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CAN ARGUMENT-DRIVEN INQUIRY-ASSISTED VIRTUAL LABORATORY IMPROVE PRE-SERVICE PHYSICS TEACHERS' MASTERY CONCEPT OF SIMPLE HARMONIC OSCILLATION?

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ABSTRACT

This study endeavors to ascertain the efficacy of the Argument-Driven Inquiry (ADI)-assisted virtual laboratory learning model in enhancing the comprehension of simple harmonic oscillation concepts among pre-service physics teachers. Employing a mixed-method approach with an embedded experimental design, the investigation employs a reasoned multiple-choice instrument comprising 15 questions. Analysis of the results reveals a noteworthy 48.38% increase in the average mastery of concepts between the pre-test and post-test, yielding an N-gain value of 0.63. Statistical scrutiny through paired sample t-tests corroborates significant disparities between pre-test and post-test scores, evidenced by a t_{count} (16.28) exceeding the critical t_{table} value (1.69) with a two-tailed significance value of 0.00. Furthermore, effect size analysis underscores the substantial impact of the ADI-assisted virtual laboratory learning model on augmenting students' conceptual mastery. This underscores the viability of employing the ADI-assisted virtual laboratory learning model to enhance pre-service physics teachers' understanding of simple harmonic oscillation concepts. However, refinement of the ADI syntax is recommended, particularly by substituting the report writing session with a learning reflection activity, without compromising the essence of ADI as an inquiry-based, argumentative learning model. It is anticipated that the outcomes of this study will influence the advancement of learning models in Indonesia, particularly the ADI paradigm.

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INTRODUCTION

In contemporary education, proficiency in a myriad of skills is imperative, prominently among them being communication skills (Afif et al., 2021; Anugerahwati, 2019; Zubaidah, 2018). Within the scientific domain, communication skills are intrinsically linked to the art of scientific argumentation, a fundamental facet of 21st-century communication competencies. This nuanced comprehension is reflected in both the learning objectives delineated in the Merdeka Curriculum and the overarching aspirations of the Merdeka Belajar-Kampus Merdeka (MBKM) initiative within higher education (Badan Standar, Kurikulum, dan Asesmen Pendidikan, 2022; Eliana & Admoko, 2020; Junaidi et al., 2020).

The cultivation of scientific argumentation finds a notable avenue through the utilization of the Argument-Driven Inquiry (ADI) learning model (Admoko et al., 2021; Hasnunidah & Wiono, 2019; Songsil et al., 2019). ADI stands as an inquiry-based instructional framework meticulously crafted to engender knowledge and foster ideation through a synthesis of laboratory engagements and collaborative discourse (Amielia et al., 2018; Bukifan & Yuliati, 2021; Cahyati et al., 2017; Demircioğlu & Ucar, 2015; Dwiretno & Setyarsih, 2018; Ginanjar et al., 2015; Hanifah & Admoko, 2019; Hasnunidah & Wiono, 2019; Irvan & Admoko, 2020; Marhamah et al., 2017; Parno et al., 2021; Sampson et al., 2011; Siahaan et al., 2019; Suliyanah et al., 2020).

However, the ADI model's extensive procedural structure often poses challenges, notably during its implementation phase, a recurring theme in scholarly discourse (Kurniasari & Setyarsih, 2017; Siahaan et al., 2019; Sulistina et al., 2018). Predominantly, the constraint of time emerges as a primary impediment to its effective deployment within educational settings, as identified by Dwiretno and Setyarsih (2018), Kurniasari and Setyarsih (2017), Marhamah et al. (2017), and Sulistina et al. (2018). Nonetheless, this constraint presents an opportunity for innovation, wherein the substitution of conventional laboratory settings with virtual laboratories emerges as a viable solution to circumvent temporal constraints and enhance the efficacy of ADI-based instruction.

