

Students' misunderstanding of the concepts of energy and thermal processes in thermodynamics

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Abstract:

This study investigates university students' misconceptions about energy and thermal processes in the thermodynamics course. It aimed to diagnose conceptual difficulties related to the fundamental principles of thermodynamics, especially the concept of energy and the related notions such as heat, work, and internal energy. The sample consisted of 88 students enrolled in exact sciences at the Universities of Djelfa and Laghouat in Algeria during the 2024/2025 academic year. Data were collected through semi-structured interviews with students and instructors, in addition to a two-tier diagnostic test composed of four alternatives with one correct answer. Students' responses were classified into different categories reflecting varying levels of understanding of these concepts. The results revealed a number of common alternative conceptions and conceptual errors among students, as most of them were unable to provide a correct justification for their answers. These findings implicitly reflect the teaching methods adopted in university and pre-university education, which may contribute to reinforcing these misconceptions. This highlights the need for targeted pedagogical strategies to improve students' understanding of thermodynamics topics. Moreover, these results can be used to develop effective instructional strategies focusing on addressing and correcting such conceptions, especially in introductory thermal physics courses.

1. Introduction

Thermodynamics is considered one of the fundamental pillars in the fields of science and engineering, as it deals with the study of the forms of energy and their transformations within physical and chemical systems (Callen, 1985). The basic principles of this field have contributed to the development of numerous practical applications ranging from thermal energy systems and internal combustion engines to refrigeration and air conditioning technologies (Moran et al., 2014). They have also provided a framework for understanding natural phenomena and biological processes such as climate cycles and phase transformations in living systems (Atkins and De Paula, 2006).

Despite its importance, many studies have shown that learning thermodynamics poses a challenge for students at various educational levels. Learners often find it difficult to grasp abstract concepts such as entropy and free energy, or to distinguish between heat and temperature, and between internal energy and enthalpy (Sozibilir, 2002). These difficulties negatively affect their academic achievement and their ability to apply fundamental laws in solving problems (Çengel and Boles, 2019).

For decades, science educators have focused on studying students' misconceptions, often referred to as "alternative conceptions," which are ideas that do not align with current scientific understanding. As highlighted in the works of Confrey (1990) and the studies of Duit and Treagust (1998), such research has led to the development of constructivist-based learning environments aimed

at supporting conceptual change among students. A key requirement for the success of this approach is that teachers be able to accurately and reliably assess the conceptions held by their students. Among the strategies used in schools to explore these conceptions are small group discussions and requesting written explanations from students.

Research findings show that understanding and applying the three laws of thermodynamics in problem-solving represents one of the main challenges for students, with the first law in particular being among the most problematic concepts (Dukhan, 2016). Multiple studies have revealed recurring confusion in distinguishing between heat and temperature (Douadi et al., 2018), as well as between internal energy and enthalpy, indicating a weakness in grasping fundamental conceptual structures (Driver et al., 1994). Recent research has also shown that university students struggle with thermal processes and the associated variables (Brown and Singh, 2022).

In the Algerian context, studies have shown that these difficulties are not limited to university education but originate as early as middle and secondary school, where many misconceptions about internal energy, heat, and work have been identified (Ben Batka, 2018, 2021). Other findings confirm that these misconceptions persist into the university level, where alternative conceptions related to the first and second laws of thermodynamics have been recorded (Douadi et al., 2018). Recent studies further revealed that university students continue to face fundamental conceptual challenges in linking thermal laws to their applications in chemistry (Khelloufi et al., 2025). Nevertheless, little work has been done on thermodynamics at the university level.

It is thus evident that addressing these issues requires a gradual teaching strategy that takes into account the accumulation of misconceptions from secondary education, while incorporating modern pedagogical approaches that promote deep understanding instead of rote memorization. These studies support the need to use diverse and advanced tools to assess conceptual understanding and analyze alternative conceptions, with the goal of developing more effective teaching strategies particularly in physics and chemistry fields that rely on complex concepts such as thermodynamics (Chi, 2005; Duit, 2009).

2. Research Aim and Questions

This study aims to analyze the difficulties in learning thermodynamics concepts in physical chemistry courses among university students, by

identifying the nature of these difficulties and classifying them according to their conceptual and cognitive dimensions. It also seeks to uncover the underlying causes of students' struggles in grasping these topics, which are often linked to the abstract and complex nature of thermal concepts on the one hand, and to the lack of connection between the mathematical and theoretical aspects on the other.

Understanding these challenges constitutes a fundamental step toward providing practical and pedagogical solutions.

Among the main objectives is also the exploration of the possibility of developing an alternative teaching approach that can alleviate these difficulties, drawing on previous teaching experiences in physical chemistry courses. These experiences have shown that building gradual and interconnected learning fosters a deeper understanding of thermodynamics concepts among university students.

In light of the above, the detailed objectives of this research are as follows:

- To identify and classify the learning difficulties faced by university chemistry students when studying the basic principles of thermodynamics in physical chemistry courses.
- To analyze the reasons that make these concepts particularly difficult for students to understand, whether at the conceptual, cognitive, or teaching-method levels.
- To propose and develop an alternative approach that contributes to addressing the educational difficulties related to chemical thermodynamics, ensuring improved quality of students' understanding and application.

Based on field experience in teaching, and relying on surveys of teachers and students through personal interviews and test results, it is evident that both teachers and students in various universities face significant difficulties in dealing with thermodynamics concepts. This is due to a set of cognitive and pedagogical obstacles that hinder deep understanding and comprehension of these concepts. From these observations arises the need to address these difficulties and diagnose their real causes, leading to the formulation of the main research question:

To what extent are alternative conceptions related to thermodynamics concepts prevalent among university students in Algeria?

