ANADOLU | GRADUATE SCHOOL OF EDUCATIONAL SCIENCES
AJESI
ANADOLU JOURNAL OF EDUCATIONAL SCIENCES INTERNATIONAL

**DOI: 10.18039/ajesi.1549530**

# Investigation of Pre-Service Physics Teachers' Transfer of Knowledge of the First and Second Laws of Thermodynamics to Daily Life

Sevim BEZEN[1], Celal BAYRAK[2]

**Date submitted:** *13.09.2024* **Date accepted:** *11.12.2024* **Type[3]:** *Research Article*

## Abstract

This study investigated how pre-service physics teachers transfer their knowledge of the first and second laws of thermodynamics to daily life. A case study, which is a qualitative research method, was utilised. The study participants consisted of 63 pre-service teachers studying in the Department of Physics Education. Criterion sampling, one of the purposeful sampling methods, was used in selecting participants. The data were collected through an 'opinion form' with seven open-ended questions. The data were analyzed within the framework of deductive content analysis. As a result of the research, it was determined that pre-service physics teachers had problems transferring their knowledge of the first and second laws of thermodynamics to daily life. It is thought that the source of this problem is the inability of pre-service teachers to understand basic concepts such as work, heat, enthalpy and entropy, and therefore, the failure of pre-service teachers to transfer their knowledge to daily life in a scientifically correct way due to the deficiencies in their prior knowledge. Because it is known that at the point where scientific knowledge is transferred to daily life, it is necessary to make sense of the knowledge first; to overcome this problem identified in the research, it can be suggested to create a learning environment enriched with various teaching methods, techniques and strategies. This way, pre-service teachers' knowledge can be structured, and transferring it to daily life can be supported.

***Keywords:*** Physics education, daily life, pre-service teachers, the first law of thermodynamics, the second law of thermodynamics.

***Cite***: Bezen, S., & Bayrak, C. (2024). Investigation of pre-service physics teachers' transfer of knowledge of the first and second laws of thermodynamics to daily life. *Anadolu Journal of Educational Sciences International, 15*(1), 275-293. https://doi.org/10.18039/ajesi.1549530



[1] (Corresponding author) Assist. Prof. Dr., Hacettepe University, Faculty of Education, Department of Mathematics and Science Education, Department of Physics Education, Türkiye, sevimbezen@hacettepe.edu.tr, https://orcid.org/0000-0002-0304-5314

[2] Professor, Hacettepe University, Faculty of Education, Department of Mathematics and Science Education, Department of Physics Education, Türkiye, cbayrak@hacettepe.edu.tr, https://orcid.org/0000-0002-9269-2029

[3] (If ethics committee approval is required) This research study was conducted with the Research Ethics Committee approval of Hacettepe University, dated 10.11.2020 and issue number 35853172-600.

## Introduction

Thermodynamics, a foundational science in physics and chemistry education, scrutinizes energy transformation, conservation, and alteration, with broader applications extending into disciplines like materials engineering. This energy-centric field encompasses the study of heat, temperature, and energy diffusion in matter (Kõlamets et al., 2023). Referred to as the "science of energy," the thermodynamics course imparts knowledge and fosters an understanding of energy by exploring its intricate interactions with matter. The practical implications of thermodynamics are evident in commonplace occurrences: a person sitting on an iron bench feels colder than a person sitting on a wooden bench, and a watermelon cut in half cools under the sun. Moreover, phenomena ranging from the operation of car engines and refrigerators to insulation systems, precipitation formation, and evaporation find elucidation through thermodynamic principles. The laws of thermodynamics, grounded in mathematical expressions, directly delineate the relationship between energy and its transformations, positioning thermodynamics as an extensive and pertinent field in our living environment. In addition, it is argued that many problems can be solved with thermodynamic knowledge and that thermodynamics is the key to the living environment (Asih et al., 2022).

The first law of thermodynamics posits that the energy exchanged between a system and its surroundings correlates with alterations in its internal energy. Heat, denoted as Q, signifies the energy transferred owing to temperature differentials between the system and its environment. Concurrently, energy is conveyed through work (W), independent of temperature distinctions. The 'Q-W' differential encapsulates the net energy influx into the system in both work and heat processes. This net energy remains constant in all circles from initial to final states. The evolution of net energy, irrespective of the process, elucidates alterations in the system's internal energy. Consequently, the first law discloses the totality of energy within the system and upholds physics's foundational principle of energy conservation. In its broadest context, this primary tenet asserts that energy cannot be spontaneously created or obliterated but instead transformed from one manifestation to another (Shahsavari & Boutorabi, 2023). Termed the 'regularity of entropy' at the microscopic scale and grounded in the operations of heat engines at the macroscopic level, this second law of thermodynamics stands as a preeminent and undisputed principle. Central to this law is entropy, manifesting distinct values at a process's initiation and conclusion, thereby elucidating its trajectory. Entropy, representing the degree of disorder, either increases or remains constant, signifying energy's predisposition towards disease. Processes marked by an increase in entropy are deemed irreversible, contrasting with reversible processes where entropy remains unchanged. The philosophical underpinning of this law resides in the conceptual realm of entropy (Singh & O'Neill, 2022).

