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Analyzing Conceptual Understanding of Work and Energy: Insights for Improving Physics Instruction

[1] Nur Rahmah Sangkala, [2] Yulianti Yusal, [3] Syarful Annam, [4] Amalia Rahmadani, Ainun Najib Alfatih[5]

[1,2,3,4,5]Universitas Negeri Makassar, Makassar, Indonesia

*Corresponding Author e-mail: nurrahmah@unm.ac.id

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Abstract

This study aimed to analyse university students' conceptual understanding of Work and Energy. A qualitative descriptive approach was applied to 36 undergraduate students enrolled in the Fundamentals of Science course at Universitas Negeri Makassar during the 2025/2026 academic year. Data were collected through a written assessment consisting of eight multiple choice and one short-answer question targeting both basic and higher-order concepts. Results show that students demonstrated strong understanding of Work concepts, particularly the relationship between force, displacement, and work. However, their grasp of Energy – especially energy transformation and conservation – was limited. The average score was 75.61%, with moderate variability and a negatively skewed distribution. These findings indicate that while procedural understanding is well developed, conceptual integration remains weak. The study recommends the use of inquiry-based and representational learning strategies to strengthen students' conceptual reasoning in Work and Energy.

Keywords: *Conceptual Understanding, Physics Instructions, Work and Energy, Science Education.*

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INTRODUCTION

The ability to comprehend physics concepts is a fundamental skill for all students, servings as the basis for further learning in discipline (Sherin, 2001; Safitri & Kusairi, 2024). Constructing scientific knowledge requires organising and connecting basic concepts systematically so that students can master principles and theories. Physics concepts are numerous and interrelated, and difficulties in grasping earlier concepts can adversely affect comprehension of subsequent ones, undermining students' overall conceptual understanding (Kamilah et al., 2024)

Among these concepts, Work and Energy are particularly complex and closely connected to other physics topic. Mastery of these concepts is essential in mechanics and supports comprehension of related concepts. Students frequently find them challenging because they are meaningfully tied to natural phenomena and are practically applicable (Sabo et al., 2016: Alonzo & Mistades, 2021). Even when students succeed in solving mathematical problems, they often struggle with the underlying concepts (Pradani Putri et al., 2024).

Robertson (2023) additionally highlights how teacher's choices and curricular framing influence students' conceptual pathways for energi. At the local (Indonesian) level, descriptive studies report subbstantial rates of misconceptions and partial understanding in work and energi topics (Putri et al., 2024; Artanti, 2025), for example difficulties distinguishing between work and every, applying the dot-product definition of work, and recognizing when mechinal energy is conversed. A strong conceptual understanding is therefore crucial for building knowledge structures and enabling transfer accross new context.

Although Work and Energy can be measured quantitavely, these concepts remain abstract and theoritically demanding (Tong et al., 2025). Empirical and intervention studies show that students often solve quantitative problems procedurally without activating the underlying conceptual anchor (the work-energi theorem), and that remedial instructional designs (conceptual tasks, multiple representations, and active-learning sequences) can partially reduce – but not fully eliminate – persistent misconceptions (Samsuddin et al., 2021; Basantes-Andrade & Guevara-Betancourt, 2024). Misconception further complicates students' learning of them (Putri et al., 2024).

Accordingly, analysing students' mastery of work and energy becomes critically important for identifying learning difficulties and guiding effective teaching, which is the aim of the present study.

METHOD

This study employed a qualitative descriptive design to investigate university students's conceptual understanding of the topic Work and Energy. The research was conducted during the odd semester of the 2025/2026 academic year as part of the *Fundamentals of Science* cource at Universitas Negeri Makassar. The participants consisted of a single class of 36 undergraduates students, representing the population for this course. The participants were first-year students majoring in Mathematics Education. Most students had limited prior exposure to advanced mechanics, making them suitable for exploring conceptual understanding at a foundation level. The central focus of the research was to analyse the extent and quality of students' conceptual comprehension of Work and Energy.