A virtual laboratory serves as a digital emulation of traditional laboratory settings, encapsulated within computer software. This innovative platform replicates a spectrum of experiments typically conducted in conventional laboratories, offering interactive simulations that enable students to engage in investigative activities irrespective of time and location (Agustine et al., 2014; Aljuhani et al., 2018; Babateen, 2011; Ekasari et al., 2016; Hastuti et al., 2016; Hermansyah et al., 2015; Kapilan et al., 2021; Sari et al., 2016; Simbolon & Sahyar, 2015; Sugiana et al., 2016; Wibawanto, 2020).

The integration of virtual laboratories into educational settings offers significant advantages in terms of time, energy, and cost savings associated with preparation, utilization, and maintenance (Aljuhani et al., 2018; Billah & Widiyatmoko, 2018; Dalgarno et al., 2012; Darrah et al., 2014; Hidayati & Masril, 2019; Kapilan et al., 2021; Nurhayati et al., 2021; Simbolon & Sahyar, 2015). This compatibility renders virtual laboratories particularly conducive to complementing the ADI learning model, known for its extensive syntactic learning structure, thereby enhancing the effectiveness and efficiency of instructional endeavors.

Simple harmonic oscillation stands as a foundational concept within physics, manifesting ubiquitous applications in daily life while serving as a cornerstone for comprehending wave phenomena (Amalia et al., 2018; Aprilia et al., 2015; Boonpo et al., 2015; Dwiretno & Setyarsih, 2018; Mahen & Nuryantini, 2018; Sufahmi & Safitri, 2017; Sugara et al., 2016; Sujarwanto, 2016). Notably, it emerges as a pivotal concept in addressing the challenges posed by globalization (National Research Council, 2012). Consequently, a proficient grasp of this concept and adept application of its principles are underscored as key learning objectives within the physics curriculum framework (BSKAP, 2022).

However, past research indicates persistent difficulties among both advanced and novice students in mastering various facets of simple harmonic oscillation, particularly pertaining to graphical representations, period, frequency, and energy dynamics within spring-mass systems and pendulums (Adolphus et al., 2013; Agustina, 2016; Fauzan et al., 2021; Husniyah et al., 2016; Kurniawan et al., 2021; Oktaviana et al., 2020; Putri et al., 2017; Putri & Ermawati, 2021; Silfitri & Yusuf, 2021; Sugara et al., 2016). Given its broad scope of material coverage and relevance to real-world applications, mastering the concept of simple harmonic oscillation assumes heightened significance, particularly for prospective physics educators entrusted with imparting these fundamental principles to future students.

Proficiency in mastering concepts serves as a longstanding hallmark of success in physics education, laying the groundwork for comprehending intricate and interrelated principles (Amnirullah, 2015; Azizah et al., 2019; Furwati et al., 2017; Hermawati et al., 2017; Sofiuddin et al., 2018). This mastery not only forms the bedrock for advanced cognitive abilities but also fosters effective communication, idea classification, critical thinking, and overall cognitive enhancement (Oktaviani et al., 2017; Sari et al., 2018; Sofiuddin et al., 2018). Moreover, it underpins the capacity for engaging in scientific discourse and constructing persuasive arguments based on sound conceptual frameworks (Amin & Corebima, 2016; Amiroh & Admoko, 2020; Chen & She, 2012; Demircioğlu & Ucar, 2012; Eliana & Admoko, 2020; Kim, 2015; Marhamah et al., 2017; Puspitaningrum et al., 2018; Salsabila et al., 2019; Supeno et al., 2015; Wardani et al., 2018). Therefore, by attaining mastery of fundamental concepts, students not only acquire diverse high-level skills but also cultivate the ability to construct scientifically grounded arguments employing accurate conceptual frameworks.

