

Development and Preliminary Evaluation of Arduino-Based Inquiry Activities for Friction and Newton's Second Law in Pre-Service Physics Teacher Education

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Received: 30 Jul 2026 Revised: 30 Aug 2026 Accepted: 31 Aug 2026

Abstract

Persistent misconceptions concerning friction and Newton's second law remain a challenge in physics education, particularly among pre-service physics teachers. This study aimed to develop, evaluate, and preliminarily examine Arduino-based inquiry learning activities designed to connect abstract physics concepts with experimental evidence. A mixed-methods developmental approach based on the ADDIE model and a one-group pretest-posttest design was employed. The developed package consisted of four interconnected learning units organized around two core Arduino-based experiments, together with instructional guides, worksheets, and experimental kits. Three experts evaluated the package, which was subsequently implemented with 30 pre-service physics teachers. Quantitative data were collected using a 30-item conceptual understanding test, while qualitative data were obtained from observations, reflective journals, and interviews. Expert evaluation indicated that the activities were of the highest overall quality ($M = 4.79$, $SD = 0.17$), with an average Index of Item-Objective Congruence of 0.98. Participants' mean conceptual understanding score increased from 8.80 out of 30 (29.33%) on the pretest to 23.40 (78.00%) on the immediate posttest, $t(29) = -24.98$, $p < .001$. The class-average normalized gain was 0.69, indicating a medium gain. Qualitative findings suggested that real-time data collection and graph-based analysis helped participants connect observable motion with relationships among force, mass, friction, and acceleration. However, difficulties distinguishing static and kinetic friction persisted. These findings provide preliminary evidence supporting Arduino-based inquiry activities for physics teacher education.

Keywords: Arduino, Physics Education, inquiry-based learning, Conceptual Understanding, Friction, Newton's Second Law, Pre-service Physics Teachers

1. Introduction

Physics education in the 21st century is undergoing a significant paradigm shift, transitioning from traditional, lecture-based learning focused on content transmission to active learning methodologies that emphasize the cultivation of deep conceptual understanding (Farrar, 2021). Conceptual understanding is a core competency that enables learners to apply physical principles to explain real-world phenomena, rather than merely solving mathematical problems. However, several fundamental concepts in mechanics, particularly friction and Newton's Second Law, remain academic challenges and primary sources of persistent misconceptions among learners at all levels (Ha & Kim, 2020; Sarapak, et al., 2025c). The quality of physics instruction at the secondary level, which serves as a critical foundation for STEM education, is directly dependent on the proficiency of its teachers (Sarapak et al., 2025a). Consequently, preparing pre-service physics teachers with an accurate and precise conceptual understanding of this content is an imperative and urgent mission for the reform of physics education.

Over the past decade, the integration of technology into physics experiments has demonstrated outstanding potential for fostering conceptual understanding. The Arduino microcontroller platform, in particular, distinguished by its low-cost and accessible nature, has emerged as a highly effective tool for transforming traditional physics laboratories into inquiry-based learning environments (Lee, 2020). A substantial body of empirical evidence confirms that Arduino-based learning activities enable students to engage in real-time data collection, a mechanism that is crucial for bridging the gap between empirical evidence and abstract theoretical principles (Çoban & Erol, 2022; Çoban & Boyacı, 2020). This hands-on process of interacting with sensors and modeling motion data not only significantly enhances student motivation and engagement (Chitolina & Santos, 2024; Sreejivungsa et al., 2025) but also cultivates essential 21st-century skills such as computational thinking and scientific process skills (Dat et al., 2024). This pedagogical approach aligns directly with Constructivist theory, which emphasizes that learners construct knowledge through interaction and practical experimentation (Ferrarelli & Iocchi, 2021).

Although the effectiveness of Arduino-based learning activities has been widely validated in the context of secondary education (Addido et al., 2023), a systematic review of the literature reveals a significant and distinct research gap. The majority of past research has concentrated on evaluating the learning outcomes of high school students, while largely overlooking a critically important cohort within the education ecosystem: pre-service physics teachers. Concurrently, the literature indicates that a primary obstacle to integrating technology in physics instruction is the level of teacher expertise and their Technological Pedagogical Content Knowledge (TPACK) (Handayani & Setya, 2022; Sarapak, et al., 2025b; Schnider & Hömöstrei, 2023). This situation raises concerns that if future educators continue to hold misconceptions about core physics concepts and lack first-hand experience in applying these technologies as learners, it is highly unlikely they will be able to effectively design and implement instruction integrating these tools in their future classrooms.

