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Enhancing Students' Conceptual Understanding of Elasticity Through IoT Based Real Time Multiple Representations: A Quasi Experimental Study

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Abstract

The students have had problems in forming a proper understanding of the concept of elasticity in terms of integrating numbers, graphs, and mathematics in understanding the relationship between force and deformation. This study was designed to investigate the effect of IoT-based real-time representation on the conceptual understanding of elasticity. A quasi-experimental design was used by taking a non-equivalent control group from eleventh graders. While the experimental group went through an IoT-based practicum in which they were able to visualize real-time numerical and graphical representations, the control group followed the standard practice in the laboratory. The test of conceptual understanding of the students involved the use of a diagnostic reasoning instrument, and the analysis of covariance was applied in analyzing the gathered data. The results showed that the use of IoT-based representation improved students' conceptual understanding of elasticity more than traditional classroom learning.

Keywords: conceptual understanding, elasticity learning, Internet of Things, multiple representations, physics education.

INTRODUCTION

Knowledge of elasticity is crucial in the study of physics at the secondary school level since it forms the foundation for understanding other concepts, such as material science and waves (Susanto, Husen, Lajis, Lestari, & Hasanah, 2021). Nevertheless, research shows that students have challenges building a conceptual framework of elasticity, especially when connecting force, elongation, and spring constant (Banda & Nzabahimana, 2021). Most learners apply Hooke's law mathematically by simply plugging values into equations without understanding the true nature of the variables. Consequently, learning results in shallow comprehension and misconceptions (Net, Marga, Ciliwung, & No, 2022).

In terms of theory, for physics to be understood meaningfully, students should coordinate various representations, including verbal descriptions, mathematics, graphics, and actual physics (Martoredjo & Thomas, 2023). The theory of multiple representations states that conceptual knowledge arises through the ability to transfer and relate information in various representations (Zou, Xue, Jin, Huang, & Li, 2024). However, the success of multiple representations is contingent upon instructional design (Liu, Wu, & Chiou, 2022). In terms of cognitive load theory, the lack of integration between different representations leads to split-attention effects and increases extraneous cognitive load, which negatively impacts conceptual learning (Hidayati & Mawardi, 2020). Therefore, multiple representations need to be integrated in a manner that enhances cognitive efficiency (Harwati & Rokhmat, 2021).

Regarding the use of elasticities in class lessons, experiments are typically carried out by employing traditional devices, manual measurements, and separate data entry (Gad, Haggag, Nashat, & Barakat, 2022). This disjunctive approach inhibits learners' access to firsthand connections between practical data and graphs or mathematical expressions (Bharadwaj, Agarwal, Chamola, Member, & Lakkaniga, 2021). Past research indicates that delayed visualization and inadequate immediate feedback constrain learners' capacity to build cohesive conceptual comprehension (Gurmu, Tuge, & Hunde, 2024). There is thus a necessity for learning aids that can facilitate simultaneous data display and representation (Ruf, Zahn, Roos, & Opwis, 2023).

Advances in digital technology, especially the development of the Internet of Things (IoT) technology, present potential possibilities to mitigate these drawbacks (Syuhendri, 2020). For instance, in the field of physics instruction, IoT-based techniques make it possible to acquire real-time data and visualize it instantly, turning experimental outcomes into graphical and numerical data (Bouchée, de Putter-Smits, Thurlings, & Pepin, 2022). Previous studies confirm the positive effect of using digital devices and microcontrollers on enhancing measurement accuracy and learners' motivation (Odoh, Akpomedaye, Ekruyato, & Godwin, 2023). Real-time visualization has also been found useful for making students grasp functional connections between different physical quantities (Amangeldy, Imankulov, Tasmurzayev, & Imanbek, 2025).

There are multiple strengths of using IoT technology for physics laboratory teaching. For one thing, the IoT systems facilitate automated data collection and make experimental data available instantly in numbers and graphs. Such an ability will contribute to more successful conceptual integration (Bouchée et al., 2022). Additionally, the IoT system enhances the precision of measurement processes and decreases errors that students can make when making calculations (Odoh et al., 2023).

It is important to point out several issues associated with implementing IoT technology for educational purposes. The introduction of IoT necessitates the presence of proper technological resources, such as sensors, microcontrollers, and connectivity. Moreover, instructors should possess adequate levels of technological literacy to incorporate IoT systems into the process of teaching. Otherwise, such technological tools can simply act as measurement tools, but not learning devices (Syuhendri, 2020).