The first and second laws of thermodynamics, encompassing the fundamental concepts of energy and entropy, underpin various aspects of our daily experiences, from the mechanics of car engines and refrigerators to the celestial structures of stars (Young & Freedman, 2008). Because the laws of thermodynamics are at the centre of our lives, this study aimed to examine the transfer of pre-service physics teachers' knowledge of thermodynamics' first and second laws to daily life. After the pre-service teachers' learning experiences of the first and second law of thermodynamics, an essential element of our daily life, it is curious how they explain its place and function in our daily life. At the same time, it is thought that transferring the first and second laws of thermodynamics to daily life is also related to the correct understanding of science and technology. The transfer of scientific knowledge about thermodynamics' first and second laws to daily life shows that science can be used actively and that the individual observes and interprets his/her environment better (Kleidon, 2023). In this context, when the literature related to the teaching of thermodynamics was examined, it was found that it was generally stated in the studies that the thermodynamics course was perceived as a challenging course by students and that students had difficulty understanding the laws of thermodynamics (Budi Bhakti et al., 2022; Bajracharya et al., 2019; Brown & Singh, 2022). It was also observed that educators stated that teaching thermodynamics courses is challenging, and students have problems in making sense of the information about the laws of thermodynamics (Finkenstaedt-Quinn et al., 2020). Difficulties in learning the basic concepts of thermodynamics were in a study by Loverude, Kautz, and Heron in 2002. Loverude et al. (2002) examined students' conceptual understanding of the first law of thermodynamics. The study discussed how students associate the first law with the adiabatic compression of an ideal gas. As a result of the study, it was found that students could not make sense of the first law, had problems explaining the concepts of work and energy, and failed to distinguish between the concepts of heat, temperature, work and internal energy. Similarly, Kautz et al. (2005) found that students had problems with the ideal gas law and could not explain the concepts of pressure, volume and temperature. Meltzer (2004), one of the essential names in the field of thermodynamics, stated that there were learning difficulties in the concepts of heat, work and internal energy and that the first law could not be used effectively. Most studies emphasised that pre-service teachers had difficulties in making sense of the first law of thermodynamics (Brown & Singh, 2021; Ultay et al., 2021). In the literature, various research results related to the second law and the first law of thermodynamics were found. The studies conducted by Cochran and Heron (2006) and Shahsavari and Boutorabi (2023) aimed to reveal students' conceptual understanding of the second law of thermodynamics. As a result of the research, it was determined that students could not associate the second law of thermodynamics with devices such as heat engines and refrigerators. Baran and Sozbilir (2018) and Smith et al. (2015) focused on students' perceptions of entropy and the second law of thermodynamics. It was determined that even after the instruction, students could not scientifically explain the concept of entropy and the concrete contexts related to the second law of thermodynamics. Haglund (2017) found that entropy is always remembered as a disorder at the macro level, and pre-service teachers have problems transferring the concept of entropy to micro-level situations. The literature found that secondary school students and engineering students mainly studied the second law. At the same time, the concept of entropy was handled more limitedly in studies compared to the first law (Bajracharya et al., 2019).

The study, in line with the information obtained from the literature, aimed to examine transfer of the knowledge of pre-service physics teachers about the first and second laws of thermodynamics to daily life. Given that the laws of thermodynamics are directly related to the environment and are a broad field, it will be possible to determine the extent to which the subject is meaningful to pre-service teachers at the point where they can apply their scientific knowledge to everyday life. It is thought that it is essential for the future of thermodynamics education that pre-service physics teachers, who will be a necessary element of the education system in the following years, construct their knowledge correctly and thus transfer it to daily life (Engström & Norström, 2022). The ability of pre-service physics teachers to make sense of their knowledge and transfer it to daily life will indicate how far their learning is from memorisation (Ultay et al., 2021).

Based on this, this study aimed to work with pre-service physics teachers, who train the basic building blocks of a productive society, and provide a more detailed picture of the transfer of their knowledge of the laws of thermodynamics to daily life. In addition, the fact that the transfer of knowledge to daily life in the literature is mainly dealt with in the subjects of optics, matter, heat, temperature and magnetism shed light on the realization of this research (Awudi & Danso, 2023; Yildiz, 2022). It is known that there is a deficiency in the field of thermodynamics, which forms the basis of modern physics fields such as energy and mechanics. It is thought that a contribution to the field can be made by determining the process of transferring the laws of this branch of science, which is widely used in physics, chemistry and technology, to daily life from the perspective of pre-service physics teachers (Bajracharya et al., 2019; Ultay et al., 2021). In line with all these statements, answers to the following research questions were sought in the study:

$RQ_1$: How do pre-service physics teachers transfer knowledge of the first law of thermodynamics to daily life?

$RQ_2$: How do pre-service physics teachers transfer knowledge of the second law of thermodynamics to daily life?

# Method

## Research Design

The study analyzed the transfer of pre-service physics teachers' knowledge of thermodynamics' first and second laws to daily life using qualitative methods. While the general design of this research was carried out with a qualitative approach, the research was designed as a case study. With the case study, events were analyzed within their natural life framework. Since the study was conducted on a single group within the scope of the case study, the holistic single-case design was utilized. Therefore, the research problem was explained holistically using data collection and analysis techniques (Yin, 2009). The qualitative approach in the study enabled in-depth exploration of participants' experiences and contextual factors necessary for understanding complex phenomena (Creswell, 2014). A holistic single-case design was chosen to focus on a bounded system, enabling researchers to analyze the phenomenon in its entirety rather than isolating individual components. In this way, by focusing on real-life contexts and in line with the principles of experiential learning (Kolb, 1984), an in-depth understanding of how theoretical knowledge is integrated into practical scenarios is desired. Thus, it will be possible to determine how participants' conceptual understandings are reflected in their daily experiences.

## Participants

The study participants comprised 63 pre-service teachers (age range 22-25; 40 female, 23 male) studying in the physics education department in the 2023-2024 academic year. Criterion sampling, one of the purposeful sampling methods, was used to select the study participants. In this context, the criteria determined in the study were determined by the researchers and the study was conducted with pre-service physics teachers who had taken and passed the thermodynamics course. To provide a more detailed profile, the participants represented a diverse range of academic performance levels, as indicated by their overall GPA scores, which ranged from 2.5 to 4.0 on a 4.0 scale. All participants were enrolled in the same institution, ensuring consistency in their educational backgrounds and exposure to similar teaching methodologies.

## Instrument and Procedures

The data were collected through an opinion form. By including open-ended questions in the opinion form, it aimed to obtain the experiences/opinions of the pre-service teachers in their own words (Patton, 2002). The literature was first reviewed during the development of the open-ended questions in the study. The researchers developed the questions using literature (Cengel & Boles, 2011). The questions were analyzed by three physics educators with doctoral degrees in the field. The experts examined the questions from a scientific point of view and did not change the form due to their evaluations. The feedback received from the experts individually and verbally showed that the agreement between them was 100%. Then, the opinion form was applied to 10 pre-service physics teachers who had the same characteristics as the study group of the research within the scope of the pilot (pre-test) application. As a result of the pilot study, the functionality and comprehensibility of the questions were re-examined by the experts, and the opinion form with seven open-ended questions was finalized. The open-ended questions in the opinion form are detailed in Table 1.