Based on the aforementioned situation and research gaps, several critical questions arise that await investigation and lack clear answers within the context of pre-service physics teachers: 1) What specific elements and development model should constitute an Arduino-based physics learning activity package designed to effectively enhance the conceptual understanding of friction and Newton's second law for pre-service physics teachers? 2) What will be the outcomes of the efficiency evaluation process for this package, considering its validity, appropriateness, and feasibility for classroom implementation? 3) To what concrete extent will the developed learning package impact the conceptual understanding of pre-service physics teachers, as measured before and after the intervention? These questions form the direct impetus for this research. The study's

primary objectives are therefore: 1) To develop Arduino-based physics learning activities aimed at enhancing the conceptual understanding of friction and Newton's second law for pre-service physics teachers; 2) To evaluate the quality and content of the developed learning activities based on their validity, appropriateness, and implementation feasibility; and 3) To study the short-term changes of the developed Arduino-based learning activities on the conceptual understanding of physics among pre-service physics teachers. The expected outcomes will not only address the conceptual misunderstandings of these future teachers but also provide them with practical preparation for integrating modern technology into their future teaching, thereby benefiting teacher education institutions by refining their curricula and positively impacting the quality of secondary physics education.

2. Methodology

2.1 Research Design

This study employed an embedded mixed-methods developmental evaluation incorporating a Research and Development (R&D) approach for the systematic development and preliminary evaluation of an instructional product (Gall et al., 2007). The development process was guided by the ADDIE model—Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The quantitative component used a one-group pretest–posttest design to examine short-term changes in pre-service physics teachers' conceptual understanding before and immediately after participation in the activities. The qualitative component was embedded within the implementation phase to explore participants' learning experiences, conceptual difficulties, and perceptions of using Arduino technology. The research process was organized into three phases that incorporated the five stages of the ADDIE model:

Analysis and Design Phase: The researchers analyzed the physics curriculum, relevant literature, common misconceptions concerning friction and Newton's second law, and the instructional needs of pre-service physics teachers. The learning objectives, activity structure, Arduino-based experimental arrangements, worksheets, and assessment instruments were subsequently designed.

Development and Validation Phase: The activity package and research instruments were developed according to the proposed design. Three experts evaluated their content alignment, instructional appropriateness, and implementation feasibility. The materials were revised based on the experts' recommendations, and the conceptual understanding test was reviewed by three experts for content alignment and was revised based on their recommendations before being administered to the study participants.

Implementation and Evaluation Phase: The revised activities were implemented with the participants. Pretest and immediate posttest data were collected to examine changes in conceptual understanding, while observations, reflective journals, and semi-structured interviews were used to provide further insight into participants' learning experiences.

2.2. Participants and Ethical Considerations

The participants were 30 first- to third-year undergraduate pre-service physics teachers enrolled at Surindra Rajabhat University during the second semester of the 2025 academic year. Participants were selected through purposive sampling. The inclusion criteria required participants to have: (1) enrolled in a physics education course or a related course and (2) successfully completed Physics I or an equivalent introductory physics course. These criteria were intended to ensure that the participants possessed sufficient foundational knowledge of mechanics to engage meaningfully in the activities. All 30 participants completed the pretest, participated in the Arduino-based inquiry activities, and

completed the immediate posttest. The same participants therefore contributed data to both measurement occasions.

The research protocol was submitted to the Human Research Ethics Committee of Surindra Rajabhat University, Thailand, and was registered under project identification number HE692013. Prior to participation, all participants were informed of the purpose and procedures of the study, the voluntary nature of participation, their right to withdraw from the study at any time without penalty, and the confidentiality of their information. Informed consent was obtained from all participants before data collection. Participant information was kept confidential and was used solely for research purposes.