Nevertheless, many studies previously conducted have emphasized more on the aspects of technical feasibility and validity of IoT-based practicum apparatus, including sensor accuracy and system stability (Yurtyapan, 2021). Studies examining the use of IoT as a cognitive tool that helps students construct multiple real-time representations and explore the influence of the tool on students' conceptual understanding are few (Erlina, Prayekti, & Wicaksono, 2022). Additionally, studies utilizing well-designed experiments to investigate the role of simultaneous multiple representations on students' cognitive processes are very scarce (Raefat, Garoum, Laaroussi, & Chihab, 2021). This scenario is a signal of a research gap concerning representation-based physics learning using IoT technology (Schoß, Becker, Keßler, Leineweber, & Wolf, 2022).

This study aims to conduct an analysis of the effect of using IoT-based practicum devices that incorporate dual representations in real time on high school students' conceptual understanding of elasticity. By utilizing a quasi-experimental research design, the study hopes to contribute empirical findings to the role of IoT technology as a cognitive tool for representation-based physics learning.

METHOD

In this study, a quasi-experimental design with the use of a non-equivalent control group design was used (Campbell & Stanley, 1963) was applied. Two intact eleventh-grade classes served as experimental and control groups (Sugiyono, 2021). IoT-based elasticity practicum with the implementation of real-time multiple representations was an independent variable, while conceptual understanding of elasticity was a dependent variable (Creswell, 2014).

The sample included 60 students, aged 16-17 years old, from a public senior high school. The sample was divided into two groups of thirty students each. The groups were instructed by one physics teacher to avoid variability in instructions. The treatment lasted three sessions within the elasticity laboratory sessions.

Conceptual understanding was assessed using a diagnostic test comprising reasoned multiple-choice questions. The questions were about force and elongation relationships, understanding of Hooke's law, spring constant calculation, and graph interpretation. The test blueprint is given in Table 1. It underwent content validation by three experts in physics education. Reliability analysis using Cronbach's alpha resulted in a coefficient of 0.82.

The experimental group engaged in elasticity experiments using an Internet of Things (IoT)-based system that featured sensors for measuring force and displacement. During the measurements, the system generated numbers and visualized graphs at the same time. The control group performed traditional laboratory tasks requiring manual measurement and late construction of graphs. The two groups received the same learning goals and instructions. The learning syntax applied in the experimental and control groups is shown in Table 2.

Data were processed both descriptively and inferentially. Before the hypotheses were tested, normality (Shapiro-Wilk) and homogeneity of variance (Levene's test) were tested. ANCOVA was used to determine whether there was a significant difference between the two groups, using post-test scores as dependent variables and pre-test scores as covariates. Partial eta squared was employed in interpreting the effect size. Normalized gain (N-gain) was also calculated.

Table 1. Blueprint of Conceptual Understanding Test

Indicator	Concept Assessed	Item Number
Force–elongation relationship	Elasticity concept	1–2
Interpretation of Hooke's Law	Conceptual understanding	3–4
Determining spring constant	Mathematical relation	5–6
Interpreting the force–elongation graph	Graphical representation	7–9
Predicting deformation behavior	Concept application	10–12

RESULT AND DISCUSSION

In order to further clarify the instructional treatment employed in the current research study, the learning syntax utilized in both groups is provided in Table 2.

Table 2. Learning Syntax in Experimental and Control Classes

Phase	Experimental Class	Control Class
Introduction	The teacher introduces the IoT-based apparatus	The teacher explains the elasticity concept
Experiment	Students experiment using IoT sensors	Students perform manual measurement
Data analysis	Real-time graphical visualization	Manual data recording
Discussion	Interpretation of digital graphs	Discussion of calculated results
Conclusion	Conceptual reflection	Summary of experiment

From Table 2 above, the experimental group was characterized by a strong focus on the integration of numbers and graphs simultaneously throughout all phases of the learning process. Specifically, at the introduction phase, learners were introduced to the IoT-based equipment that was used to display force and displacement data visually at the same time. Similarly, at the experiment phase, the use of IoT sensors allowed the learners to view changes in variables and their corresponding graphs simultaneously.

By contrast, in the control group, the conventional procedure involved collecting data, recording results, and plotting graphs separately. It is possible that such a separate procedure led to a delay in identifying the functions among the variables. Thus, the primary difference in learning syntax between the two groups is related to the immediacy of representation – the experimental group was exposed to simultaneous data-graph construction, whereas the control group was exposed to delayed representation. Such a difference is important from a pedagogical point of view since real-time representation can facilitate faster conceptual.

Before the treatment phase, there was a pretest that was conducted to test whether the concepts related to elasticity were equally understood by the students. The pretest and posttest data results of the two groups are presented in Table 3.

Table 3. Mean Pretest and Posttest Scores of Students' Conceptual Understanding

Groups	Pretest (Mean ± SD)	Posttest (Mean ± SD)
Experiment	24.80 ± 2.81	27.50 ± 2.22
Control	25.20 ± 3.01	25.60 ± 3.21

The pretest mean-scores of the experimental and control groups presented in Table 3 were statistically equal. Thus, it can be stated that there is no statistically significant difference between the pretest mean scores of the experimental and control groups ($p > 0.05$). Hence, before the intervention, both groups had equal levels of baseline conceptual understanding. The equality of the groups' conceptual understanding is important for increasing the internal validity of the research design.