**Table 1**

*Questions*

| | |
|---|---|
| **First Law of Thermodynamics** | **Question 1:** A refrigerator is placed in a room with tightly closed doors and windows and well-insulated walls where heat loss and gain through the walls are neglected. The door of the refrigerator is opened and turned on. Do you think the average air temperature in the room will increase, decrease or remain constant? Explain. |
| | **Question 2:** If a fan is placed in the room under the conditions described in the first question, do you think the average temperature of the air in the room will increase, decrease or remain constant? Explain. |
| | **Question 3:** You may have noticed that when we put our car in the sun, the temperature inside the car is much hotter than the air outside. Why do you think the car got too hot? Explain. |
| **Second Law of Thermodynamics** | **Question 4:** Why do you think a cup of hot coffee left on the table in a cool room cools down over time, while a cup of cold coffee in the same room does not heat up? Explain. (The initial temperature of cold coffee is not below room temperature). |
| | **Question 5:** Can a refrigerator standing in front of a window with the door open and facing the cold outside heat the house? Explain. (The outdoor environment is colder than the indoor environment.) |
| | **Question 6:** In explaining the second law of thermodynamics, a hypothetical body with a large thermal energy capacity (mass x specific heat) that can give off or receive a finite amount of heat without a temperature change is commonly used. Can the atmosphere be warmed at this point by the heat passing from many houses to the surrounding air, especially in winter? Explain. |
| | **Question 7:** Gas molecules with high kinetic energy in a container cannot rotate a propeller placed in the container. What do you think is the reason for this? Explain. |

As seen in Table 1, three questions were related to the first law of thermodynamics, and four were associated with the second law of thermodynamics. In the study, the thermodynamics course was taught for one semester using the content of the current curriculum, and no different application was made during the learning. The opinion form was applied outside of class hours, in a period suitable for the researchers and pre-service teachers. The application was carried out within 45-50 minutes, taking into account the principle of voluntariness during the application.

## Data Analysis

The data were analyzed within the framework of deductive content analysis. Deductive content analysis is particularly suitable for research in which the theoretical framework guides the categorization of data (Pandey, 2019). In this study, the analysis method enabled the systematic examination of the transfer of pre-service physics teachers' knowledge of the first and second laws of thermodynamics to daily life. Therefore, in this study, the transfer of pre-service physics teachers' knowledge of the first and second laws of thermodynamics to daily life was interpreted richly. In this approach, a coding scheme based on existing theoretical structures and research questions was used. A coding scheme that is functional in similar studies such as Yalçın and Emrahoğlu (2017), Emrahoglu and Mengi (2012) and Şahin and Danaci (2022) was used. This predetermined coding scheme provided a structured basis for data analysis and allowed the findings to gain depth by classifying the data under themes and sub-themes. Therefore, the findings obtained based on themes and sub-themes were associated with the theoretical framework and interpreted in a meaningful way. In this context, the analyses in the study were carried out independently and collaboratively by the researchers. The process of analyzing the research data is explained in detail below.

**Figure 1**

*Analysis Steps of the Research*

***Phase 1: Recognize the data.***

- In this step, the data obtained from the opinion form were read and re-read by the researchers. While the data were recognized in this way, the researchers noted down their initial ideas.

***Phase 2: Generation of initial codes.***

- In the study, similar data for each question were brought together. The researchers first divided the data into 'wrong answer' and 'correct answer' and then coded the correct answers as 'correct answer no explanation', 'correct answer wrong explanation', 'correct answer unrelated explanation', 'correct answer incomplete explanation' and 'correct answer correct explanation'.

***Phase 3: Theme creation.***

- The researchers came together on the first codes and discussed the codes. After the codes were finalized in collaboration, it was decided to collect them under potential themes. The researchers organized the data under two question-based themes in accordance with the research purpose. The answers to the first, second and third questions were grouped under the theme **"(1) Transfer of the first law of thermodynamics to daily life"**; the answers to the fourth, fifth, sixth and seventh questions were grouped under the theme **"(2) Transfer of the second law of thermodynamics to daily life"**.

***Phase 4: Sub-theme creation.***

- The researchers came together and decided that each theme needed sub-themes. Considering the purpose of the research and the themes, sub-themes were created as Zero Transfer, Incomplete Transfer and Full Transfer (Emrahoglu & Mengi, 2012).
  - **Zero Transfer;** 'wrong answer', 'correct answer no explanation', 'correct answer wrong explanation', 'correct answer unrelated explanation'.
  - **Incomplete Transfer;** 'correct answer incomplete explanation'.
    - "Zero and incomplete transfer indicate that pre-service teachers have incomplete or incorrect knowledge and do not transfer their knowledge to daily life or transfer their knowledge incompletely."
  - **Full Transfer;** 'correct answer correct explanation'.
    - "Full transfer shows that pre-service teachers can transfer their scientifically correct knowledge to daily life."

***Phase 5: Correcting and defining themes, sub-themes and codes.***

- Researchers and experts came together for the themes, sub-themes and codes determined in this step. The researchers and experts discussed the themes, sub-themes and codes in a general framework and certain arrangements were made in line with the expert opinions. After these arrangements, a consensus was reached among the experts that the themes, sub-themes, and codes reflected the transfer of physics pre-service teachers' knowledge of the first and second laws of thermodynamics to daily life.

## Validity and Reliability

Four strategies were utilized within the scope of validity and reliability of the data (Yin, 2009). With credibility; direct quotations were included for the realism of the findings, the presentation of the data was objective, and the data obtained were finalized by consulting expert opinion. Data were presented in an unbiased manner, supported with fair evidence, and findings were shared with experts for verification. Peer debriefing sessions with external experts further ensured the reliability of the results by providing critical feedback and avoiding researcher bias.