From this main question, the following sub-questions emerge:

1. What are the percentages of alternative conceptions related to thermochemistry concepts held by university students?
2. Where do these misconceptions originate, and what are their sources?

3. Methodology and Procedures

This research aims to diagnose and identify the alternative conceptions related to thermodynamics concepts and to investigate the main challenges students face in learning them, particularly those linked to the fundamental laws of thermodynamics and core concepts such as **enthalpy**, **entropy**, heat, and work. The study sample included students from the Faculty of Exact Sciences and Computer Science at Djelfa University, as well as students from the Faculty of Technology at Laghouat University, with a total of about **88 participants**.

The research adopted a **multi-method approach** in order to ensure the accuracy of results and the diversity of data sources. Data were collected using:

1. Conceptual Diagnostic Test (Two-tier Diagnostic Test):

This tool aimed to assess students' understanding of fundamental concepts and identify their alternative conceptions. Based on a content analysis of thermodynamics concepts taught in the first and second years of exact sciences and technology programs in Algerian universities, a diagnostic test was developed to reveal the difficulties students face in learning these concepts.

- The test consisted of 16 items covering basic definitions of thermodynamics concepts and multiple-choice questions (MCQs).
- Each question had four options with only one correct answer, and students were asked to justify their choice through a second level containing possible explanations, one of which was correct.
- An additional section was included for open-ended questions allowing students to express their opinions on:
- The applications of thermodynamics in daily life.

- Suggested teaching methods that could help improve their understanding and achievement in this field.

The analysis of these opinions and suggestions helped identify several obstacles that hinder the learning process, thereby contributing to practical solutions to overcome them.

To verify content validity, the test was reviewed by a group of university professors and secondary school teachers specialized in physical sciences. Their comments and suggestions were incorporated, and some items were reformulated to reach the final version. Regarding reliability, Cronbach's alpha coefficient was calculated, yielding a value of $\alpha = 0.72$, which confirms the tool's suitability for application.

2. Structured Interviews:

Conducted with a sample of students and teachers to provide in-depth qualitative data about the nature of the educational and cognitive difficulties.

The research procedures were carried out in three main stages:

- **Diagnosis Stage:** Identifying weaknesses and misconceptions among students.
- **Analysis Stage:** Studying the causes of difficulties by linking questionnaire, test, and interview results.
- **Interpretation Stage:** Relating difficulties to pedagogical, cognitive, and linguistic factors that may hinder students' understanding of thermodynamics concepts.

This integrated methodological approach enabled the construction of a comprehensive view of the challenges facing the learning of thermodynamics at the university level, thereby paving the way for the development of more effective alternative teaching strategies.

4. Cognitive Background of University Students in Algeria

University curricula under the Ministry of Higher Education and Scientific Research in Algeria are subject to the regulation and development of study programs across various scientific disciplines. University education in the sciences, particularly chemistry and physics, relies on official curricula issued by the Ministry, which are periodically updated to keep pace with scientific advances and

labor market requirements. These curricula aim to provide students with both theoretical and practical knowledge, in addition to developing critical thinking, scientific research, and problem-solving skills.

In the fields of physics and chemistry, the first- and second-year programs include fundamental topics in thermodynamics, covering concepts such as heat, temperature, enthalpy, and the laws of thermodynamics, as well as the study of chemical reactions and their energetic changes. University programs also encourage the use of interactive teaching methods, such as laboratory experiments and computer simulations, in order to enhance students' understanding and to apply scientific concepts to practical phenomena.

The main educational axes are represented in the following areas:

- **Axis One:** Properties of systems and thermodynamic processes.
- **Axis Two:** The first law of thermodynamics.
- **Axis Three:** The second and third laws of thermodynamics.
- **Axis Four:** Chemical equilibrium.

5. Theoretical Framework

Difficulties in Understanding and Learning Thermodynamics Concepts among Students

Many researchers have focused on studying students' misconceptions regarding the concepts of heat and temperature (Sozibilir, 2003). At a basic level, the main problem lies in students' inability to clearly distinguish between these two concepts (Carlton, 2000; Jara-Guerrero, 1993; Yeo & Zadnik, 2001). For example, Paik, Cho, and Go (2007) conducted a study on students aged 4 to 11 years in Korea and found that most of them did not have a clear understanding of the concept of thermal equilibrium.

In another study, Luera, Otto, and Zitzewitz (2006) used the Thermal Concept Evaluation (TCE) test as a pre- and post-assessment to identify misconceptions related to heat and temperature, with a focus on improving instructional design.

At a more advanced level, Harrison, Grayson, and Treagust (1998) observed that the concepts of heat and internal energy cause significant confusion for both secondary and university students (Lewis & Linn, 2003; Niaz, 2006). Furthermore, research has shown that science students as well as teachers at the primary and secondary levels lack sufficient

knowledge about thermal equilibrium, specific heat capacity, and heat capacity (Douadi et al., 2018).

Thermodynamics concepts are among the most challenging topics in physics and chemistry courses at the higher education level. Many students experience considerable difficulties in understanding and assimilating these fundamental concepts, which form the core of numerous scientific and engineering phenomena. These include temperature, heat, latent heat, specific heat capacity, thermal equilibrium, enthalpy, and entropy, while thermal conduction also represents a particularly difficult concept for students to grasp correctly (Sozibilir, 2003; Niaz, 2006).