On the other hand, the control group was subjected to a traditional laboratory protocol where the students themselves measured force and elongation, tabulated the results, and then plotted graphs. This step-by-step method created a time gap between the collection of data and its interpretation, thus restricting chances for instant integration of concepts. Before the ANCOVA test, the necessary assumption tests were carried out, namely the tests for normality and homogeneity of variance, and their outcomes are shown in Table 4.

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Table 4. Results of Prerequisite Tests

Test	Groups	Sig. (p)	Verdict
Normalitas (Shapiro-Wilk)	Eksperiment	0.67	Normal
	Control	0.66	Normal
Homogenitas (Levene)	·	0.36	Homogeneous

Shapiro-Wilk normality test confirmed that both groups had normally distributed posttest scores, as their significance values were greater than 0.05. In addition, Levene's test demonstrated that the variance among groups was equal. Thus, all prerequisites for conducting ANCOVA analysis were met.

To evaluate the impact of the intervention and control for pre-existing knowledge, ANCOVA analysis was performed, where posttest scores were used as the dependent variable and pretest scores were the covariate. The results are presented in Table 5.

According to ANCOVA analysis results, there is a statistically significant influence of instructional treatment on posttest scores, $F(1,57) = 7.87$, $p = 0.007$, with the effect size being moderate (partial eta squared = 0.121). Thus, the results can be considered educationally significant. The covariate did not significantly influence posttest scores ($p > 0.05$).

Table 5. ANCOVA Results

Source of Variance	Sum of Squares	df	F	P	Partial η^2
Covariate (pretest)	19.30	1	2.60	0.113	0.043
Groups	58.48	1	7.87	0.007	0.121
Residual	42.40	57			

The statistically significant result obtained through the ANCOVA technique implies that the inclusion of IoT-based real-time multiple representations significantly enhanced the students' comprehension of the concept of elasticity. The medium effect size of $\eta^2p = 0.121$ implies that the method not only shows statistical significance, but it also has some educational importance, especially in the classroom setting. This means that real-time visualization of the relation between the applied force and the displacement will enable the students to interpret graphically and relate it physically more efficiently compared to the traditional method.

In order to determine the extent of improvement within the two groups, the N-gain analysis was performed. Table 6 displays the findings.

Table 6. N-Gain Comparison Between Groups

Groups	N-gain	Category
Eksperiment	0.72	High
Control	0.39	Medium

This study seeks to test the impact of using multiple representations in real-time within IoT for improving students' concept of elasticity. Based on the results from ANCOVA and N-gain, we can conclude that the research question is addressed affirmatively. Students who had undergone the IoT-based practicum showed significantly better conceptual gains as opposed to those undergoing conventional teaching.

The learning process for the experimental group used a real-time integration of representational methods in the experimental process. Students witnessed the relation between force and elongation through graphical representations that were automatically generated. Through this method, students were able to analyze the functions directly through representation during the experimental procedure. On the other hand, the control group was subjected to the traditional lab experiment procedures such as measuring, recording, and constructing graphs. According to Lore, Lee, Pallant, and Chao (2024)it is evident that delayed constructivism hinders pattern recognition.

It can therefore be concluded that the use of real-time integration of numerical and graphical representations plays a key role in aiding conceptual changes. The experimental group, unlike the control group that was subjected to a conventional practicum process, witnessed an increase in force and graphical patterns simultaneously.

With regards to cognitive load, automation of data gathering lessened extraneous cognitive loads due to manual calculation and graph construction. Students have been provided with enough mental energy to focus on conceptualization. This effect is supported by cognitive load theory, which states the importance of reducing superfluous processes to aid effective learning.

The results from this study are compatible with existing literature on how the use of multiple representations aids in conceptual understanding of physics among students (Lore et al., 2024). Dynamic representation supports representational fluency through the ability of the learner to make significant connections between graphs, numbers, and symbols. Likewise, Amangeldy et al. (2025) found that visualization of experimental data helped the students perceive dynamic relations in their experiments. These results reveal that the integration of representations through visualization facilitates conceptual learning by directly interpreting the functional relation of experimental data.

Moreover, investigations conducted on real-time data acquisition systems have revealed that immediate feedback improves students' interpretation skills as well as their capacity to associate graphical representations with physical phenomena (Thornton & Sokoloff, 1998). Real-time data visualization allows learners to track the changes in variables while carrying out experiments and, thus, makes the process more conceptually oriented. Thus, building on existing evidence, the current investigation seeks to prove that IoT-based real-time multiple representations not only increase the level of representation but also contribute to achieving medium-sized learning effects.