Thus far, the ADI learning model has predominantly emphasized the cultivation of high-level abilities, including reasoning, critical thinking, and scientific argumentation (Admoko et al., 2021; Atqiya et al., 2021; Hidayat & Aripin, 2019; Inthaud et al., 2019; Rosidin et al., 2019; Songsil et al., 2019; Suliyanah et al., 2020). However, it's imperative to recognize that mastery of fundamental concepts also plays a pivotal role in fostering these abilities. Notably, the ADI model facilitates knowledge construction through laboratory activities and collaborative discussions, offering an apt platform for nurturing students' conceptual mastery. Nevertheless, the implementation of the ADI model is often impeded by time constraints.

The nature of physics learning materials, particularly those concerning simple harmonic oscillators, presents an ideal fit for virtual laboratory environments. These materials often involve abstract concepts and experiments necessitating ideal conditions devoid of external influences like friction. Despite this alignment, there is a notable absence of research integrating the ADI-assisted virtual laboratory learning model in classrooms to evaluate pre-service physics teachers' mastery of concepts in simple harmonic oscillation materials. Consequently, there is a keen interest among researchers to investigate whether the ADI-assisted virtual laboratory learning model can enhance pre-service physics teachers' conceptual mastery in the realm of simple harmonic oscillations.

METHOD

The present study adopts a mixed-method approach with an embedded experimental design, encompassing rigorous data collection and analysis techniques as outlined by Creswell and Creswell (2017). It integrates both quantitative and qualitative methodologies to investigate the efficacy of the Argument-Driven Inquiry (ADI)-assisted virtual laboratory learning model in enhancing the conceptual understanding of simple harmonic oscillation among pre-service physics teachers. The participant pool comprised 35 students enrolled in physics education programs, specifically targeting pre-service physics teachers, at a university situted in Central Kalimantan, Indonesia.

Table 1. Sub-material and value of r in simple harmonic oscillation (r_{11} = 0.742).

Sub-Material	Number of Question	*r*
Sub-Material 1: The motion of simple harmonic oscillation	1	0.624
	2	0.560
	3	0.606
	6	0.530
	7	0.595
Sub-Material 2: Simple harmonic oscillations of spring-mass systems	4	0.537
	8	0.598
	9	0.626
	10	0.566
Sub-Material 3: Simple harmonic oscillations in pendulums	5	0.533
	11	0.482
	12	0.336
	13	0.561
	14	0.292
	15	0.510

Table 2. N-gain criteria (Sutopo & Waldrip, 2014).

N-Gain $\langle g \rangle$	Criteria
$\langle g \rangle < 0.25$	Low
$0.25 \leq \langle g \rangle < 0.45$	Lower – Medium
$0.45 \leq \langle g \rangle < 0.65$	Medium – Upper
$\langle g \rangle \geq 0.65$	High

The research employed a concept mastery test, designed based on prior studies addressing the challenges encountered in comprehending simple harmonic oscillation. This test consisted of 15 multiple-choice questions, crafted to gauge participants' understanding. Quantitative data were derived from participants' responses to the multiple-choice questions, while qualitative data were extracted from their justifications. The validity and reliability of the test were assessed using statistical techniques, specifically the Product Moment Correlation and Spearman-Brown (r_{11}) analysis conducted via SPSS. The calculated coefficient correlation (r) exceeded the critical value $r_{count} > r_{table}$ (0.201), indicating satisfactory validity. Moreover, the reliability coefficient (r_{11}) demonstrated consistency across sub-materials, as delineated in Table 1, presenting a comprehensive overview of the research findings.

Quantitative data underwent analysis employing descriptive statistics and a normalized gain test, as proposed by Hake (2002) and Sutopo & Waldrip (2014), respectively. The normalized gain test was utilized to ascertain the extent of improvement between pre-test and post-test scores. The interpretation of the obtained N-gain value was guided by predefined criteria, facilitating a comprehensive assessment of the effectiveness of the intervention.

Additionally, a difference t-test analysis and an effect size test were conducted to evaluate disparities between pre-test and post-test scores and gauge the impact of implementing the ADI-assisted virtual laboratory learning model on the conceptual mastery of pre-service physics teachers (Morgan et al., 2019; Morgan et al., 2004). Concurrently, qualitative data, specifically participants' justifications, underwent reduction and triangulation to augment the robustness of quantitative findings.