• Temperature vs. Heat:

Temperature represents the measure of the average kinetic energy of particles in a system, whereas heat refers to the transfer of energy between objects due to temperature differences (Carlton, 2000). Studies indicate that many students confuse the two, believing for example that temperature is energy itself, or that a hot object contains a fixed amount of heat regardless of its mass (Yeo & Zadnik, 2001). This confusion is partly due to linguistic overlap and the imprecise use of terms in everyday life, which exacerbates the educational challenge (Paik, Cho, & Go, 2007).

• Latent Heat:

Latent heat is the energy required to change the state of matter without altering its temperature, such as water transitioning from liquid to vapor. Students struggle to distinguish between energy changes accompanied by temperature variations and those associated with phase changes. Moreover, latent heat is closely tied to thermal equilibrium, as students must understand how energy is transferred until a stable temperature is reached (Woldamanuel et al., 2015).

• Specific Heat Capacity:

This concept refers to the amount of heat required to raise the temperature of one unit of mass of a substance by one degree Celsius. Students often face difficulty linking this concept to real-life applications, and in distinguishing between specific heat capacity and the total heat absorbed by a body (Douadi et al., 2018). These difficulties significantly hinder their ability to explain phenomena related to thermal changes in materials.

• Enthalpy and Entropy:

Enthalpy, defined as the energy of a system that includes internal energy, pressure, and volume, is an abstract concept that students find difficult to visualize in the context of chemical reactions and thermodynamic processes (Woldamanuel et al., 2015). Entropy, which represents the measure of disorder or randomness in a system, is also among the most challenging concepts, especially in understanding its relationship to natural processes and directionality in physics and chemistry (Niaz, 2006).

- **Thermal Conduction:**

Thermal conduction refers to the transfer of heat within a material due to temperature differences across its points. Students' understanding of this concept is tied to their ability to visualize how thermal energy moves within solids. Research indicates that many students lack a comprehensive grasp of conduction, often associating heat transfer only with convection or radiation while overlooking the molecular collisions that occur in solids (Saricayir et al., 2016).

These educational difficulties stem from several factors, including the way the subject matter is presented—often theoretical and abstract along with the lack of practical and interactive experiments that help students construct understanding on their own (Brown & Singh, 2022). This highlights the importance of integrating innovative teaching methods such as computer simulations, problem-based learning, and cooperative learning into thermodynamics instruction to enhance comprehension and improve learning outcomes (Chi, 2005).

Taken together, these studies emphasize the importance of understanding students' cognitive backgrounds regarding thermal concepts and point to the urgent need to develop teaching strategies that systematically target the correction of these misconceptions.

6. Alternative Conceptions in the Field of Thermochemistry

Thermochemistry is a central branch of chemistry, as it seeks to explain the energy changes accompanying chemical reactions and physical transformations through key concepts such as internal energy, enthalpy, entropy, and Gibbs free energy. However, many educational studies have revealed that students, whether at the secondary or university level, face fundamental difficulties in understanding these concepts, which leads to the

emergence of alternative conceptions (also known as preconceptions or misconceptions). The danger of these conceptions lies in the fact that they form entrenched cognitive frameworks that resist change and negatively affect the construction of correct scientific understanding.

Research indicates that one of the most prominent alternative conceptions relates to the distinction between heat and temperature. Many students confuse the two, believing that heat is a property of the body, like mass or volume, whereas in reality it is a form of energy transfer between a system and its surroundings as a result of temperature differences (Atkins & de Paula, 2010; Erickson, 1979; Brown & Singh, 2022). Temperature is also sometimes mistakenly perceived as the "amount of heat" stored in a body an idea inconsistent with the thermodynamic interpretation based on the kinetic energy of particles.

Students also face difficulty in understanding the first law of thermodynamics. Some believe it only refers to the principle of conservation of heat, neglecting the integral roles of both work and heat as contributors to the system's energy changes (Landsberg, 1990). Alternative conceptions also appear regarding internal energy, with some students associating it only with molecular kinetic energy, while ignoring the potential energy arising from intermolecular forces of attraction and repulsion.

Regarding the second law of thermodynamics, the concept of entropy is often misunderstood. Students tend to reduce its meaning to simply "a measure of disorder," without sufficiently linking entropy to the microscopic probabilities of systems, or interpreting it as a measure of the number of possible states of the system (Brown & Singh, 2022; Styer, 2000). Some students also mistakenly believe that entropy always decreases in natural processes, whereas the second law states that entropy increases or remains constant in isolated systems.

At a more advanced level, confusion arises in understanding the role of Gibbs free energy (G) in determining the spontaneity of chemical reactions. Some students think that a negative ΔG necessarily means the reaction is "fast," while in fact the change in free energy only determines the spontaneous direction of the reaction and provides no direct information about its rate, which is mainly governed by chemical kinetics (Atkins & de Paula, 2006). Similarly, the relationship between ΔG and the equilibrium constant is often misinterpreted. Some students assume that the reaction stops

completely when $\Delta G=0$, while in reality this represents a state of dynamic equilibrium.

These alternative conceptions do not arise randomly; they are often rooted in traditional teaching practices, such as emphasizing rote memorization of equations without connecting them to experiments or molecular models. Misleading everyday language in teaching also plays a role for instance, saying “the system has heat” or “the system consumes entropy” which reinforces misunderstandings.

Studies show that alternative conceptions in thermochemistry pose a real barrier to deep understanding of thermodynamic concepts. Therefore, addressing these misconceptions requires innovative teaching practices that integrate theory with application, placing students in learning situations that allow them to re-examine their ideas and build knowledge that is more scientific and coherent.