With transferability, data were presented objectively and in detail. Direct quotations serve as evidence. Statements were conveyed to the readers in the tables. At the same time, pre-service teachers were identified through purposive sampling and the research criterion was detailed. The detailed description of the sampling process enabled other researchers to replicate or adapt the study design in similar contexts.

Consistency was ensured by examining all the data in the study by the same experts. Then, the examinations made by the experts in different periods for the themes, sub-themes and codes were compared and the consistency between the experts was examined. The consistency between two experts with a doctoral degree in physics education was calculated according to Miles and Huberman (1994). As a result of the calculation, it was determined that the reliability of the study was 0.94. It can be stated that the research is reliable as the agreement above 75% in the literature is expressed as perfect agreement (Miles & Huberman, 1994). Afterwards, the experts came together for the different codings, came to a common idea, and thus the themes, sub-themes and codes of the research were finalized.

Confirmability was strengthened by harmonizing the research findings with the data obtained and cross-referencing the results with the relevant literature. To avoid subjective bias, findings were systematically presented within a logical framework and subjected to external review. The reliability of the analysis was also strengthened through inter-coder agreement. Multiple researchers independently applied the coding scheme to a subset of the data and resolved any inconsistencies through iterative discussion. This process ensured that the final coding framework was both robust and consistent with the theoretical underpinnings of the study (Yin, 2009).

Finally, deductive content analysis was used to link the data directly to the theoretical framework, providing structured insights into how pre-service teachers transfer their knowledge to real-world contexts. This systematic approach not only enhanced the validity and reliability of the research, but also ensured that the findings were robust, transparent and replicable.

## Ethical Issues

Ethical principles and rules were followed in the research's planning, data collection, analysis and reporting stages. The pre-service teachers were informed before the investigation. The pre-service teachers were informed that their participation in the research was voluntary. They were told they could leave the study anytime and that their data would be deleted. The relevant University Ethics Committee evaluated the study as ethical and notified in writing by the Rectorate.

# Findings

The study analyzed pre-service physics teachers' transfer of knowledge of the first and second laws of thermodynamics to daily life under two themes. The findings of each theme are explained in detail below.

## Transfer of the First Law of Thermodynamics to Daily Life

This section analyzed the pre-service physics teachers' transfer of knowledge of the first law of thermodynamics to daily life. Table 2 presents the sub-themes and codes determined under the "Transfer of the First Law of Thermodynamics to Daily Life" theme.

**Table 2**

*Transfer of the First Law of Thermodynamics to Daily Life*

| Theme | Sub Theme | Codes | | Participants (f, %) | | | Total (%) |
|---|---|---|---|---|---|---|---|
| | | | | $Q_1$* | $Q_2$* | $Q_3$* | |
| Transfer of the first law of thermodynamics to daily life | Zero Transfer | Wrong Answer | | 48 (76%) | 53 (84%) | 27 (43%) | 74 |
| | | Correct Answer | Correct answer no explanation | 5 (8%) | - | 4 (6%) | |
| | | | Correct answer wrong explanation | - | - | | |
| | | | Correct answer unrelated explanation | - | - | 2 (3%) | |
| | Incomplete Transfer | | Correct answer incomplete explanation | - | - | - | - |
| | Full Transfer | | Correct answer correct explanation | 10 (16%) | 10 (16%) | 30 (48%) | 26 |

***(Q: Question, #: Question Number)

As seen in Table 2, pre-service physics teachers gave mostly incorrect answers (68%) to three questions about the first law of thermodynamics. Only in the third question was the number of pre-service teachers who gave correct responses higher than those who gave incorrect answers. Table 3 presents selected examples/direct quotations from pre-service physics teachers' written responses to three open-ended questions on the first law of thermodynamics.

**Table 3**

*Sample Statements of Pre-Service Physics Teachers for the First Theme*

| Sub Theme | | Example description** |
|---|---|---|
| Zero Transfer | $Q_1$ | **[Wrong answer]**<br>$PT_8$: Since the refrigerator engine is running, the fridge's coldness and the heat from the engine balance each other. So, the temperature of the environment remains constant.<br>$PT_{41}$: The refrigerant inside the refrigerator takes heat from the environment and causes the climate to cool down. So, the temperature of the environment decreases.<br>**[Correct answer no explanation]**<br>$PT_{13}$: The heat generated by the refrigerator's motor will increase the air temperature in the room. |
| | $Q_2$ | **[Wrong answer]**<br>$PT_{37}$: A fan does not make the environment hot or cold. It only moves the air inside and displaces the air molecules. Therefore, the average temperature of the air does not change.<br>$PT_5$: The fan blows cold air into the environment. Meanwhile, electrical energy is converted into wind energy, reducing the average temperature of the air. |
| | $Q_3$ | **[Wrong answer]**<br>$PT_{21}$: Heat exchange is from hot to cold. The temperature of the car is first lower than the temperature outside. So, the heat from outside passes into the car. Then, the temperatures equalize.<br>**[Correct answer no explanation]**<br>$PT_{28}$: It is the same in greenhouses.<br>**[Correct answer unrelated explanation]**<br>$PT_{38}$: Global warming can explain this. Indoor areas are scorching as a result of global warming. |
| Full Transfer | $Q_1$ | **[Correct answer correct explanation]**<br>$PT_6$: The heat generated by the refrigerator motor will raise the ambient temperature. In other words, the electrical energy entering the room turns into thermal energy and increases the average temperature of the air. |
| | $Q_2$ | **[Correct answer correct explanation]**<br>$PT_{17}$: The electrical energy entering the room through the fan is converted into thermal energy, increasing the average temperature of the air in the room. |
| | $Q_3$ | **[Correct answer correct explanation]**<br>$PT_{58}$: A car is like a closed system. The vehicle's windows transmit visible light, and heat is trapped inside the car, increasing the energy. Therefore, the internal temperature of the car increases. |

**(**PT: Pre-Service Teacher, #: Pre-Service Teacher Number)

As supported by the sample expressions in Table 3, it was determined that the pre-service physics teachers' transfer of the first law of thermodynamics to daily life was at the zero transfer stage (74%). At this point, it was revealed that pre-service physics teachers had problems transferring their knowledge of the first law of thermodynamics to daily life.