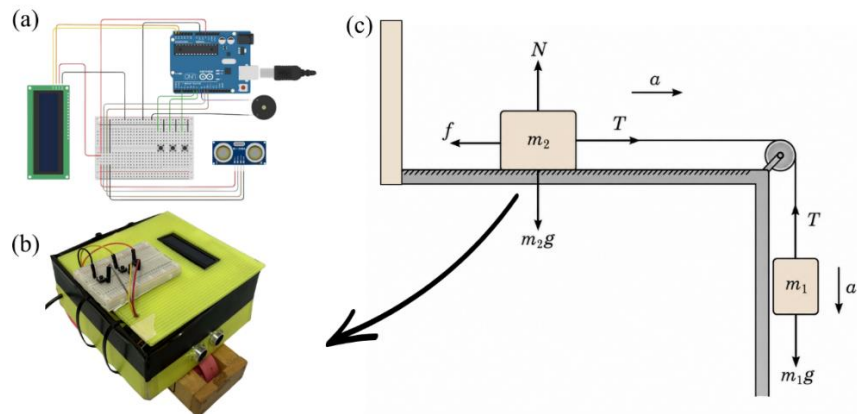


Figure 1. Arduino-based experimental setup for investigating friction and Newton's second law: (a) schematic of the Arduino UNO, ultrasonic sensor, LCD, and associated circuit connections; (b) photograph of the constructed experimental apparatus; and (c) free-body diagram of the two-mass system, showing the forces acting on the block and the hanging mass. The ultrasonic sensor measures the position of the moving block as a function of time, from which the acceleration is determined and subsequently used to calculate the frictional force, tension, and net force.

Record of Experimental Results

Part 1: Investigating the Relationship Between Mass and Frictional Force

No.	Mass m_1 (kg)	Mass m_2 (kg)	$\mu_s = \frac{m_1}{m_2}$
1			
2			
3			
4			
5			

Data Analysis

Trial	a_{exp}	a_{graph}	$\mu_k = \frac{m_1 g - (m_1 + m_2)a}{m_2 g}$
1			
2			
Average			

Therefore, the values of the kinetic friction coefficient μ_k from trial 1 and trial 2 are
 $\mu_k =$ _____.

Part 2: Investigating the Relationship Between Distance and Time

In the experiment, lift $m_1 =$ _____ kg and $m_2 =$ _____ kg

No.	Time t (s)	Distance s (m)	t^2 (s^2)	Acceleration a
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Average				

Part 3: (Using the average t^2 from Part 2), find the acceleration.

	Calculation of acceleration
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Figure 2. Inquiry activity and data-recording worksheet for the core experiment on static and kinetic friction.

Part 3: Determining the Tension in the String

No.	m_1 (kg)	m_2 (kg)	$x(t)$	$v(t)$	$a(t)$	μ_s	μ_k	T (experimental)	T (theoretical)	% error
1										
2										
3										
4										
5										
6										

Show the calculation steps for T (experimental), T (theoretical), and % error for data set 6.

Figure 3. Inquiry activity and data-recording worksheet for the core experiment on the relationships among force, mass, and acceleration.

2.3. Research Instruments

The research instruments consisted of four components: the Arduino-based physics learning activities, the activity package quality assessment form, the conceptual understanding test, and qualitative data-collection instruments.

2.3.1 Arduino-Based Physics Learning Activities

The package included lesson plans, instructor guides, student worksheets, Arduino programs, and experimental equipment. The experimental system consisted of an Arduino UNO board, an ultrasonic distance sensor, connecting circuits, a pulley-and-mass apparatus, and software for real-time data acquisition and visualization. The ultrasonic sensor was used to measure the position of the moving object at successive time intervals. It did not directly measure force. The recorded distance–time data were fitted to a constant-acceleration kinematic model to determine the acceleration of the system. The calculated acceleration, together with the known masses of the objects, was subsequently used in the relevant force-balance equations to determine the net force, frictional force, and coefficients of friction.

The activities were designed according to an Inquiry-Based Learning approach. Participants were required to make predictions, assemble and operate the Arduino-based experimental apparatus, collect real-time distance–time data, construct and interpret motion graphs, and fit the recorded data to determine acceleration. They then used the calculated acceleration and known masses to calculate force-related quantities, compare the experimental results with theoretical relationships, and formulate evidence-based conclusions.

2.3.2 Activity Package Quality Assessment Form

The activity package quality assessment form was used by three experts to evaluate the developed activities. The experts possessed relevant expertise in physics, physics education, educational measurement, or educational technology.

The Index of Item–Objective Congruence was used to evaluate the alignment among the objectives, content, activities, and assessment components.

The experts evaluated the quality of the activity package using a five-point rating scale ranging from 1 (lowest quality) to 5 (highest quality) covering the following dimensions:

1. Content Accuracy
2. Pedagogical Appropriateness
3. Feasibility of Implementation.

Open-ended comments from the experts were used to revise the learning activities and research instruments before implementation.

2.3.3 Conceptual Understanding Test

The conceptual understanding test was a researcher-developed, 30-item, four-option multiple-choice test. It was designed to assess participants' understanding of friction and Newton's second law. The assessed concepts included static friction, maximum static friction, kinetic friction, net force, acceleration, the relationship among force, mass, and acceleration, and the interpretation of force and motion graphs.