7. Results and Discussion

Findings of the First Research Question and Their Interpretations

The first research question of the study states:

What are the percentages of alternative conceptions related to thermochemistry concepts held by university students?

To answer this question, the data were statistically processed as shown in the table 1.

General Analysis of the Results:

The Figure 1 illustrates the distribution of students' responses across 16 diagnostic questions, showing different patterns of understanding and alternative conceptions:

1. Entrenched Alternative Conceptions

(Majority Incorrect): In items 5, 6, 8, 11, 12, and 13, most students ($\geq 40\%$) selected the same incorrect answer.

- This indicates the presence of deeply rooted alternative conceptions shaping their thinking, which requires targeted instructional interventions based on **conceptual change strategies**.

2. Moderate Understanding (45–59% Correct

Answers): In items 2, 3, 7, 10, 14, 15, and 16, the percentage of correct answers was relatively higher but did not reach mastery level.

- This reflects partial understanding that needs reinforcement through supportive activities linking the **microscopic (molecular)** level with the **macroscopic (observable)** level.

3. Partial Understanding (35–44% Correct

Answers): In item 1, students demonstrated initial but incomplete knowledge, requiring further clarification and refinement of concepts.

4. Severe Weakness in Understanding (<35% Correct

Answers): In item 4, results reveal a major deficiency in comprehending the concept of **heat capacity**, calling for a complete reconstruction of the concept using simplified and gradual teaching approaches.

5. Strong Understanding ($\geq 60\%$ Correct

Answers): In item 9, the majority achieved a high percentage of correct answers, indicating that the concept is well established among most students.

- These students can be utilized as role models in **collaborative learning activities**.

The results show a variation in the levels of understanding among students, ranging from strong to very weak, with a clear emergence of entrenched alternative conceptions in certain topics of thermodynamics.

Analysis of the Results Based on the Above Chart

The test results reveal a striking variation in the percentages of correct answers among students. Very low percentages were recorded in some items, while in most questions fewer than half of the students answered correctly, and only one item demonstrated an advanced level of understanding. This pattern clearly indicates that the difficulties are not merely due to a lack of knowledge but rather to entrenched alternative conceptions that cause students to experience conflict between their prior cognitive structures and the correct scientific concept.

The items with low success rates showed that students face particular difficulty in distinguishing between fundamental concepts, such as the relationship between heat and temperature, or in grasping the dual role of work and internal energy within the first law of thermodynamics. This aligns with Landsberg (1990), who noted that thermodynamic laws are often taught in mathematical form without sufficient connection to deeper physical concepts.

The items reflecting moderate levels of understanding suggest that students possess preliminary knowledge, but it remains fragile and easily collapses when faced with problems that require microscopic explanations or integration between mathematical and descriptive representations. This is consistent with the findings of Douadi et al. (2018), which showed that Algerian students tend to adopt superficial strategies for solving thermodynamics problems, hindering their deep comprehension of concepts.

Accordingly, these difficulties can be traced to cognitive origins (alternative preconceptions), pedagogical causes (teaching methods focused on abstract mathematical formulations), and linguistic issues (students' limited grasp of precise scientific terminology). These conclusions reinforce the need for alternative instructional strategies based on cognitive conflict, the use of multiple representations, and collaborative learning, thereby contributing to rebuilding understanding on more solid and lasting foundations.

Evaluation of the Results According to the Two-Tier Instrument

This section aims to uncover students' alternative conceptions in thermochemistry by analyzing their choices in multiple-choice diagnostic questions. The tool is structured on two levels:

- **First level:** Selecting the answer (A, B, C, D).
- **Second level:** Justifying the choice, which makes it possible to identify the underlying conception behind the answer.

2 – Quantitative Results Analysis

Based on the previous table, the following observations can be noted:

- **Item 1:** A considerable proportion of students (43.2%) chose the correct conception (B), while the remaining responses were distributed among A, C, and D, revealing the presence of overlapping conceptions.
- **Item 2:** About half of the students (50%) identified the correct answer (D), while the rest were divided among incorrect options, indicating that the concept remains challenging for a large group.
- **Item 3:** The largest proportion (45.5%) directly selected the correct answer (A), but a significant share (22.7%) adhered to the alternative conception (C).

- **Items 4 and 5:** A clear problem emerges, as choices were almost equally distributed, reflecting the absence of stable understanding of the concept (C).
- **Item 6:** Nearly half of the students (48.9%) managed to determine the correct answer, while the rest were dispersed among alternative conceptions.
- **Items 7 and 16:** There was a strong tendency toward the correct answer (B) with nearly half of the students choosing it, but about a quarter still held on to alternative conceptions.
- **Item 9:** A distinct result appears, as the majority of students (62.5%) selected the correct answer (D), which is a positive indicator.
- **Items 10, 11, and 12:** Performance was relatively good, especially in Item 12 (68.2% correct answers), indicating that this concept is clearer compared to others.
- **Item 13:** Although the largest group (42%) chose the correct answer, nearly one third of the students (31.8%) adopted the alternative conception (A), reflecting the persistence of a misconception within this subgroup.
- **Item 14:** Nearly half of the students (45.5%) demonstrated understanding of the concept, though a quarter still adopted alternative conceptions.
- **Item 15:** Fewer than half (47.7%) identified the correct answer, while the remaining responses were evenly split among incorrect options, reflecting the relative difficulty of the concept.