RESULTS

The findings demonstrate a notable enhancement in the comprehension of simple harmonic oscillation principles among pre-service physics educators, as evidenced by the considerable rise in pre-test to post-test scores. Additionally, this improvement is corroborated by the elevated average scores achieved by students in the domain of simple harmonic oscillations. Detailed descriptive analysis data is presented in Table 3 for reference.

Table 3. The result of descriptive analysis and N-gain.

	Sub-Material 1			Sub-Material 2			Sub-Material 3			Simple Harmonic Oscillation		
	Pre	Post	$\langle g \rangle$	Pre	Post	$\langle g \rangle$	Pre	Post	$\langle g \rangle$	Pre	Post	$\langle g \rangle$
N	35	35		35	35		35	35		35	35	
Min.	0	7	0	0	7	0.25	0	0	0	0	40	0.27
Max.	27	33	1	13	27	1	27	40	1	67	100	1
Mean	10.69	28.71	0.77	4.29	20.43	0.72	7.49	21.49	0.44	22.31	70.69	0.63
Std. Dev.	8.91	5.79	0.32	4.59	6.04	0.25	6.36	10.51	0.31	14.29	16.66	0.20

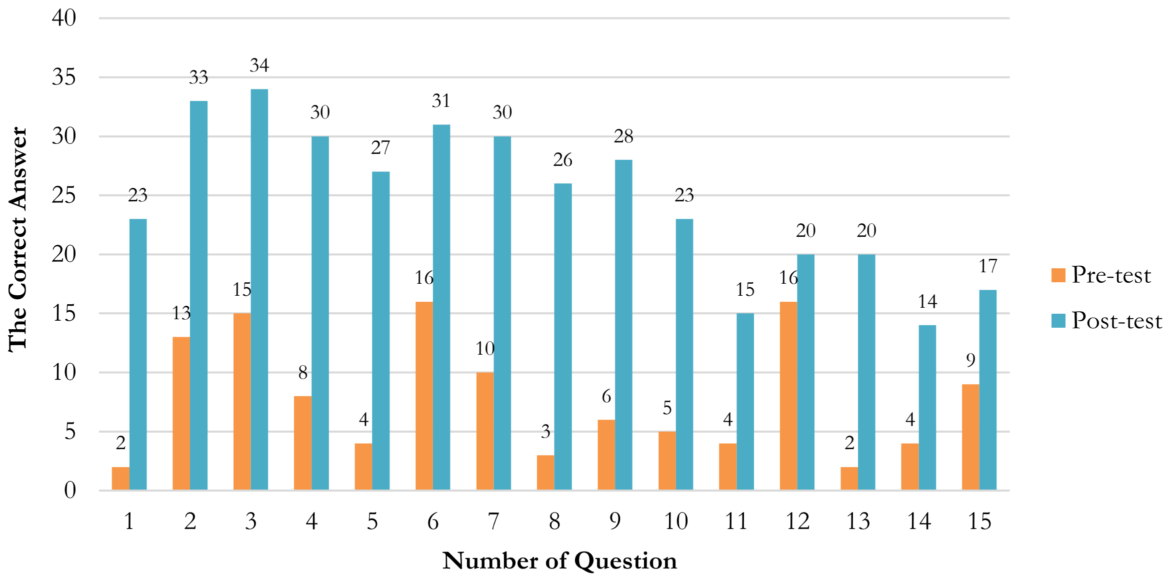
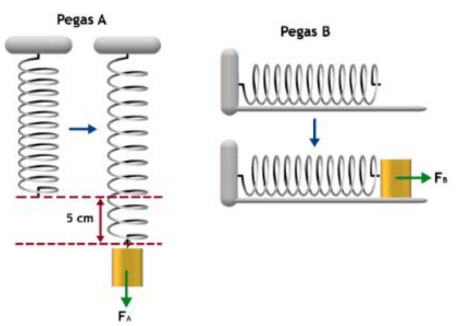


Figure 1. The distribution of correct answers in simple harmonic oscillation mastery concepts.