## Transfer of the Second Law of Thermodynamics to Daily Life

This section analyzed the pre-service physics teachers' transfer of knowledge of the second law of thermodynamics to daily life. Table 4 presents the sub-themes and codes determined under the "Transfer of the Second Law of Thermodynamics to Daily Life" theme.

**Table 4**

*Transfer of the Second Law of Thermodynamics to Daily Life*

| Theme | Sub Theme | Codes | | Participants (f, %) | | | | Total (%) |
|---|---|---|---|---|---|---|---|---|
| | | | | $Q_4$* | $Q_5$* | $Q_6$* | $Q_7$* | |
| Transfer of the first law of thermodynamics to daily life | Zero Transfer | Wrong Answer | | 8 (13%) | 36 (57%) | 38 (60%) | 25 (40%) | 61 |
| | | Correct Answer | Correct answer no explanation | - | - | 16 (25%) | - | |
| | | | Correct answer wrong explanation | - | 8 (13%) | - | - | |
| | | | Correct answer unrelated explanation | - | - | 9 (15%) | 13 (20%) | |
| | Incomplete Transfer | | Correct answer incomplete explanation | 2 (3%) | - | - | - | 1 |
| | Full Transfer | | Correct answer correct explanation | 53 (84%) | 19 (30%) | - | 25 (40%) | 38 |

*****(Q: Question, #: Question Number)

As seen in Table 4, it was determined that pre-service physics teachers mostly answered four questions about the second law of thermodynamics correctly (57.5%). Although the pre-service teachers mostly answered the questions correctly, it was noteworthy that no one answered the sixth question correctly and gave a correct explanation. The fifth question also found that the number of pre-service teachers who gave incorrect answers was higher than that of pre-service teachers who gave correct answers. Pre-service physics teachers' written responses to open-ended questions about the second law of thermodynamics were analyzed. Pertinent sub-themes were illustrated with selected examples in Table 5.

**Table 5**

*Sample Expressions of Pre-Service Physics Teachers for the Second Theme*

| Sub Theme | | Example description** |
|---|---|---|
| Zero Transfer | Q4 | **[Wrong answer]**<br>PT$_{7}$: Hot coffee cools down, and cold coffee warms up as there is equalization with the ambient temperature. |
| | Q5 | **[Wrong answer]**<br>PT$_{44}$: The refrigerator only cools the environment.<br>**[Correct answer wrong explanation]**<br>PT$_{60}$: A refrigerator can heat the house. Suppose the air is warmer than the refrigerator—heat transfers from the warm environment to the cold climate. |
| | Q6 | **[Wrong answer]**<br>PT$_{1}$: If the collective heat emitted by houses exceeds the atmosphere's heat, the atmosphere warms up. Heat passes from an environment with more heat to one with less.<br>PT$_{32}$: Increased carbon dioxide in the atmosphere leads to global warming. The atmosphere heats up and becomes polluted because the heat energy generated does not disappear.<br>**[Correct answer no explanation]**<br>PT$_{48}$: In winter, heat transfer from many dwellings to the air does not warm the atmosphere.<br>**[Correct answer unrelated explanation]**<br>PT$_{25}$: The atmosphere cannot heat up. Because the atmosphere is too far away. |
| | Q7 | **[Wrong answer]**<br>PT$_{59}$: Molecules cannot move without external influence.<br>**[Correct answer unrelated explanation]**<br>PT$_{11}$: The power of the molecules is not enough to turn the propeller. |
| Incomplete Transfer | Q4 | **[Correct answer incomplete explanation]**<br>PT$_{16}$: The answer to this question can be explained by the second law of thermodynamics. |

**Table 5**
*(Continue)*

| Sub Theme | | Example description** |
|---|---|---|
| Full Transfer | Q4 | **[Correct answer correct explanation]** PT$_3$: The change of state does not occur in the opposite direction. A process that transfers heat from one temperature to a higher temperature is impossible. So, the state change is from hot to cold, not from cold to hot. |
| | Q5 | **[Correct answer correct explanation]** PT$_{20}$: An ordinary refrigerator placed in the window of a house with the door open and facing the cold outside environment functions as a heat pump. The work that goes into a heat pump ensures that the thermal energy taken from the cold external environment is given to the warm internal environment. While the refrigerator tries to cool the outside by taking heat from the outside environment, the heat taken in through the pipes behind the fridge, which acts as a condenser, is given into the house and the house is heated. |
| | Q7 | **[Correct answer correct explanation]** PT$_{50}$: The space between gas molecules shows too much disorder. It is impossible to convert disordered energy into work. Therefore, the propeller does not rotate. |

**(**PT: Pre-Service Teacher, #: Pre-Service Teacher Number)

As supported by the sample expressions in Table 5, it was determined that, in general terms, pre-service physics teachers' transfer of the second law of thermodynamics to daily life was at the zero transfer stage (61%). At this point, it was revealed that pre-service physics teachers had problems transferring their knowledge of the second law of thermodynamics to daily life.