The test items were evaluated by three experts using the Index of Item–Objective Congruence. Items that did not meet the predetermined content-validity criterion were revised based on expert recommendations. Following expert evaluation and revision, the test was administered directly to the 30 study participants as both the pretest and immediate posttest.

The test was not pilot-tested with a separate group before the main implementation. Therefore, pilot-test statistics such as item difficulty, item discrimination, and pilot reliability coefficients were not used as evidence of instrument quality in this study. The principal evidence supporting the test was expert-based content validity.

2.3.4 Qualitative Data-Collection Instruments

Qualitative data were collected through behavioral observations, reflective journals, and semi-structured interviews. The observation protocol focused on participants' engagement with the activities, use of the Arduino equipment, interpretation of experimental graphs, development of explanations, and difficulties encountered during the inquiry process. Reflective journals asked participants to describe what they had learned, how experimental evidence influenced their understanding, and their perceptions of using Arduino in future physics teaching. Semi-structured interviews were used to obtain more detailed explanations of participants' learning experiences and conceptual difficulties. The interview questions focused on participants' understanding of friction and Newton's second law, their use of experimental evidence, and their confidence in using Arduino technology.

2.4 Research Procedures

The research was conducted sequentially in three phases corresponding to the ADDIE development process.

2.4.1 Phase 1: Analysis and Design

Participants/Information Sources: No study participants were directly involved in this phase. The analysis was based on the physics curriculum, relevant literature, previous studies concerning misconceptions in friction and Newton's second law, and the instructional context of pre-service physics teacher education.

Instruments and Materials: Curriculum documents, relevant literature, instructional design specifications, draft learning objectives, activity plans, worksheets, and draft research instruments were used during this phase.

Data Collection: The researchers reviewed the physics curriculum and relevant literature to identify important conceptual difficulties related to friction and Newton's second law and considered the instructional needs of pre-service physics teachers. Based on this analysis, the researchers established the learning objectives and designed four interconnected Arduino-based inquiry learning units, lesson plans, instructor guides, student worksheets, experimental arrangements, a conceptual understanding test, and qualitative data-collection instruments.

Data Analysis: Information from the curriculum and literature review was synthesized to identify key content, common conceptual difficulties, learning objectives, and instructional requirements. The findings from this analysis informed the design of the learning activities and research instruments.

2.4.2 Phase 2: Development and Expert Validation

Participants: Three experts with expertise in physics, physics education, educational measurement, or educational technology participated in the validation of the developed activity package and research instruments.

Instruments and Materials: The instruments and materials included the Arduino-based learning activity package, the activity package quality assessment form, the 30-item conceptual understanding test, and the Index of Item–Objective Congruence (IOC) evaluation forms.

Data Collection: The Arduino-based activity package was developed and the experimental equipment was assembled according to the proposed design. The Arduino program and data-acquisition procedures were adapted and refined from Çoban and Salar (2023) to suit the objectives and equipment configuration of the present study. Three experts evaluated the alignment among the objectives, content, activities, and assessments and rated the quality of the activity package in terms of content accuracy, pedagogical appropriateness, and feasibility of implementation. Their comments were also collected and used to revise the materials before implementation.

Data Analysis: Expert evaluation data were analyzed using the mean, standard deviation, and Index of Item–Objective Congruence (IOC). The qualitative comments provided by the experts were reviewed and used to guide revisions of the activities and research instruments.

2.4.3 Phase 3: Implementation and Evaluation

Participants: Thirty first- to third-year undergraduate pre-service physics teachers at Surindra Rajabhat University participated in this phase. All participants completed both the pretest and immediate posttest.

Instruments: The instruments included the 30-item conceptual understanding test, Arduino-based inquiry learning activities, behavioral observation protocol, reflective journals, and semi-structured interview questions.

Data Collection: Participants first completed the conceptual understanding pretest. They then completed four interconnected learning units over a total duration of three hours, including an introduction to Arduino and sensor-based data collection, investigations of friction and Newton's second law, and graph interpretation and evidence-based conclusion construction. Immediately after the activities, participants completed the same conceptual understanding test as a posttest. Behavioral observations were conducted during the activities, reflective journals were collected following implementation, and semi-structured interviews were conducted to obtain additional information about participants' learning experiences and conceptual difficulties.

Data Analysis: Pretest and posttest scores were analyzed using descriptive statistics and a paired-samples t-test after examination of the normality of the paired difference scores. The class-average normalized gain and Cohen's d_z were calculated to describe the magnitude of the observed change. Item-level analysis was conducted by comparing the numbers and percentages of correct responses for each test item. Qualitative data from behavioral observations, reflective journals, and semi-structured interviews were analyzed using content analysis. The qualitative findings were subsequently compared with the quantitative findings to support interpretation of participants' learning experiences and conceptual difficulties.