Table 3 illustrates a discernible augmentation across various metrics, including minimum, maximum, and average pre-test and post-test scores within sub-materials, as well as an overarching improvement in understanding simple harmonic oscillation concepts. Notably, the extent of this advancement is quantified through the average normalized gain (N-gain) values, with values of 0.77, 0.72, and 0.44 observed for different sub-materials, indicative of high and lower-medium categorizations, respectively. Moreover, the N-gain value of 0.63 attributed to simple harmonic oscillation material falls within the upper-medium category, further emphasizing the substantive progress achieved. This enhancement is further underscored by the escalation in the number of correct responses to individual questions, as depicted in Figure 1.

Figure 1 exhibits a notable increase in the distribution of correct responses across all questions, with an average increment of 16.8 correct answers observed. Particularly striking is the substantial growth observed in question number 8 (Figure 2), where the disparity between the number of pre-service physics teachers answering correctly during the pretest and posttest amounted to 23 students. Question number 8 pertains to the spring-mass system within the realm of simple harmonic oscillations and is designed to evaluate comprehension of the concept of restoring force within such a system, both when the arrangement is horizontal and vertical.

Table 4 illustrates the distribution of student responses to question 8 as a percentage. In the pre-test phase, a substantial majority of students opted for option A, indicating a belief that the force acting on spring A exceeded that of spring B. This trend suggests an incomplete grasp of the concepts pertaining to restoring force and equilibrium position within the spring-mass system among pre-service physics teachers. However, following instruction utilizing the ADI approach aided by a virtual laboratory learning model, there was a noteworthy improvement in the percentage of students selecting the correct response (answer C) during the post-test, with a marked increase of 65.72%. This discernible shift indicates an enhanced understanding among students regarding the concepts of restoring force and equilibrium position within the spring-mass system subsequent to the instructional intervention.



Two identical springs (spring A and spring B) are placed in different positions (without friction), as shown in the picture. When given an object of the same mass, spring A increases in length by 5 cm while spring B remains.

If both objects are pulled 6 cm and released simultaneously, then the magnitude of the restoring force (resultant force) on both objects after release is...

A. $F_A > F_B$
B. $F_A < F_B$
C. $F_A = F_B$
D. $2F_A = F_B$
E. $F_A = 2F_B$

Figure 2. Question number 8.

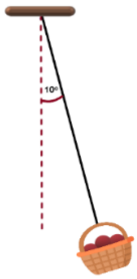
Table 4. Response to question number 8.

Response	Pre-test		Post-test	
A. $F_A > F_B$	60.00%	(21 students)	17.14%	(6 students)
B. $F_A < F_B$	17.14%	(6 students)	5.71%	(2 students)
C. $F_A = F_B$	8.57%	(3 students)	74.29%	(26 students)
D. $2F_A = F_B$	5.71%	(2 students)	0.00%	(0 students)
E. $F_A = 2F_B$	8,57%	(3 students)	2.86%	(1 students)

During the pre-test, students encountered difficulty in answering question number 13, with only a small fraction providing correct responses. Question number 13 pertains to the period of the pendulum system and seeks to analyze the effects of changing mass on the pendulum's period (Figure 3). Table 5 depicts the distribution of responses to question 13 as a percentage. During the pre-test phase, merely two students were able to provide correct responses to this question. Notably, there was a preference among students for option D, indicating a belief that the period would double if the mass doubled. This suggests a lack of mastery concerning simple harmonic oscillations, particularly in understanding the relationship between period and mass in pendulum oscillations. However, following instruction, students demonstrated improvement in their ability to answer this question accurately. Post-learning, students displayed a comprehensive understanding of the concept of simple harmonic oscillations in a pendulum, as evidenced by a notable increase of 51.43% in correct responses.