Data were collected through classroom observation and a written assessment. The assessment comprised eight multiple-choice items and one short-answer question. Each multiple-choice item contained a single correct response, while the short answer question required students to match prompts with their corresponding correct answer. The multiple choice items were designed at low and moderate levels of difficulty, whereas the short-answer question was constructed to assess higher-order conceptual understanding. This structure was intended to elicit responses that reflected students understanding. Insufficient conceptual mastery would likely result in in correct answers. Tabel 1 provides an overview of the subtopics assessed under each main topic, along with the specific concepts evaluated in each question.

Tabel 1. Main topic, subtopic, and description of the concept evaluated by each question

Main Topic	Subtopic	Level	Question	Concept evaluated in the question
Work	Formula for Work	Low	1, 2	Understanding scalar nature od work; relationship between magnitude, direction, and displacement.
	Graphical Representation of Work	Low	3, 4	Conceptualization of work as the area under the F-x curve.
Energy	Potential Energy & Height	Medium	5, 6	Dependence of potential energi on position or deformation; conceptual link to force fields.
	Kinetic Energy	Medium	7, 8	Relationship between mass, velocity, and kinetic energi.
	Energy Conversion	Hard	9	Transfer between potential and kinetic energi during motion.

The instrument was developed based on a review of previous conceptual studies on work and energy (e.g., Sabo et al., 2016; Tong et al., 2023) and adapted to the local curriculum context. Content validity was established through expert judgement involving two physics education lecturers and one science pedagogy specialist. Revisions were made based on their feedback regarding conceptual accuracy, clarity of wording, and alignment with learning objectives. A pilot test with ten students outside the research sample was conducted to ensure item clarity and to estimate reliability.

RESULT AND DISCUSSION

The mean score of the students was 75.61, with a median of 77.77. The score distribution deviated significantly from normality according to the Shapiro-Wilk test (W=0.929, p=0.023). The distribution exhibited a slight negative skewness (-0.44), indicating that a greater proportion of students obtained relatively high scores, and a negative kurtosis (-0.64), suggesting a flatter-than-normal distribution. These results indicate that while most students demonstrated good conceptual understanding, performance levels varied moderately across the group.

Figure 1 displays the distribution of students’ scores. The histogram shows that most students scored between 60-89%, with the highest concentration in the 80-89% range (10 students).

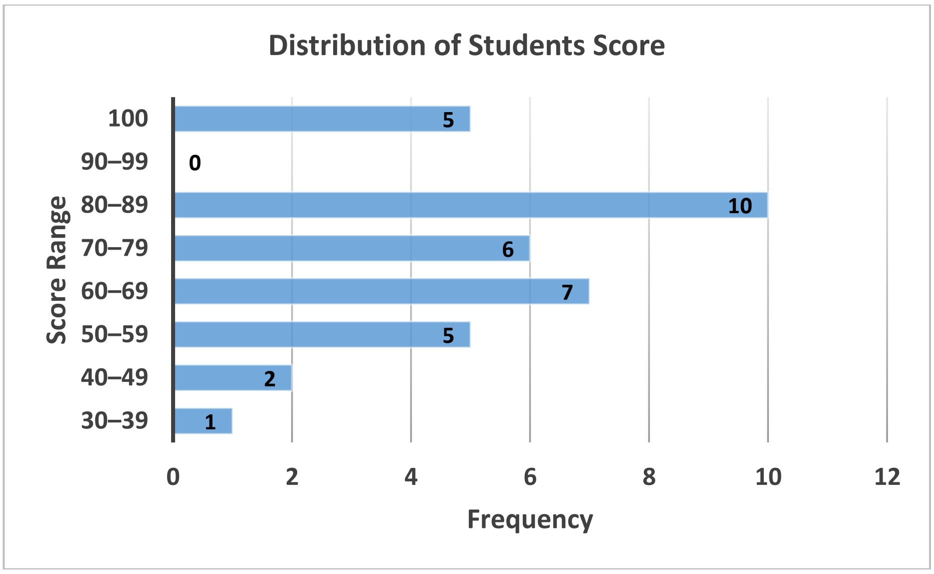

Figure 1. Distribution of Students' Scores on the Work and Energy Concept Test.