3. Interpretation According to the Two-Tier Model

- **Scientific Conception:** Clearly appears in items 3, 6, 9, and 12, where the percentage of correct answers exceeded 45%.
- **Alternative Conceptions:** Evident particularly in items 4, 5, and 13, where responses were distributed almost equally among all options, indicating the absence of decisive understanding.
- **Knowledge Gaps:** Items 2, 14, and 15 reflect moderate difficulty, with a significant portion of students standing in a transitional zone between alternative and scientific conceptions.

4. Preliminary Conclusions

- Students show better ability in dealing with simpler or more practical concepts (such as items 9 and 12).
- There is a clear need for targeted instructional interventions to address alternative conceptions in complex or abstract topics (such as thermal equilibrium and closed vs. open systems).
- The two-tier instrument proved effective in revealing that some students sometimes provide the correct answer but without sound scientific justification, which indicates that superficial understanding is strongly present.

8. General Discussion and Analysis

The results of the present study, obtained through the analysis of students' responses to the two-tier diagnostic instrument in thermochemistry, reveal that their level of understanding is highly heterogeneous across the four main domains: properties of systems and thermodynamic processes, the first law of thermodynamics, the second and third laws, and chemical equilibrium. Correct answer rates ranged between 31.8% and 68.2%, reflecting both knowledge gaps and deeply rooted alternative conceptions among a large portion of the sample.

For instance, in Item 9 (adiabatic transformations), 62.5% of students selected the correct answer—a relatively high percentage compared to other items. This indicates that students are capable of grasping some tangible physical transformations, especially when related to perceptible cases or familiar classroom experiments. By contrast, in Item 4 (heat capacity), responses were almost evenly distributed among the four options, with only 31.8% correct answers. This points to the absence of a solid scientific conception of this topic. The contrast between these two items illustrates that students struggle more with abstract concepts, while they deal more easily with observable phenomena.

The results also show that some alternative conceptions remain strong and influential. This was clearly observed in Item 3 (adiabatic compression), where 45.5% gave the correct answer, but a considerable proportion (22.7%) chose option C (incorrect). This suggests that students tend to link the phenomenon to everyday experiences or inaccurate prior knowledge. Such a pattern is consistent with Treagust (1988), who argued that alternative conceptions do not simply disappear but reproduce themselves at the university level unless properly addressed through targeted strategies.

In Item 13 (bond energy), 42% of students selected the correct answer, while nearly one-third (31.8%) were attracted to an incorrect option that reflects a common misconception—confusing bond formation energy with bond dissociation energy. This pattern indicates partial understanding of chemical concepts: students hold fragments of knowledge but lack sufficient depth to explain the phenomenon scientifically. A similar issue appeared in Item 14 (compound formation energy), where the largest share (45.5%) chose the correct option, while the rest were divided among distractors close to the correct idea but not fully accurate.

Another notable finding was in Item 12 (temperature change during a phase transition), where 68.2% of students answered correctly the highest rate in the test. This can be explained by the fact that the concept is closer to students' direct experiences and everyday observations, confirming that moving from the tangible to the abstract is not seamless but requires additional pedagogical support. This result is consistent with Vosniadou (2013), who noted that concrete concepts are easier to grasp, while abstract thermodynamic notions remain a major source of difficulty.

Moreover, analysis of the second level of the instrument (justification of answers) revealed that some students provided the correct answer but failed to justify it scientifically. This indicates the presence of superficial understanding, based more on memorization than on deep comprehension. It also shows that some students lack coherent cognitive structures, relying instead on partial or mechanical recall of information—explaining the fragility of their conceptions when asked to provide scientific reasoning.

When compared with previous studies, the findings of this research align with those of Driver et al. (1994) and Chiu (2007), which highlighted that concepts such as internal energy, enthalpy, and entropy are among the most misunderstood by chemistry and science students. They also resonate with Woldamanuel et al. (2015), who showed that students face major difficulties in understanding reversible and irreversible processes, often favoring everyday notions over accurate scientific explanations.

In conclusion, the findings of this study reflect the urgent need to adopt more effective teaching approaches such as computer simulations and visual modeling to make abstract concepts more accessible to students and to connect them with tangible experiences. Furthermore, the two-tier diagnostic instrument proved to be effective not only in identifying correct answers but also in

evaluating the depth of understanding and quality of reasoning, providing rich insights for designing remedial programs aimed at addressing alternative conceptions and supporting the gradual shift from sensory understanding to theoretical abstraction in thermochemistry.

Results of the Second Research Question

The second research question of the study states:

Where do these misconceptions originate, and what are their sources?

The results of the test and semi-structured interviews showed that misconceptions in thermochemistry arise from multiple sources, which can be classified according to what has been indicated in the specialized literature.

From a **cognitive perspective**, studies (Doménech et al., 2007) revealed that the abstract nature of concepts such as internal energy and enthalpy makes students rely on direct sensory perception rather than building correct scientific models. This explains the confusion between heat and temperature.

From a **pedagogical perspective**, research (Bain et al., 2014) highlighted that traditional teaching focusing on memorizing mathematical laws without linking them to physical interpretations reinforces superficial understanding and leads to accumulated errors.

From a **linguistic perspective**, Sozbilir (2003) pointed out that students often use terms such as *heat* and *temperature* interchangeably due to the lack of precise clarification of scientific terminology in multilingual educational contexts, which creates semantic confusion.

In addition, our results showed that some students are influenced by **previous educational experiences** from secondary school, which aligns with Boo (1998). His research demonstrated that alternative conceptions based on everyday experiences hinder deeper understanding once students reach university.