Contrary to existing literature, which predominantly considers simulation as the main means for improving visualization, the current research highlights the importance of real-time empirical experiments facilitated by IoT.

The findings of the current research show that using IoT-based real-time multiple representations is effective for enhancing students' conceptual knowledge since there is a statistically significant difference in favor of the experiment group found via ANCOVA analysis ($p < 0.05$) and because the N-gain score was higher for the experiment group than the control group. This finding suggests that experimental group students better understand the relationship between force and elongation.

Such an improvement could be accounted for by the effect of real-time synchronization on representational coherence. Unlike previous theories, which focused on representation translation, the results of this research revealed the benefit of visualizing both representations at once in order to notice the relationships between variables instantly during an experiment. In this way, learners could develop representational coherence directly from their experience.

Concerning the work done by (Sweller, 1988) the elimination of extraneous cognitive load associated with collecting and analyzing the data contributes significantly to cognitive efficiency. Consequently, students spend less energy on procedures and pay more attention to conceptual knowledge.

Finally, the results obtained in this paper have theoretical significance since they enrich representational coherence theory. Based on the empirical evidence provided here, it could be concluded that representational coherence would be better developed through synchronizing and representing several representations in real time, thus facilitating deep conceptual reasoning by simplifying procedural activities.

Therefore, this intervention can be considered a representation scaffold that assists learners at different prior knowledge levels. The non-significance of the covariate suggests that IoT real-time visualization lowers the importance of initial graph interpretation skills and, hence, provides more equal conceptual access to physics concepts.

In light of the above, this research study proposes that IoT-based real-time representation coherence is achieved based on two mechanisms: improved representation mapping and lowered extraneous cognitive load. The new perspective expands theoretical frameworks on technology-enhanced physics teaching by explicitly accounting for the underlying cognitive processes.

With the medium effect size ($\eta^2p = 0.121$), this intervention can be considered to have practical implications for pedagogy. IoT real-time visualization tools can be considered useful pedagogical inventions in physics classes, especially where graphical function understanding is needed, such as in elasticity.

However, several limitations must be mentioned. First, this research study was conducted within one institution with a small sample. Second, only immediate posttests were administered, so no information about long-term retention could be obtained.

Future research efforts will need to conduct delayed posttests, increase sample sizes, and explore the comparative effectiveness of simulation-based methods.

CONCLUSION

The study assessed the role of practicum of elasticity based on IoT-based multiple representations on conceptual understanding. The results revealed that students who were exposed to the IoT-supported laboratory activities recorded higher levels of conceptual understanding than those exposed to the traditional practicum. After accounting for the prior knowledge, the instructional treatment had significant educational value, as evidenced by the effect size and gain in normalized values in the experimental treatment.

This result is supported by various research works that have indicated that technology-enabled multiple representations improve students' conceptual understanding in the context of a physics learning environment. For example, according to Lore et al. (2024), dynamically linked representations have been proven to boost representational fluency and conceptual integration among students. Also, Amangeldy et al. (2025) noted that real-time visualization helps learners make sense of functional relationships in laboratory experiments.

With its reduced procedural requirements and coherent representations, the system acts as a cognitive tool that enhances conceptual building among learners. This result corroborates the work carried out by Thornton and Sokoloff (1998), where they found out that a real-time data collection system improves students' understanding of the connections between graphical representations and the physical phenomena.

Based on the findings, the success of IoT-based practicum in terms of teaching the concept of Hooke's law is more than about technological innovations since it offers a way to create synchronized numeric and graphic representation of the phenomena observed in practice. Real-time synchronization seems to create better conditions for linking concepts through experiments.

The obtained results indicate that the development of laboratory equipment in physics classes requires the creation of a representational environment instead of mere focus on precise measurements. It is confirmed by the research conducted in this field before, which revealed the positive influence of representational learning environments on students' conceptual understanding (Lore et al., 2024).

When it comes to teachers, the implementation of real-time visualization tools could be beneficial in creating a context for conceptual thinking. Teachers should encourage their students to analyze graphically changing data to link the phenomenon with related physical concepts since such visual representation is proved to increase students' interpretative skills (Amangeldy et al., 2025).

Schools are recommended to invest in cost-effective IoT-based laboratory facilities since they might foster representational science learning environments. The idea is confirmed by Thornton and Sokoloff's (1998) work on real-time data acquisition systems.

Future research could focus on studying the long-term retention of real-time representational integration and its application to other topics in physics and other levels of education. Studies could also be carried out to explore the wider implementation potential of the technology in different schools.

In summary, this study presents empirical proof that IoT-supported real-time multiple representations greatly improve students' conceptual knowledge about elasticity and could be used to further develop technological laboratory activities in secondary school physics education.

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