2.5 Data Analysis

Quantitative and qualitative data were analyzed separately and subsequently integrated during the interpretation of the findings. Expert evaluations of the activity package were analyzed using the mean, standard deviation, and Index of Item–Objective Congruence. Pretest and posttest scores were summarized using the mean, standard deviation, minimum, maximum, and percentage of the total score. After examining the normality of the paired difference scores, a paired-samples t -test was conducted at the .05 significance level to determine whether participants’ conceptual understanding differed significantly between the pretest and immediate posttest. The magnitude of the within-participant difference was estimated using Cohen’s d_z , calculated as $d_z = |t|/\sqrt{N}$. The class-average normalized gain was also calculated using $\langle g \rangle = (\%Post - \%Pre)/(100 - \%Pre)$ and interpreted as low when $\langle g \rangle < 0.30$, medium when $0.30 \leq \langle g \rangle < 0.70$, and high when $\langle g \rangle \geq 0.70$. In addition, item-level analysis was conducted by comparing the numbers and percentages of correct responses for each test item to identify concepts showing improvement and those for which difficulties persisted. Qualitative data from behavioral observations, reflective journals, and semi-structured interviews were analyzed using content analysis. The data were organized, repeatedly reviewed, coded, grouped into related categories, and synthesized into themes representing participants’ learning experiences and conceptual difficulties. Finally, the qualitative themes were compared with the quantitative and item-level findings to provide a more comprehensive interpretation of the observed changes in conceptual understanding.

3. Results and Discussion

The findings are presented according to the three research objectives: the development of the Arduino-based learning activity package, the expert evaluation of its content alignment and quality, and the examination of participants’ conceptual understanding and learning experiences following implementation.

3.1 Development of Arduino-Based Physics Learning Activities

Following the analysis, design, and development phases, the researchers developed the Physics Learning Activities Using Arduino Technology package to support pre-service physics teachers’ understanding of friction and Newton’s second law. The package comprised four interconnected components: a teacher’s guidebook, a student handbook and worksheets, an Arduino experimental kit, and a conceptual understanding test.

The student materials consisted of four interconnected learning units organized around two core Arduino-based experiments: (1) introduction to Arduino and sensor-based data collection; (2) investigation of static and kinetic friction; (3) investigation of the relationships among force, mass, and acceleration; and (4) interpretation and application of experimental graphs. Units 2 and 3 constituted the two core experiments, while Units 1 and 4 supported equipment familiarization, data analysis, graph interpretation, and evidence-based conclusion construction. The experimental kit included an Arduino UNO board, an ultrasonic sensor, connecting wires, and the equipment required for real-time data collection. The conceptual understanding test consisted of 30 four-option multiple-choice items covering friction and Newton’s laws. The test was evaluated for content alignment by three experts before implementation. The activities required participants to predict experimental outcomes, collect real-time data, construct and interpret graphs, compare empirical evidence with theoretical relationships, and formulate evidence-based conclusions. Figure 1 presents the Arduino-based experimental arrangement used to collect distance–time data in the two core inquiry experiments.

3.2 Evaluation of Quality, Content Validity, Appropriateness, and Implementation Feasibility

Three experts evaluated the content alignment and overall quality of the developed activity package. The IOC values of the 30 conceptual understanding test items ranged from 0.67 to 1.00, with all items meeting the predetermined criterion of 0.50. The activity package obtained an average IOC value of 0.98, indicating strong alignment among the learning objectives, content, activities, and assessment components. The quality of the activity package was also evaluated using a five-point rating scale. As shown in Table 1, the overall quality of the activity package was rated at the highest level ($M=4.79$, $SD=0.17$). Content accuracy received the highest mean rating, followed by pedagogical appropriateness and feasibility of implementation. These findings indicate that the experts considered the package accurate, instructionally appropriate, and feasible for implementation with pre-service physics teachers. However, expert ratings represent evidence of perceived quality and content alignment rather than direct evidence of learning effectiveness.

