66		

The average N-Gain score was 0.51, which falls into the "Medium" category. This demonstrates that the learning package was sufficiently effective in enhancing students' understanding of the concept of viscosity. A detailed comparison of pretest and posttest scores for each student is visualized in Figure 1.

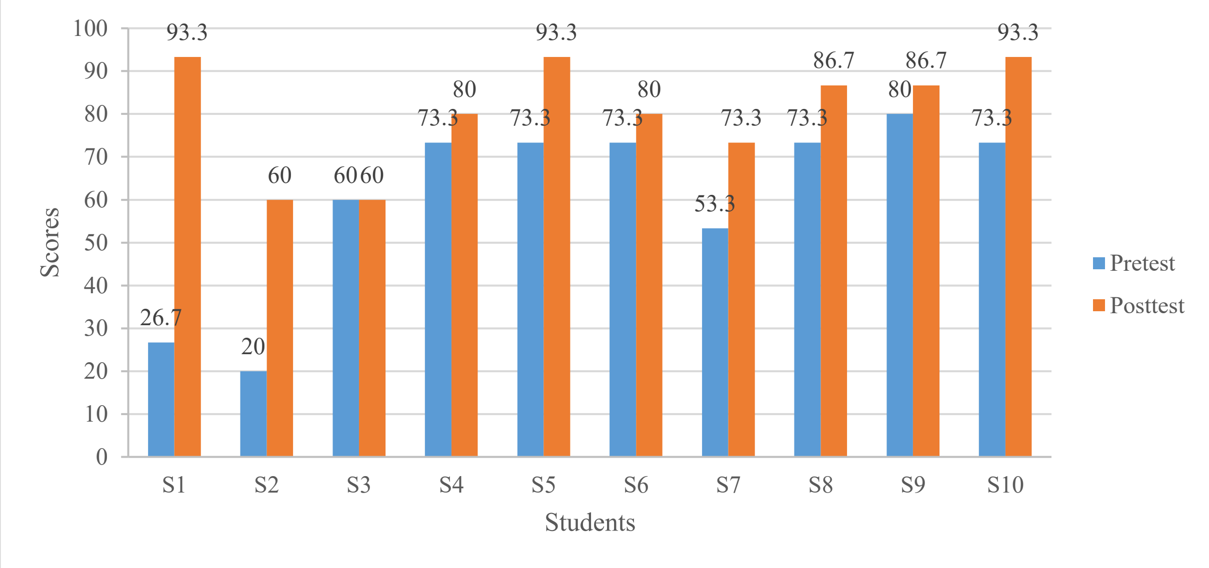

Figure 2. Comparison of Student Pretest and Posttest Scores

Discussion

The results affirm that the developed Arduino Nano-based viscometer learning package is of high quality and suitable for educational purposes. The "Very Valid" and "Reliable" ratings from a combination of academic and practical experts confirm that the product is well-designed, functionally sound, and aligns with the physics curriculum, thereby minimizing the risk of misconceptions. This high level of validity is crucial for any teaching aid before it is used in a learning environment (Ewar et al., 2023).

The validity score of 93.18% for the viscometer is particularly significant given the novelty of the sensor used. While previous studies like Doyan et al. (2023) and Rahmani et al. (2022) utilized magnetic sensors requiring specific magnetic objects, this study's implementation of an inductive sensor simplifies the hardware architecture. This modification allows for a more robust detection mechanism without relying on external magnets, thereby minimizing setup errors and potential misconceptions during experiments.

The "Very Practical" rating (92.00%) from students is a crucial indicator of the product's usability in a real classroom setting. This finding is critical, as the practicality of a learning tool directly influences its adoption and effectiveness in the classroom (Tampenawas et al., 2025; Wahyudi et al., 2022). It suggests that the device and its accompanying materials are user-friendly and can be implemented without significant hurdles. This aligns with the perspective of Ali et al. (2022), who emphasize that interactive laboratories must be accessible to bridge the gap between theoretical instruction and practical application. By automating the timing process with Arduino, students can focus more on analyzing the physical phenomenon of viscosity rather than struggling with manual stopwatch synchronization, a common issue in conventional methods (Maulani et al., 2022).

The effectiveness of the product, demonstrated by the "Medium" category N-Gain score of 0.51, is a significant outcome. This result supports the argument that technology-based learning tools can be more effective than traditional methods for teaching complex scientific topics. This effectiveness stems from the tool's ability to reduce measurement uncertainty. As highlighted by Isnaini et al. (2024), conventional methods often result in large relative errors (up to 34.52%), whereas sensor-based tools can drastically reduce this error (to approx. 1.54%), making abstract concepts more tangible and verifiable for students.

Furthermore, introducing novel, sensor-based tools like this viscometer can increase student enthusiasm and engagement in the experimental process (Herwinarso et al., 2024). The interactive nature of the device allows students to receive immediate feedback via the LCD screen, fostering a more dynamic learning environment. This is consistent with findings by Maryani et al. (2023), who noted that digital physics tools significantly aid in visualizing kinematic concepts. Consequently, the increase in test scores indicates that the interactive experiment facilitated a deeper level of learning than traditional theoretical methods. This result also aligns with similar R&D studies in physics education that have reported moderate effectiveness for innovative learning models (Wahyudi et al., 2023). This result also corroborates the broader educational goal of integrating STEM skills into the curriculum, preparing students for the demands of the 4.0 Industrial Revolution through hands-on experience with microcontrollers.

CONCLUSION

Based on the comprehensive evaluation, it is concluded that the developed learning package, consisting of an Arduino Nano-based viscometer and its supporting materials, is valid, practical, and effective for enhancing students' conceptual understanding of viscosity. The product successfully meets its objective as an innovative and feasible educational tool for physics learning, providing a practical solution to the common problem of limited laboratory facilities by utilizing low-cost and accessible technology (Azmi et al., 2024). For future development, it is recommended to utilize a more precise sensor and a larger tube to improve accuracy and minimize the wall effect, as well as to further simplify the operating procedure.

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