9. Sources of Misconceptions

1. Cognitive Factors

- These are related to the nature of thermodynamic concepts themselves. Internal energy, enthalpy, and entropy are abstract notions that are difficult to represent in tangible reality.
- Students usually encounter them only through symbols and mathematical

equations rather than through direct physical understanding.

- This abstraction generates confusion, such as equating heat with temperature, or believing that internal energy changes simply with pressure or volume without recognizing the role of temperature.
 - Several studies (Doménech et al., 2007) confirmed that this abstraction provides fertile ground for misconceptions, especially in the absence of adequate pedagogical support.
- ### 2. Pedagogical Factors
- Teaching methods in many university courses focus heavily on mathematical derivations and solving quantitative exercises, while neglecting qualitative explanations and visual representations.
 - As a result, students treat the first law, for example, as a bare mathematical equation ($\Delta U = Q - W$) without understanding the balance between internal energy, heat, and work.
 - Research (Bain et al., 2014) emphasized that the lack of variety in teaching strategies (e.g., virtual experiments or conceptual modeling) fosters superficial conceptions and entrenches misconceptions.
- ### 3. Linguistic Factors
- The linguistic aspect is a significant barrier, especially in multilingual contexts like Algerian universities.
 - Terms such as *heat* and *temperature* are often used interchangeably in daily language and even in some textbooks, leading to confusion among students.
 - Other terms like *internal energy* or *entropy* may be translated or used in inconsistent ways, which hinders accurate distinction.
 - Sozbilir (2003) confirmed that the gap between scientific and everyday language directly contributes to distorted understanding of concepts.
- ### 4. Cumulative Factors
- Misconceptions are not necessarily formed at the university level but are often inherited from secondary education.
 - Students who were exposed to oversimplified or inaccurate explanations in secondary school carry these misconceptions to university, where they become more entrenched if not corrected.
 - For example, the belief that pressure “produces heat” or that internal energy can be measured directly like heat.

- Boo (1998) highlighted that the accumulation of misconceptions without reconstruction is a major cause of persistent misunderstanding at university.
5. Curricular Factors
- These relate to the way curricula are designed. Many university courses fail to provide adequate integration between the experimental (laboratory) and theoretical (lecture) components.
 - The lack of computer simulations or digital modeling deprives students of visual and interactive tools to understand thermal system dynamics.
 - This separation between theory and practice leads students to rely on rote memorization instead of observation and explanation, leaving room for misconceptions to persist.
6. Psychological-Social Factors
- Studies show that students often perceive thermochemistry as a “difficult subject” requiring high mental effort and rote memorization rather than deep understanding.
 - This negative perception discourages them from engaging with the concepts.
 - Social context such as performance pressure and exam assessments that emphasize quantitative problem-solving reinforces the tendency to treat thermodynamics as a “mathematical subject” rather than a “conceptual science.”
 - Bain et al. (2014) highlighted in their studies that students’ psychological attitudes significantly affect their understanding of chemical concepts.

Synthesis

These factors **cognitive, pedagogical, linguistic, cumulative, curricular, and psychological-social** do not operate in isolation but intertwine to form a complex web of causes. This makes addressing misconceptions a real challenge that requires a **holistic educational approach**, integrating theory with practice, relying on precise language, continuous assessment, and the use of educational technology.

10. Conclusion

By adopting the experimental approach, this study was able to identify a set of fundamental concepts in thermodynamics that students show remarkable

difficulty in comprehending, such as internal energy, enthalpy, entropy, and types of thermal transformations. The results revealed that these difficulties are not isolated from what is documented in the previous literature, as the nature of alternative conceptions recorded among university students aligns with what has been reported in earlier studies. However, the prevalence of these conceptions and the underlying reasons behind them differ depending on the level of education (secondary or university) and the educational context. The extracted data indicated that there is an urgent need to develop teaching strategies and adopt more effective approaches to overcome the obstacles students face in learning thermodynamics concepts. The research revealed that students hold several alternative conceptions and misconceptions that hinder the construction of correct scientific understanding, and the lack of sufficient prior knowledge weakens their ability to connect new concepts with previous knowledge.

The study also showed that the main reasons behind these alternative conceptions are linked to several factors, the most important of which are: the nature of the educational environment, which is largely characterized by rote learning; the structure of curricula that excessively focus on quantitative aspects without linking them to practical applications; in addition to the absence of experimental and simulation components in presenting concepts, which leads to reinforcing superficial rather than deep understanding. Accordingly, these results highlight the need to reconsider the adopted educational approaches and move toward teaching strategies that integrate conceptual and practical aspects to reduce the gap of alternative conceptions among students.

Based on the results of the study, which revealed a set of misconceptions and difficulties in comprehending thermodynamics concepts, the urgent need became evident to put forward practical recommendations that contribute to improving the teaching of this field and simplifying its concepts for students through curriculum development, teacher training, and the enhancement of applied activities. From these results, a set of recommendations can be proposed as follows:

- Adopting modern teaching approaches that focus on linking conceptual understanding with practical application.
- Enhancing the use of computer simulations and alternative experiments to simplify abstract concepts.
- Revisiting the curricula to ensure a clearer presentation of thermal concepts.

- Incorporating regular diagnostic activities to detect misconceptions and address them early.
- Training teachers in active teaching strategies that aim to foster deep understanding rather than relying on memorization.
- Integrating the experimental aspect with the theoretical aspect to strengthen students' awareness of the connection between laws and applications.
- Clarifying scientific terms and comparing them with their everyday uses to avoid linguistic confusion.