Table 1. Expert Evaluation of the Quality of the Arduino-Based Learning Activity Package (N=3)

Dimensions	Mean	S.D.	Quality Level
1. Content Accuracy	4.87	0.12	Highest
2. Pedagogical Appropriateness	4.78	0.21	Highest
3. Feasibility of Implementation	4.71	0.19	Highest
Overall	4.79	0.17	Highest

3.3 Short-Term Changes in Pre-Service Physics Teachers' Conceptual Understanding

To address the third research objective, quantitative and qualitative findings were integrated to examine short-term changes in participants' conceptual understanding following the Arduino-based inquiry activities. The findings are presented in terms of overall pretest–posttest performance, item-level and sub-concept changes, and participants' learning experiences and engagement during the activities.

3.3.1 Overall Pretest and Posttest Comparisons

As shown in Table 2, the 30 participants obtained a mean pretest score of 8.80 out of 30 ($SD = 6.20$), corresponding to 29.33% of the total score. Following participation in the Arduino-based inquiry activities, the mean posttest score increased to 23.40 ($SD = 4.32$), corresponding to 78.00% of the total score. The observed mean increase was 14.60 points, equivalent to an increase of 48.67 percentage points.

A paired-samples t -test was conducted to examine the difference between the pretest and posttest conceptual understanding scores. The results indicated that the mean posttest score was statistically significantly higher than the mean pretest score, $t(29) = -24.98$, $p < .001$. The negative t value resulted from calculating the paired difference in the order of pretest minus posttest. These findings indicate a statistically significant short-term increase in conceptual understanding scores following participation in the Arduino-based inquiry activities. The mean increase was 14.60 points, with an estimated 95% confidence interval ranging from 13.40 to 15.80 points. The class-average normalized gain was 0.69, indicating a medium learning gain. To examine the magnitude of improvement relative to the maximum possible gain, the class-average normalized gain was calculated using the corrected pretest and posttest percentages. The participants' mean score increased from 29.33% on the pretest to 78.00% on the posttest. The normalized gain was therefore calculated as $\langle g \rangle = (78.00 - 29.33) / (100 - 29.33) = 0.69$. Based on the adopted classification criteria, this value represents a medium normalized gain. Although the result was close to

the threshold of 0.70 for the high-gain category, it remained within the medium-gain classification. The magnitude of the within-participant difference was also examined using Cohen's d_z , an effect-size measure appropriate for paired observations. The calculated effect size was $d_z = |t|/\sqrt{N} = 4.56$, indicating a very large within-participant effect. This result suggests that the observed difference between the pretest and immediate posttest scores was large relative to the variability in the paired difference scores. However, because the study used a one-group pretest–posttest design without a comparison group, the effect size may be interpreted as the magnitude of the observed short-term change rather than as evidence that the Arduino-based activities alone caused the improvement.

Table 2: Descriptive Statistics and Paired-Samples t-Test Results for Pretest and Posttest Scores

Assessment	N	Mean	S.D.	Mean (%)	t	df	p-value
Pretest	30	8.80	6.20	29.33	-24.98	29	<.001
Posttest	30	23.40	4.32	78.00			

Note. The negative value of the t statistic results from calculating the paired difference as pretest minus posttest.

Table 3: Summary of Item Analysis (N=30)

Item	Pretest (N)	Posttest (N)	%Correct (Pretest)	%Correct (Posttest)
1	18	27	60	90
2	12	27	40	90
3	9	24	30	80
4	12	27	40	90
5	3	24	10	80
6	15	18	50	60
7	12	27	40	90
8	9	27	30	90
9	21	24	70	80
10	0	6	0	20
11	3	24	10	80
12	12	24	40	80
13	3	18	10	60
14	15	24	50	80
15	6	30	20	100
16	6	24	20	80
17	6	27	20	90
18	3	18	10	60
19	9	24	30	80
20	12	27	40	90
21	12	24	40	80
22	15	21	50	70
23	15	21	50	70
24	3	21	10	70
25	3	21	10	70
26	6	24	20	80
27	0	21	0	70
28	9	18	30	60
29	9	30	30	100
30	6	30	20	100

Persistent Difficulty with Friction: Item 10

For Item 10, none of the participants answered correctly on the pretest, whereas six of the 30 participants answered correctly on the posttest. The proportion of correct responses therefore increased from 0% to 20%. Although this represented an improvement of 20 percent, 80% of the participants continued to answer incorrectly.

This result indicates that the relationship between pulling force, net force, and kinetic friction remained difficult for most participants. The response pattern may indicate continued confusion between static friction, maximum static friction, and kinetic friction. However, specific misconceptions should be concluded only when supported by distractor-response data, written explanations, or interview evidence. The activity should therefore be refined by incorporating explicit comparisons of the friction phases and additional prediction–observation–explanation tasks using force–time graphs.