The results of the descriptive analysis reveal that the skewness value of both the pre-test and post-test data is less than 1.00, indicative of a normal distribution (Morgan et al., 2019; Morgan et al., 2004). Consequently, a paired sample t-test was conducted to assess the difference between pre-test and post-test scores. The outcomes of this test, as presented in Table 6, indicate that the calculated *t*-value (16.28) surpasses the critical *t*-value (1.69), with both datasets exhibiting a significance level of 0.00. This signifies a statistically significant disparity between pre-test and post-test scores, affirming the efficacy of the ADI-assisted virtual laboratory learning model in enhancing pre-service physics teachers' comprehension of simple harmonic oscillation concepts.

Furthermore, the impact of the ADI-assisted virtual laboratory learning model on augmenting students' mastery of simple harmonic oscillation concepts can be further elucidated through an examination of effect size. The effect size analysis yields a d value of 3.13, indicating a substantial improvement in students' understanding of simple harmonic oscillation concepts following the implementation of the ADI-assisted virtual laboratory learning model.



A basket of mass m is hung on a rope to form a swing. The swing oscillates without friction with period T. If several objects are put into the basket until their mass becomes two times bigger, then the period of oscillation becomes …

A. $\frac{1}{4}T$
B. $\frac{1}{2}T$
C. T
D. $2T$
E. $4T$

Figure 3. Question number 13.

Table 5. Response to question number 13.

Response	Pre-test		Post-test	
A. $\frac{1}{4}T$	20.00%	(7 students)	11.43%	(4 students)
B. $\frac{1}{2}T$	20.00%	(7 students)	17.14%	(6 students)
C. T	5.71%	(2 students)	57.14%	(20 students)
D. $2T$	34.29%	(12 students)	11.43%	(4 students)
E. $4T$	20.00%	(7 students)	2.86%	(1 students)

Table 6. The result of *t*-test and effect size.

Topic	*t*-test		Effect Size (*d*)
	t_{count}	Sig. (2-tailed)	
Simple harmonic oscillation	16.28	0.00	3.13

DISCUSSION

This study demonstrates the efficacy of the Assisted Discovery Inquiry (ADI) virtual laboratory learning model in enhancing the comprehension of simple harmonic oscillation concepts among pre-service physics teachers. Through structured discussions and hands-on experimental activities within the classroom environment, students significantly improve their grasp of these fundamental principles. The ADI framework facilitates a progressive learning approach, wherein students engage in task identification, inquiry-based investigations, argumentation, and reflective discussions to tackle given problems. Each component of the ADI model serves to guide students in the discovery, exploration, comprehension, and reconstruction of their conceptual understanding of simple harmonic oscillation phenomena through collaborative group discussions and empirical exploration. This approach is corroborated by findings from prior research (Parno et al., 2021; Salsabila et al., 2019), which underscore the ADI model's capacity to refine conceptual understanding by empowering students to design experiments and articulate arguments. Notably, the inclusion of argumentation sessions within the ADI framework plays a pivotal role in fostering critical thinking, enhancing communication skills—both verbal and written—and consolidating conceptual mastery (Demircioğlu & Ucar, 2012; Ginanjar et al., 2015; Irvan & Admoko, 2020; Marhamah et al., 2017; Rosidin et al., 2019; Sampson et al., 2011; Sulistina et al., 2018).