Figure 2 represent the corresponding boxlpot summarizing the distribution. The median scores of 77.77% lies above the central tendency, reflecting generally strong students performance. Given the non-normality, quartiles were used as more appropriate measure of spread. The lower quartile (Q1) was 66.66 and the upper quartile (Q3) was 88.88, resulting in interquartile range of 22.22. The interquartile range indicates moderate variablity, with scores spanning from 33.33% to 100%. No. outliers were detected, suggesting relatively consistent performance accross the sample. .

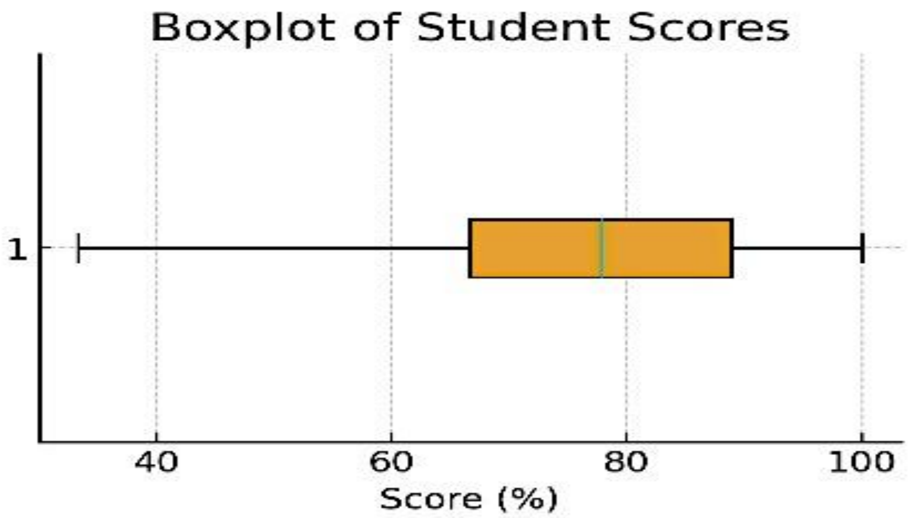

Figure 2. Boxplot of Students' Scores on the Work and Energy Concept Test.

A clooser look at the item-level analysis provides additional insight into how students performed across the two main topic – Work and Energy. The Work topic consisted of four questions (Q1-Q4) classified as easy. The proportion of correct answer for this items was high: 82%, 72%, 90% and 97%, respectively (Figure 3). These results indicate that students were able to apply fundamental relationship between force, displacement and work done effectively. These findings suggest a solid procedural and conceptual grasp of work, likely because the topic involves more concrete and directly observable phenomena. The present findings are consistent with those of Brundage, Maries and Singh (2023), who reported that students demonstrated a solid understanding of the relationship between force, displacement, and work. Similar to their study, the students in the present research appeared to rely on concrete, directly observable relationship when reasoning about work problems.

In contrast, the Energy topic included five questions (Q5-Q9), with varying difficulty levels: four medium and one difficult. The percentage of correct responses for these items were 82%, 86%, 62%, 73% and 16%, respectively (Figure 3). Although students maintained relatively high success on the medium-level items, performance dropped sharply on the final, most difficult question. This steep decline implies that while students could handle straightforward applications of energi concepts, they struggled when asked to integrate multiple ideas, such as energi transformation and conservation, within complex or abstract contexts.