Items Showing the Largest Observed Improvements

The largest observed increases occurred for Items 15 and 30. For both items, the percentage of correct responses increased from 20% on the pretest to 100% on the posttest, representing an improvement of 80 percentage points. Items 5, 11, 17, 27, and 29 also showed increases of 70 percentage points. These findings demonstrate substantial short-term improvement on several assessed concepts, although causal conclusions cannot be drawn from the one-group design.

Zero-Net-Force Concept: Item 9

Item 9 assessed the relationship between zero net force and constant velocity. The percentage of correct responses increased from 70% on the pretest to 80% on the posttest, representing an improvement of 10 percentage points. Although this item did not show the largest gain, it was included because it addressed an important relationship between Newton's first and second laws.

Some participants may have continued to associate zero net force only with an object at rest rather than recognizing that an object may also move with constant velocity. The item-level results suggest that further activities comparing zero net force with constant nonzero net force may help strengthen this conceptual distinction.

3.3.3 Qualitative Findings on Conceptual Learning and Activity Engagement

Qualitative data from observations, reflective journals, and semi-structured interviews were analyzed using content analysis. Three themes emerged from the analysis. The first theme concerned participants' developing understanding of friction. Participants reported that real-time distance–time data and fitted motion graphs helped them examine changes in the object's motion before and after the onset of movement. By determining acceleration from the fitted graphs and applying the relevant force-balance equations, participants were able to connect the observed motion with static and kinetic friction. Nevertheless, the low posttest performance on Item 10 indicates that this concept remained difficult for many participants. The qualitative evidence should therefore be interpreted as illustrating participants' learning experiences rather than demonstrating that the misconception was fully resolved.

The second theme concerned the connection between theoretical relationships and experimental data. Participants described how collecting distance–time data, determining acceleration through curve fitting, and calculating force from the known mass helped them interpret $F_{\text{net}} = ma$ as an experimentally supported relationship rather than merely a formula to memorize. These experiences suggest that data visualization and modeling may support evidence-based reasoning in inquiry-oriented physics learning. The third theme concerned participants' attitudes toward technology integration. Participants reported reduced anxiety and increased confidence in operating Arduino equipment and

interpreting sensor data. These findings indicate more positive attitudes and perceived readiness to use Arduino in future teaching. However, they should not be interpreted as direct evidence of increased TPACK because the study did not use a validated TPACK instrument or performance-based teaching assessment.

Overall, this study addressed its three objectives through the development, expert evaluation, and preliminary implementation of Arduino-based inquiry activities for friction and Newton's second law. The findings suggest that the developed activities are a promising instructional resource for pre-service physics teacher education. However, because the study employed a one-group pretest–posttest design without a comparison group, the results should be interpreted as short-term changes following participation rather than as definitive evidence of causal effectiveness.

The activity package was systematically developed using the ADDIE model and comprised four interconnected components. The three experts rated its overall quality at the highest level ($M = 4.79$, $SD = 0.17$), while the average Index of Item–Objective Congruence was 0.98. These results indicate strong expert agreement concerning content alignment, instructional appropriateness, and implementation feasibility. The integration of Inquiry-Based Learning with accessible Arduino technology is consistent with previous studies showing that low-cost microcontroller systems can support active experimentation and real-time data collection in physics learning (Çoban & Boyacı, 2020; Lee, 2020). Nevertheless, expert ratings represent evidence of perceived quality and content validity rather than direct evidence of learning effectiveness. Regarding conceptual understanding, the participants' mean score increased from 8.80 out of 30 on the pretest, corresponding to 29.33%, to 23.40 on the immediate posttest, corresponding to 78.00%. The observed increase of 14.60 points was statistically significant, $t(29) = -24.98$, $p < .001$. The class-average normalized gain was 0.69, which is classified as a medium gain. Cohen's d_z , calculated for paired observations, was 4.56, indicating a very large within-participant difference. These findings are broadly consistent with previous studies showing that Arduino-supported experiments can facilitate engagement with physical variables, real-time measurement, and the interpretation of relationships among force, mass, and acceleration (Addido et al., 2023). However, the large effect size represents the magnitude of the observed pretest–posttest difference and should not be interpreted as proof that the activities alone caused the improvement. The qualitative findings provide a possible explanation for the observed increase in conceptual understanding scores. The ultrasonic sensor allowed participants to collect real-time distance–time data from the moving system. By fitting these data to a constant-acceleration model, participants determined the acceleration and subsequently calculated the net and frictional forces using the known masses and force-balance equations. This sequence enabled participants to connect directly observed motion with derived acceleration and calculated force relationships. Such an evidence-based process may have helped participants move beyond formula memorization toward a more integrated understanding of the relationships among force, mass, friction, and acceleration. Such experiences may have generated cognitive conflict and encouraged participants to reconsider their prior conceptions, consistent with Constructivist Learning Theory. Participants also reported moving from memorizing $F = ma$ toward interpreting and modeling relationships using their own data, supporting inquiry-based learning in which learners construct explanations from evidence (Ferrarelli & Iocchi, 2021). Nevertheless, conceptual improvement was not uniform across all test items. For Item 10, which assessed the distinction between static and kinetic friction, the percentage of correct responses increased from 0% to only 20%. Thus, 80% of participants continued to answer incorrectly after the activity. This finding is consistent with Ha and Kim (2020), who identified friction as a persistent source of conceptual difficulty. The activity should therefore be refined by incorporating explicit comparisons among static