Within the ADI learning model, the virtual laboratory assumes a pivotal role in facilitating the mastery of simple harmonic oscillation concepts. By offering harmonic oscillation experiments under ideal conditions, the virtual laboratory ensures that students' conceptualizations align closely with theoretical expectations. This alignment aids students in refining their conceptual frameworks and rectifying any misconceptions stemming from their everyday experiences. Moreover, the virtual laboratory furnishes an array of tools and materials without limitations, thereby enabling students to engage in diverse experiments pertaining to simple harmonic oscillations continuously. Notably, virtual laboratories possess the ability to visually represent abstract physics concepts, thereby enhancing students' grasp of these concepts while simultaneously augmenting their problem-solving aptitude, critical thinking, and creativity (Billah & Widiyatmoko, 2018; Gunawan et al., 2015; Hermansyah et al., 2015; Hidayati & Masril, 2019; Kapilan et al., 2021; Simbolon & Sahyar, 2015). Research by Hermansyah et al. (2021) and Kapıcı & Coştu (2023) further corroborates the significant role of virtual laboratories in concept development and the cultivation of inquiry skills.

The Motion of Simple Harmonic Oscillation

The sub-material encompasses questions pertaining to the displacement, velocity, and acceleration of simple harmonic oscillations, often presented graphically. Walker et al. (2022), along with several preceding studies (Raflesiana et al., 2019; Syarqiy & Admoko, 2017), have highlighted students' challenges in discerning variables within graphical representations, formulating relevant equations, and drawing conclusions from simple harmonic oscillation graphs. This difficulty was further evidenced in the pre-test phase of the study, wherein students encountered obstacles in identifying graph variables and utilizing them to resolve problems.

Following instruction employing the ADI-assisted virtual laboratory model, notable improvements were observed among students. They demonstrated enhanced comprehension of simple harmonic oscillation principles, successfully identifying requisite variables depicted in the graphical representations. Moreover, students exhibited proficiency in reconstructing equations to address problems and drawing informed conclusions based on graph analyses.

Simple Harmonic Oscillations of Spring-Mass System

The sub-material encompasses problems concerning the period, frequency, restoring force, and potential energy within the spring-mass system. During the pre-test phase, students encountered challenges in solving these questions, particularly when dealing with graphical representations, restoring forces, and energy concepts. This struggle echoes findings from prior studies by Aprilia et al. (2015), Khairunnisa et al. (2018), Putri et al. (2017), Raflesiana et al. (2019), and Sugara et al. (2016), which reported similar difficulties among students.

One notable instance was observed in question number 7, where many students erroneously chose option A. This misconception stemmed from the assumption that spring A, positioned vertically, is influenced solely by gravity, leading students to believe that the restoring force on spring A (F_A) would surpass that of spring B (F_B), positioned horizontally ($F_A > F_B$). However, students failed to grasp that both spring A and spring B reach equilibrium positions when a mass is applied without displacement. Consequently, when displaced by the same magnitude, the restoring force in both cases remains equal.

Following the instructional intervention, students demonstrated improved understanding of the equilibrium position concept within the spring-mass system. They comprehended that when a mass is suspended from a spring, the system reaches an equilibrium state where no external forces act upon it. Additionally, students grasped the relationship between displacement, spring constant, and restoring force, as encapsulated by the equation $F = -k \cdot x$. This understanding was bolstered through the utilization of the ADI-assisted virtual laboratory learning model, wherein visualization of equilibrium states, the forces exerted on the mass-spring system, as well as the direction of displacement and resultant force, proved instrumental in enhancing comprehension of sub-materials pertaining to the mass-spring system.

Simple Harmonic Oscillations in Pendulums

The questions within this sub-material pertain to graphical representations, displacement, restoring forces, periods, and energy within pendulum systems. To effectively solve these problems, students need to discern the variables affecting displacement and period, identify the forces at play, and comprehend energy transitions within pendulum dynamics. During the pre-test phase, students encountered challenges, notably in addressing question number 13, which pertained to the relationship between a pendulum's mass and its period.

In tackling this problem, students must grasp that the period or frequency of a pendulum remains solely influenced by the length of the string and the acceleration due to gravity. This insight is pivotal for understanding the fundamental principles governing pendulum motion ($T = 2\pi\sqrt{\frac{l}{g}}$ or $f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$).