## Discussion, Conclusion and Implications

The study investigated the pre-service physics teachers' transfer of knowledge of the first and second laws of thermodynamics to daily life. As a result of the research, it was determined that the pre-service teachers mostly gave wrong answers to the questions related to the first law of thermodynamics. At this point, it was determined that the pre-service teachers were at the zero transfer level in transferring their knowledge to daily life. Therefore, they could not transfer their knowledge of the first law of thermodynamics to daily life. This result obtained in the research is similar to the results of the studies in the literature, and it is argued that this is due to the inability to distinguish the concepts of heat, temperature, work and internal energy from each other. In the literature, it is stated that students who cannot make sense of the basic concepts related to the first law of thermodynamics often cannot associate their knowledge with daily life (Budi Bhakti et al., 2022; Nurulwati & Rahmadani, 2019). For example, in the first question of the research, the first thing that comes to the minds of the pre-service teachers is that the room temperature will decrease when the cold air in the refrigerator mixes with the warm air in the room. However, it should be considered that the refrigerator motor will generate heat, and if the heating effect is higher than the cooling effect, the room temperature will increase. According to the principle of energy conservation, energy is not stored in a refrigerator or refrigerator motor. In other words, the electrical energy entering the room turns into thermal energy and increases the average temperature of the air. The same conclusion applies to the fan example in the second question. At this point, it is revealed that the knowledge of the pre-service teachers who answered the questions incorrectly as a majority is incorrect or incomplete about the principle of energy conservation. Brown and Singh (2021) also supported the study's results and argued that the problem stemmed from their lack of knowledge about heat, work and cyclic processes. This situation reveals that pre-service physics teachers have difficulties transferring the first law of thermodynamics to daily life and thus, as argued by Stroumpouli and Tsaparlis (2022), indirectly in the problem-solving stage. The third question, related to transferring the first law of thermodynamics to daily life, determined that the number of pre-service teachers who gave correct answers and those who gave incorrect answers were close to each other. This question determined that the number of pre-service teachers who could 'fully transfer' thermodynamic knowledge to daily life was slightly less than that of pre-service teachers who could 'zero transfer'. In the question, the pre-service teachers were expected to know that when you leave the car under the sun, the glass of a certain thickness transmits the light. The glass of a car is largely transparent to visible light, so the energy is absorbed by the objects inside the car (the seats, dashboard, and so on), thus increasing their temperature. These objects then emit infrared radiation, and the glass is quite opaque to this radiation, and the energy largely remains in the car. Therefore, more energy enters the glass than escapes. The greenhouse effect works the same way. However, the greenhouse effect raises the earth's average temperature and causes climate change in some regions. This situation is known as global warming. At this point, it is thought that pre-service physics teachers could not answer the question correctly because they could not associate the concepts of greenhouse effect and global warming with the question asked. At the same time, it was revealed that the pre-service physics teachers confused the concepts of heat and energy while answering the question. It is thought that these pre-service teachers, who have primarily wrong knowledge about the first law of thermodynamics, cannot handle environmental problems in an integrated manner with the laws of thermodynamics and do not have the knowledge to explain all events in nature with energy transfer and transformation (Cotignola et al., 2002). At this point, considering that the laws of thermodynamics, which are entirely related to heat exchange and energy, are an interdisciplinary subject, it can be suggested that knowledge about the relationship between thermodynamics and the environment should be transferred through chemistry and biology undergraduate education programmes as well as physics (Ultay et al., 2021).

When the answers of pre-service physics teachers to the questions related to the second law of thermodynamics were analyzed in terms of sub-themes, it was found that the pre-service teachers were at the level of 'zero transfer' in transferring their knowledge to daily life. At this point, it is revealed that pre-service physics teachers have problems in transferring the second law of thermodynamics to daily life. Therefore, pre-service physics teachers are thought to have problems making sense of the concept of entropy (Finkenstaedt-Quinn et al., 2020). For example, in the fourth question of the study, it was determined that most pre-service teachers had the correct knowledge and could explain the change of state. The pre-service teachers generally understood that state changes occur in a certain direction but not in the opposite direction and that this situation obeys the second law of thermodynamics. The pre-service teachers who answered this question incorrectly neglected the second law of thermodynamics and gave answers by the first law. Cochran and Heron (2006) mentioned this problem and stated that pre-service teachers often make the same mistake. Kulkarni and Tambade (2013) suggest that the source of this error is that pre-service teachers confuse the concept of entropy with energy. Because the first law does not set a limitation on the direction of change of state. In other words, it does not mean the state change will occur when the first law is accepted. Here, the inadequacy of the first law was overcome by the second law in the process. Therefore, it is concluded that the state change can be realised when the first and second laws of thermodynamics are provided together. It should also be noted that the second law of thermodynamics deals with the quantity and quality of energy together. The first law deals only with the quantity and transformation of energy. At this point, it can be stated that the second law is used to reveal the level of perfection of a state change and, at the same time, to eliminate defects (Kulkarni & Tambade, 2013). In the fifth research question, it was determined that the pre-service teachers mostly gave incorrect answers. The pre-service teachers who answered the question correctly stated that an ordinary refrigerator placed in the window of a house with its door open and facing the cold outside environment functions as a heat pump. Here, while the refrigerator tries to cool the outside by taking heat from the external environment, the house's interior is heated thanks to the heat from the pipes behind the refrigerator, which acts as a condenser. Air conditioners are not different from refrigerators. In summer, it cools the room by giving the heat it receives from the room to the outside, while in winter, when placed in the opposite direction, it acts as a heat pump and heats the room. The heat pump ensures that the environment remains at a high temperature. Therefore, it is thought that the pre-service teachers who answered the question incorrectly could not answer it correctly because they thought that the refrigerator only had the function of cooling objects. At the same time, Shahsavari and Boutorabi (2023) stated that pre-service teachers could not associate the second law of thermodynamics with systems such as heat machines and refrigerators. The sixth question of the study determined that the pre-service teachers had problems transferring their knowledge related to the second law to daily life. It was determined that the pre-service teachers thought the atmosphere warms with the heat passing from the houses to the air in winter. However, the second law of thermodynamics defines large bodies of water such as oceans, lakes and rivers as thermal energy reservoirs. Therefore, there is no warming of the atmosphere by heat transfer from houses to the air in winter. As another example, the waste energy released from power plants into rivers does not cause a significant change in the temperature of the water. At this point, it was determined that the pre-service teachers with incorrect or incomplete information used the concepts of greenhouse effect, global warming, etc., in their explanations. Therefore, the pre-service teachers could not associate entropy with the concept of environment. However, contrary to this result in the literature, in a study on thermodynamics and environment (Kirtak Ad & Demirci, 2013), it is stated that pre-service teachers mentioned the concept of entropy and explained many environmental problems in nature with the increase of entropy. In the related study, it can be stated that pre-service teachers know that all changes in our environment are irreversible. The seventh question of the study determined that the number of pre-service teachers who gave correct and incorrect answers was almost the same. In this question, the pre-service teachers who had the correct information stated that the molecules in the gas phase have very high kinetic energy. However, even though the kinetic energy of these molecules is high, it is stated that the molecules in the container cannot rotate the propeller and, therefore, cannot do work. Because gas molecules and their energies are irregular. In other words, since the number of gas molecules trying to rotate the propeller in different directions is equal, the propeller cannot rotate. Therefore, it is impossible to convert irregular energy into work. It was determined that the pre-service teachers who could not answer the question in this way had problems in transferring their knowledge to daily life by having wrong or incomplete knowledge by using the expressions of the power of molecules and the necessity of an external effect. The pre-service teachers' problem stems from their inability to understand the concepts of entropy, energy and work correctly (Baran & Sozbilir, 2018; Smith et al., 2015).