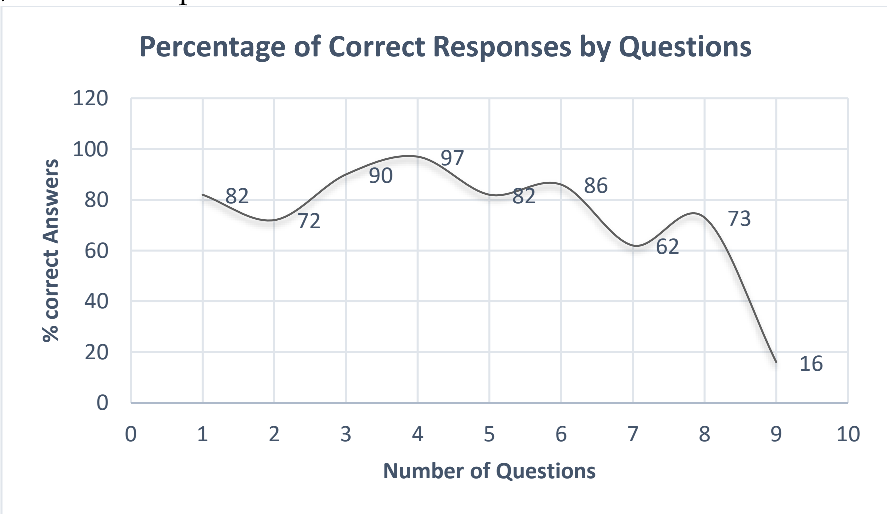

Figure 3. Percentage of Correct Answers per Question on the Work and Energy Concept Test.

This topic-wise pattern aligns with prior studies indicating that learners often demonstrate a sequential understanding of these two domains – developing proficiency with Work erlier than with Energi, which requires reasoning about energi conservation across context (Tong et al., 2023). The high performance in Work items and moderate-to-low performance in Energy items together indicate a partial conceptual mastery, where students rely on formulaic reasoning rather than conceptual integration when facing more complex energy problems.

Pedagogically, these results emphasize the importance of reinforcing conceptual linkages between work and energy. Activities that require students to visualize energi transfer – such as using energi bar charts, flow diagrams, or inquiry-based modelling – can help bridge the gap between operational understanding and theoritical reasoning (Dinsever et al., 2023; Wandi et al., 2023). Furthermore, increasing exposure to non-routine or contextual problems can strengthen students' abilty to apply the principle of energi transformation flexibly (Adisna et al., 2024).

Sources of misconceptions and the abstract nature of energy

The steep drop on the most difficult Energi items echoes findings from rigorous PER studies that document fragmation og knowledge and context dependence in students' energi reasoning (Tong et al., 2023). Energy is inherently a system-level, non-observable quantity; students therefore need to coordinate multiple representation (mathematical, pictorial, verbal) and system definitions to reason correctly. Work by contrast, can often be tied to visible motion and force-displacement relationships, which lowers representational demand and explains higher success rates on work items (Sabo et al., 2016)

Students' written responses indicate common alternative framings: treating enery as a consumable "stuff" (energi-getting/losing langauge), conflacting force with energi, or interpreting work only as "effort" rather than the dot product of force and displacement. These alternative framings are concistent with conceptual resources identified in prior studies and reflect robust intuitive ontologies that compete with scientific conceptions (Robertson et al., 2023; Sabo et al., 2016). In other words, students often possess locally coherent intuitions that permit correct procedural responses in routine situations but fail when a task required re-categorization (for instance, recognizing that internal/external work and systems boundary choices affect conservation claims).

Implications for theory and teaching

The present pattern supports conceptual-change accounts that emphasizr the need for instruction to create cognitive conflict and provide richly connected representations (Posner et al., 1982; Brundage et al., 2023). Specifically improving energi understanding rewuires teaching that: (a) *explicitly scaffolds system definition* and *representation translation* (mathematical ⇄ bar chart ⇄ verbal description), and (b) provides opportunities for students to test and revise their ontological commitments about energy (i.e., process vs substance). Work-energy bar charts and related multiple-representation strategies (Van heuvelen, 2021) have empirical support as tools that encourage students to reason about energy flows and transformations rather than only manipulating formulas.

Overall, the analysis shows that while most students demonstrated strong understanding of basic Work concepts, the comprehension of Energi – particulary in complex scenario – remains limited. The combination of a negatively skewed score distribution and topic-spesific patterns highlight the need for instructional strategies that move beyond computational fluency toward deeper conceptual reasoning and integration.

CONCLUSION

This study concludes that students exhibit a moderate level of conceptual understanding of Work and Energy. While basic procedural knowledge appears well developed, challenges persist in applying and integrating energy principles across varied contexts, indicating incomplete conceptual mastery. These findings underscore the need for instructional designs that promote conceptual reasoning through inquiry-based and representational learning design.

The study was limited by its sample size and focus on single cohort, which may restrict the generalizability of the results. Future research should include larger and more diverse samples and incporporate mixed-method approaches to explore students' reasoning patterns and misconceptions more comprehensively.

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