Students often harbor misconceptions regarding the period or frequency of a pendulum, as evidenced by their responses to question number 13. Many students erroneously believe that the mass of the pendulum affects its oscillation time. This misunderstanding is reflected in the responses of students who chose options D and E, presuming that increasing the mass introduces resistance to the pendulum's motion, consequently prolonging its oscillation period. Conversely, students who selected options A and B held a contrary notion, suggesting that greater mass leads to swifter movement and shorter oscillation times. This pattern of erroneous thinking aligns with findings from studies conducted by Putri and Ermawati (2021) and Amalia et al. (2018), wherein it was observed that students commonly attribute the pendulum's mass to its motion characteristics, including period and frequency.

Before engaging with the ADI-assisted virtual laboratory model, students held the misconception that the mass of a pendulum influences its period. However, through experimental investigations conducted using the virtual laboratory and guided discussions facilitated by the ADI-assisted virtual laboratory learning model, students came to the realization that alterations in mass do not affect the pendulum's period. This understanding is supported by the fundamental equation governing the period and frequency of a pendulum, which solely relies on the length of the string and the acceleration due to gravity.

Overall, the ADI-assisted virtual laboratory learning model demonstrates the potential to enhance the mastery of simple harmonic oscillation concepts among pre-service physics teachers. This improvement is achieved through the construction of concepts via collaborative discussions and the design of experiment activities utilizing the virtual laboratory. The virtual laboratory component within the ADI framework proves constructive in rendering learning sessions more effective and efficient. However, it is essential to acknowledge that the implementation of a virtual laboratory necessitates prior familiarity and training, as some students may encounter difficulties in operating it, thus requiring additional adaptation time. Furthermore, the reliance on an internet connection or electricity for the virtual laboratory poses limitations, rendering it inaccessible in environments lacking these facilities.

Moreover, the syntax employed for generating reports and conducting double-blind reviews within the ADI learning model consumes considerable learning time. Therefore, future endeavors should aim to streamline this process by incorporating simpler writing activities, such as reflection exercises on completed learning sessions or straightforward individual reports. It is imperative to note that these adaptations should not compromise the essence of the ADI learning model, which prioritizes argument development through the inquiry process. Consequently, the implementation of this learning model holds promise for high school settings, offering a more efficient and effective use of instructional time.

CONCLUSION

The utilization of the ADI (Argument-Driven Inquiry) assisted virtual laboratory learning model represents a promising approach for enhancing the grasp of simple harmonic oscillation concepts among pre-service physics teachers. Evident enhancements in conceptual mastery are discernible through the comparison of pre-test and post-test averages, exhibiting a notable increase of 48.38% alongside an N-Gain value of 0.63, categorizing within the upper-medium range. Statistical analysis, specifically the paired sample t-test, underscores the significant disparity between pre-test and post-test scores, with a calculated tcount (16.28) surpassing the critical ttable value (1.69), resulting in a two-tailed significance value of 0.00. Furthermore, effect size assessment underscores the substantive influence of the ADI-assisted virtual laboratory learning model on pre-service physics teachers' conceptual mastery. This influence is primarily facilitated through the process of concept construction inherent in the discussion and inquiry phases of the ADI model within the virtual laboratory environment. Additionally, findings suggest a tangible impact of virtual laboratory integration on the efficacy of the ADI learning approach and the process of concept construction among pre-service physics educators. It is worth noting that the scope of this study is confined to the mastery of simple harmonic oscillation concepts. Thus, future investigations are encouraged to explore diverse high-order cognitive abilities across various physics domains that may be cultivated through the implementation of the ADI-assisted virtual laboratory learning model.

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AUTHOR CONTRIBUTIONS

All authors contributed to the conception and design of the study, data collection, analysis, interpretation, writing, and revision of the manuscript. The final version of the manuscript was approved by all authors.

CONFLICT OF INTEREST STATEMENT

Regarding the research, writing, and publication of this paper, the authors state they have no competing interests.

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