As a result, in this study, it was determined that the pre-service physics teachers' transfer of knowledge of the first and second laws of thermodynamics to daily life were mainly at the level of 'zero transfer' and therefore, the pre-service teachers had problems in transferring their knowledge to daily life. In the studies on thermodynamics in the literature, it is generally stated that the basic concepts such as work, heat, enthalpy and entropy in the learning of thermodynamics cannot be understood by pre-service teachers and the subject cannot be learnt due to the deficiencies in the prior knowledge of the pre-service teachers and therefore the transfer of knowledge to daily life cannot be made. Because it is known that at the point where scientific knowledge is transferred to daily life, it is known that making sense of knowledge will be an expected result (Bajracharya et al., 2019); to overcome this problem identified in the research, it can be suggested to create a learning environment enriched with various teaching methods, techniques and strategies. In this way, it is believed that pre-service teachers' knowledge will be structured, and their awareness that many events in nature can be explained by the laws of thermodynamics will increase (Sasmaz Oren & Sahin, 2023). As an example of various teaching methods, techniques and strategies used in teaching thermodynamics courses, cooperative learning was used in a study conducted by Partanen (2016). As a result of the study, it was determined that cooperative learning contributed positively to the learning of thermodynamics courses and student motivation. Baran and Sozbilir (2018) investigated the applicability of context and problem-based learning in thermodynamics courses and its effect on student achievement, attitude, motivation and interest. As a result of the research, they revealed that context and problem-based learning is effective in thermodynamics learning and causes an increase in students' achievement, attitude, motivation and interest in the course. In addition, it is argued that context-based thermodynamics teaching increases the level of science literacy so that concepts can be associated with daily life and increases students' self-confidence (Cigdemoglu & Geban, 2015). Vieira et al. (2018) argue that computer-assisted thermodynamics education supports pre-service teachers to make sense of knowledge. Although these studies did not include the association of thermodynamics knowledge with daily life, the teaching methods, techniques and strategies that produced successful results in thermodynamics teaching were evaluated. In this context, in future studies, considering that actions should be taken to eliminate the problems identified in the transfer of thermodynamics knowledge to daily life, it can be suggested to support the association of scientific knowledge with daily life by using proven teaching methods, techniques and strategies in the teaching process of thermodynamics course. It is believed that through an enriched learning environment created in this way, the training of future teachers who can transfer their knowledge of the laws of thermodynamics to daily life can be supported (Rosenberg & Lawson, 2019).

## Statement of Conflict of Interest

The authors do not have any conflict of interest.

## References

Asih, F. E., Poedjiastoeti, S., Lutf, A., Novita, D., Ismono, I., & Purnamasar, A. P. (2022). The practicality and effectiveness of case study-based module on chemical thermodynamics course (ideal and real gases) as learning tool during the COVID-19 pandemic. *JOTSE*, *12*(2), 466-483. http://dx.doi.org/10.3926/jotse.1654

Awudi, B., & Danso, S. (2023). Improving students' performance and conceptual understanding of heat transfer using demonstration method. *Journal of Mathematics and Science Teacher*, *3*(2), em037. https://doi.org/10.29333/mathsciteacher/13164

Bajracharya, R. R., Emigh, J. P., & Manogue, A. C. (2019). Students' strategies for solving a multirepresentational partial derivative problem in thermodynamics. *Physical Review Physics Education Research, 15*(2), 020124, 1-17. https://doi.org/10.1103/PhysRevPhysEducRes.15.020124

Baran, M., & Sozbilir, M. (2018). An application of context-and problem-based learning (C-PBL) into teaching thermodynamics. *Research in Science Education*, *48*, 663-689. https://doi.org/10.1007/s11165-016-9583-1

Brown, B., & Singh, C. (2021). Student understanding of the first law and second law of thermodynamics. *European Journal of Physics*, *42*(6), 065702. https://doi.org/10.1088/1361-6404/ac18b4

Brown, B., & Singh, C. (2022). Student understanding of thermodynamic processes, variables and systems. *European Journal of Physics*, *43*(5), 055705. https://doi.org/10.1088/1361-6404/ac7af2

Budi Bhakti, Y., Agustina Dwi Astuti, I., & Prasetya, R. (2022). Four-tier thermodynamics diagnostic test (4T-TDT) to identify student misconception. *KnE Social Sciences*, *7*(14), 106–116. https://doi.org/10.18502/kss.v7i14.11958

Cochran, M. (2005). *Student understanding of the second law of thermodynamics and the underlying concepts of heat, temperature, and thermal equilibrium* [Unpublished doctoral dissertation]. University of Washington, USA.

Cochran, M., & Heron, P. (2006). Development and assessment of research-based tutorials on heat engines and the second law of thermodynamics. *Am. J. Phys. 74,* 734-741. https://doi.org/10.1119/1.2198889

Cotignola, M. I., Bordogna, C., Punte, G. ve Cappannini, O. M. (2002). Difficulties in learning thermodynamic concepts: Are they linked to the historical development of this field?. *Science & Education, 11,* 279–291. https://doi.org/10.1023/A:1015205123254

Cengel, A. Y., & Boles, A. M. (2011). *Thermodynamics: An engineering approach (Seventh edition in SI units)*. New York: McGraw-Hill.

Cigdemoglu, C., & Geban, O. (2015). Improving students' chemical literacy levels on thermochemical and thermodynamics concepts through a context-based approach. *Chemistry Education Research and Practice*, *16*(2), 302–317. https://doi.org/10.1039/c5rp00007f

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches (4th ed.).* SAGE Publications.