Table 1. The answer of what are the percentages of alternative conceptions related to thermochemistry concepts held by university students?

Rank	Frequency Percentage for Choice A	Frequency Percentage for Choice B	Frequency Percentage for Choice C	Frequency Percentage for Choice D	Correct Conception
1	22.7	43.2	20.5	13.6	B
2	15.9	10.2	23.9	50.0	D
3	45.5	17.0	22.7	14.8	A
4	14.8	21.6	31.8	31.8	C
5	40.9	14.8	33.0	12.5	C
6	48.9	30.7	11.4	9.1	B
7	11.4	50.0	25.0	13.6	B
8	8.0	40.9	25.0	26.1	D
9	17.0	10.2	10.2	62.5	D
10	51.1	17.0	11.4	20.5	A
11	25.0	14.8	54.5	5.7	A
12	8.0	6.8	17.0	68.2	C
13	31.8	42.0	12.5	13.6	A
14	25.0	45.5	25.0	4.5	B
15	20.5	9.1	22.7	47.7	D
16	25.0	48.9	17.0	9.1	B

Table 2. Results Discussion Table

Item	Correct Conception	Percentage of Correct Answers	Notes
1	B - There is no interaction between the molecules	43.2%	A relatively good percentage, but about half of the students confused the definitions, which reflects alternative conceptions about the ideal gas.
2	D - Pressure decreases when the volume increases isothermally	50%	Only half of the students recognized the inverse relationship between V and P; the confusion between heat and pressure is evident.
3	A - T increases in adiabatic compression	45.5%	Less than half; most errors reflect the conception that T is always constant during compression.
4	C - The amount of heat required to raise T by 1 K	31.8%	Weak percentage; students confuse heat, pressure, volume, and work.
5	C - ΔH is the molar heat at constant pressure	33%	Low percentage; the common conception is that enthalpy = heat + work.
6	B - ($\Delta U = C_v \Delta T$)	30.7%	Less than one third; most students consider it related to enthalpy.
7	B - $\Delta U = W$ in the adiabatic transformation	50%	Half of the sample answered correctly, while the other half confused Q with W.

8	D ($-\Delta H=0$)	26.1%	Weak percentage; many thought that Q or W equals zero, reflecting a lack of distinction between state functions and path functions.
9	D ($-Q=0$) in the adiabatic transformation	62.5%	The best result; more than half of the students understood the condition accurately.
10	A $-U=0$ in the isothermal transformation	51.1%	Only half answered correctly, which reflects confusion between the conditions of the transformations.
11	A -U and H depend only on T)	25%	Very weak; more than half of the students believe it depends on P or V.
12	C (T remains constant during the physical change)	68.2%	Highest success rate; this concept is clear to them.
13	A - Bond energy: the energy required for breaking	31.8%	Weak; most students confuse breaking with formation.
14	B $-\Delta H_f$: formation energy from simple elements	45.5%	Average; many students think it is related to the physical state.
15	D - Work is not a state function	47.7%	Average; many confuse state functions with path functions.
16	B - Work depends on the type of transformation	48.9%	About half; this reflects their lack of connection between the PV diagram and work.