friction, maximum static friction, and kinetic friction, together with prediction–observation–explanation tasks and repeated interpretation of force–time graphs.

Participants also reported increased confidence and more positive attitudes toward using Arduino in future teaching, addressing concerns about teacher readiness for technology integration (Handayani & Setya, 2022; Schnider & Hömöstre, 2023). Overall, the findings provide preliminary evidence of short-term improvement in conceptual understanding and confidence toward technology integration. Future studies should include a comparison group, a delayed posttest, larger samples, and direct assessments of teaching performance and TPACK.

4. Conclusion

This study was undertaken to address persistent misconceptions concerning friction and Newton’s second law among pre-service physics teachers by bridging abstract physics concepts with observable experimental evidence. A mixed-methods developmental approach was employed, combining Research and Development based on the ADDIE model with a one-group pretest–posttest design involving 30 pre-service physics teachers. The resulting Physics Learning Activities Using Arduino Technology package consisted of four interconnected learning units organized around two core Arduino-based experiments, together with instructional guides, worksheets, and experimental kits. The expert evaluation indicated that the developed package was appropriate for implementation in physics teacher education. Its overall quality was rated at the highest level ($M = 4.79$, $SD = 0.17$), and the average Index of Item–Objective Congruence was 0.98, demonstrating strong content alignment and instructional appropriateness. Following participation in the activities, the participants’ mean conceptual understanding score increased from 8.80 out of 30 on the pretest (29.33%) to 23.40 on the immediate posttest (78.00%). The difference was statistically significant, $t(29) = -24.98$, $p < .001$. The class-average normalized gain was 0.69, representing a medium gain, while Cohen’s $d_z = 4.56$ indicated a very large within-participant difference. The qualitative findings suggested that real-time distance–time data collection, motion-graph fitting, and subsequent force calculations supported participants in connecting observable motion with the abstract relationships among force, mass, friction, and acceleration. Participants reported that collecting distance–time data, determining acceleration from fitted graphs, and calculating force using the known mass helped them move beyond memorizing $F_{\text{net}} =$ toward understanding it as a relationship supported by experimental motion data.

They also expressed greater confidence and more positive attitudes toward using Arduino in future physics teaching. Despite the overall improvement, the activities did not fully resolve all conceptual difficulties. For Item 10, which assessed the distinction between static and kinetic friction, the percentage of correct responses increased from 0% to only 20%, indicating that this misconception remained problematic for most participants. Therefore, the findings provide preliminary evidence that the developed activities are a promising instructional resource associated with short-term improvement in conceptual understanding and confidence toward technology integration. Further refinement, particularly concerning friction concepts, and more rigorous evaluation using a comparison group, delayed posttest, and direct assessment of teaching performance are required before conclusions can be made regarding causal effectiveness, long-term retention, misconception remediation, or TPACK development.

Acknowledgments

This research was financially supported by the Thailand Science Research and Innovation Fundamental Fund, fiscal year 2025 (Grant No. FRB. 69007), through Surindra Rajabhat University (SRRU). The authors would also like to thank the pre-service physics teachers from the Faculty of Science and Technology, Surindra Rajabhat University, for their participation and support throughout this study.

Declaration

The authors declare that Generative AI (ChatGPT/Gemini) was only used to help improve the English language and for minor translation tasks. The AI was not used to create any scientific content, conduct data analysis, or interpret results. All ideas, experimental design, data collection, analysis, and conclusions were solely carried out by the authors. Following ethical research standards and academic integrity policies, the authors confirm that AI tools were used openly, ethically, and under the full supervision of the authors to ensure the manuscript's accuracy and appropriateness.

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