Emrahoglu, N. & Mengi, F. (2012). An investigation of 8th grade primary school students' level of transferring science and technology topics into everyday life problem solving. *Journal of Cukurova University Instute of Social Sciences, 21*(1), 213-228.

Engström, S., & Norström, P. (2022). How physics courses can make highly valued strategies and dispositions visible to physics teacher students. *European Journal of Science and Mathematics Education*, *10*(4), 396-411. https://doi.org/10.30935/scimath/12078

Finkenstaedt-Quinn, S. A., Halim, A. S., Kasner, G., Wilhelm, C. A., Moon, A., Gere, A. R., & Shultz, G. V. (2020). Capturing student conceptions of thermodynamics and kinetics using writing. *Chemistry Education Research and Practice*, *21*(3), 922-939. https://doi.org/10.1039/C9RP00292H

Haglund, J. (2017). Good use of a 'Bad' metaphor. *Science & Education, 26,* 205-214. https://doi.org/10.1007/s11191-017-9892-4

Kautz, C., Heron, P., Loverude, M., & McDermott L. (2005). Student understanding of the ideal gas law, Part I: A macroscopic perspective. *Am. J. Phys. 73,* 1055-1063. https://doi.org/10.1119/1.2049286

Kirtak Ad, V. N., & Demirci, N. (2013). Physics, chemistry and biology teacher candidates' level of application of the second law of thermodynamics to daily events. *Turkish Science Education and Research Association, 1*(2), 67-80.

Kleidon, A. (2023). Working at the limit: A review of thermodynamics and optimality of the Earth system. *Earth System Dynamics, 14*(4), 861-896. https://doi.org/10.5194/esd-14-861-2023

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development.* Prentice Hall.

Kõlamets, L., Kasuk, H., Holbrook, J., & Mamlok-Naaman, R. (2023). The relevance of learning outcomes included in Estonian grade 7-9 science subject curricula associated with the concept of energy. *Journal of Baltic Science Education*, *22*(4), 653-667. https://doi.org/10.33225/jbse/23.22.653

Kulkarni, V. D., & Tambade, P. S. (2013). Enhancing the learning of thermodynamics using computer-assisted instructions at undergraduate level. *International Journal of Physics and Chemistry Education*, *5*(1), 2-10.

Loverude, M. E., Kautz, C. H., & Heron, P. R. L. (2002). Student understanding of the first law of thermodynamics: Relating work to the adiabatic compression of an ideal gas. *American Journal of Physics, 70*(2), 137-148. https://doi.org/10.1119/1.1417532

Meltzer, D. (2004). Investigation of students' reasoning regarding heat, work, and the first law of thermodynamics in an introductory calculus-based general physics course. *Am. J. Phys., 72*(11), 1432-1446. https://doi.org/10.1119/1.1789161

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook (2nd edition).* California: Sage.

Pandey, J. (2019). Deductive approach to content analysis. In *Qualitative techniques for workplace data analysis* (pp. 145-169). IGI Global.

Partanen, L., Hanninen, V., & Halonen, L. (2016). Effects of global and local anharmonicities on the thermodynamic properties of sulfuric acid monohydrate. *Journal of Chemical Theory and Computation*, *12*(11), 5511-5524. https://doi.org/10.1021/acs.jctc.6b00683

Patton, M. Q. (2002). *Qualitative research and evaluation methods.* California: Sage.

Sasmaz Oren, F., & Sahin, F. (2023). An inquiry and context-based activity supporting lifelong learning: Enzymes in daily life. *Journal of Teacher Education and Lifelong Learning*, *5*(1), 336-362. https://doi.org/10.51535/tell.1281528

Shahsavari, S., & Boutorabi, S. M. A. (2023). Energy structure theory: A general unified thermodynamics theory. *International Journal of Thermodynamics, 26*(3), 47-62. https://doi.org/10.5541/ijot.1257725

Singh, M. S., & O'Neill, M. E. (2022). The climate system and the second law of thermodynamics. *Reviews of Modern Physics*, *94*(1), 015001. https://doi.org/10.1103/RevModPhys.94.015001

Smith, T., Christensen, W., Mountcastle, D., & Thompson, J. (2015). Identifying student difficulties with heat engines, entropy, and the carnot cycle. *Phys. Rev. ST Phys. Educ. Res. 11,* 020116. https://doi.org/10.1103/PhysRevSTPER.11.020116

Stroumpouli, C., & Tsaparlis, G. (2022). Chemistry students' conceptual difficulties and problem solving behavior in chemical kinetics, as a component of an introductory physical chemistry course. *Chemistry Teacher International*, *4*(3), 279-296. https://doi.org/10.1515/cti-2022-0005

Şahin, Ö., & Danaci, D. (2022). Investigating the effect of history-of mathematics activities on middle-grade students' mental computation and opinions: An action research. *International Journal of Mathematical Education in Science and Technology, 53*(9), 2281-2318. https://doi.org/10.1080/0020739X.2020.1857859

Ultay, E., Durukan, U. G., & Ultay, N. (2021). Determination of prospective science teachers' level of knowledge about thermodynamics and their reasoning with daily life examples. *Journal of Science Learning*, *4*(3), 298-308. https://doi.org/10.17509/jsl.v4i3.29544

Vieira, C., Magana, A. J., García, R. E., Jana, A., & Krafcik, M. (2018). Integrating computational science tools into a thermodynamics course. *Journal of Science Education and Technology*, *27*, 322-333. https://doi.org/10.1007/s10956-017-9726-9

Yalçın, O. & Emrahoğlu, N. (2017). Examining the high school students' transfer levels of modern physics topics to daily life. *Pegem Journal of Education and Instruction, 7*(1), 115-158, http://dx.doi.org/10.14527/pegegog.2017.005

Yildiz, A. (2022). Pre-service teachers' levels of understanding the light-related concepts. *World Journal of Education*, *12*(4), 1-7. https://doi.org/10.5430/wje.v12n4p1

Yin, R. K. (2009). *Case study research: Design and methods (4th ed.).* California: Sage.

Young, H. D., & Freedman, R. A. (2008). *University Physics (Vol. I: Pearson).* Boston: Addison Wesley.