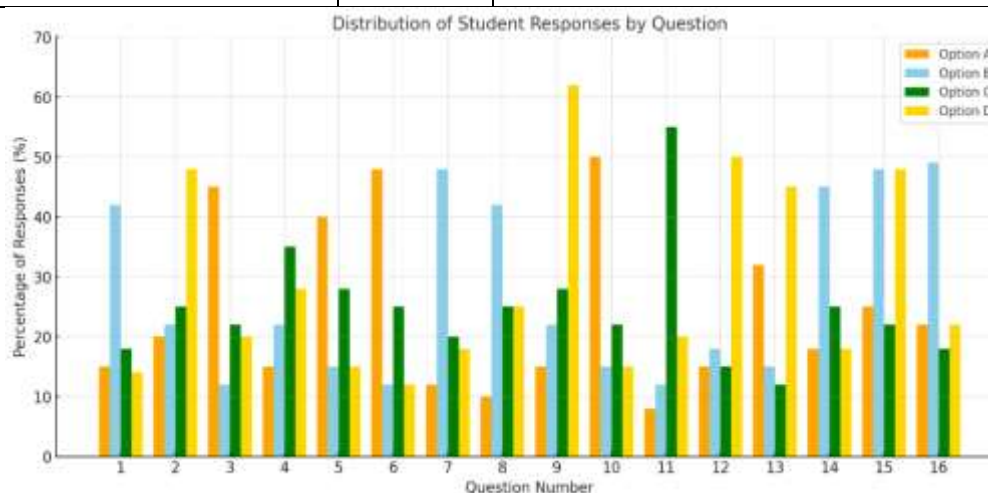


Figure 1. The distribution of students' responses across 16 diagnostic questions

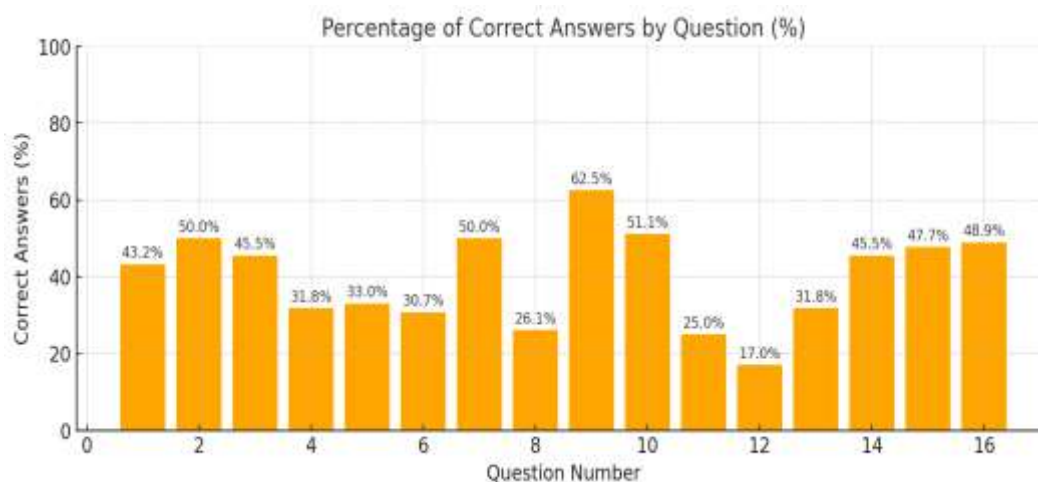


Figure 2. Bar graph of the percentages of correct answers by students

ANNEX

Testing thermodynamic concepts (Two-tier Diagnostic Instrument)

Item	Question (Level One)	Choices	Correct Answer	Reason (Level Two)
1	The Ideal Gas Definition	a) It does not interact with other gases b) There is no interaction between its molecules c) It is not affected by external factors d) It does not exchange energy with the external environment	b	Because the molecules have no volume and collide only elastically.
2	Isothermal Transformation: When the volume increases	a) T increases b) T decreases c) P increases d) P decreases	d	Because the law shows that $P \cdot V = \text{constant}$
3	Adiabatic Transformation	a) T increases b) T decreases c) T remains constant d) P remains constant	a	Because $Q=0$ and the work done increases the energy of the molecules.
4	Heat Capacity of a Gas	a) The amount of heat required to change the volume of the gas by 1 liter b) The amount of heat required to change the pressure by 1 atmosphere c) The amount of heat required to change the temperature by 1 kelvin d) The amount of heat required to produce work of 1 joule	c	Because heat capacity is defined as $C = Q/\Delta T$
5	Enthalpy ΔH	a) The sum of heat and work b) At constant volume c) At constant pressure d) At constant temperature	c	Enthalpy is defined as $H = U + PV$ and is measured experimentally at constant
6	Internal Energy ΔU	a) The change in enthalpy b) The molar heat at constant volume c) The molar heat at constant pressure d) The molar heat at constant temperature	b	Because $\Delta U = nC_v\Delta T$
7	ΔU in the Adiabatic Transformation	a) Heat b) Work c) The sum of heat and work d) The sum of kinetic energy and potential energy	b	Because $Q = 0$ and therefore $\Delta U = W$
8	Cyclic Transformations	a) Heat is zero b) The work done is zero c) Internal energy is zero d) The change in enthalpy is zero	c	Because $\Delta U = 0$ after a complete cycle.
9	Adiabatic Transformation $Q = 0$	a) Isothermal transformation b) Isobaric transformation c) Isochoric transformations d) Adiabatic transformation	d	Because the adiabatic transformation does not allow heat transfer.
10	Isothermal Transformations $\Delta U = 0$	a) Isothermal transformation b) Isobaric transformation c) Isochoric transformations d) Adiabatic transformation	a	Because $\Delta U = nC_v\Delta T$ and T is constant.
11	What U and H Depend On	a) Temperature b) Pressure c) Pressure and temperature d) Volume	a	Because the ideal gas depends only on T
12	Change in Temperature During a Physical Change	a) Increases b) Decreases c) Remains constant d) Changes then stabilizes	c	Because heat is used to change the state rather than to raise the temperature.
13	Bond Energy	a) The energy required to break the bond in the gaseous state b) The energy required to form the bond c) The energy of compound formation d) The energy of physical state change	a	Because it represents the amount of energy that must be supplied to separate the atoms.
14	Compound Formation Energy	a) The energy released during the formation of the compound's atomic bonds b) The energy consumed or released during the formation of the compound from its simple elements c) The energy consumed or released during the formation of the compound from its complex elements d) The energy consumed or released during the change of	a	Because bond formation releases energy.

		physical state		
15	State Functions	a) Internal energy b) Enthalpy c) Entropy d) Work	d	Because its value depends on the path, not only on the initial and final states.
16	Work Done by the Ideal Gas	a) Type of system b) Type of transformation c) Type of gas d) Duration of transformation	b	Because $W = \int P \, dV$ and it depends only on the transformation.

Two-tier Diagnostic Instrument Model

Item 1: Definition of the Ideal Gas Second Level (Reasoning): - Because the molecules have no volume and collide only elastically - Because the temperature is constant - Because the pressure does not change - Because the gas does not absorb or release energy	Item 6: Internal Energy Second Level (Reasoning): - Because $\Delta U = nC_v\Delta T$ - Because $\Delta U = \Delta H + P\Delta V$ - Because it depends only on pressure - Because it never changes
Item 2: Isothermal Transformation Second Level (Reasoning): - Because the law shows that $P \cdot V = \text{constant}$ - Because the temperature increases - Because the internal energy increases - Because the gas absorbs heat	Item 7: ΔU in the Adiabatic Transformation Second Level (Reasoning): - Because $Q = 0$ and therefore $\Delta U = W$ - Because heat is transferred to the surroundings - Because $\Delta U = \Delta H$ always - Because the kinetic energy does not change
Item 3: Adiabatic Transformation Second Level (Reasoning): - Because $Q=0$ and the work done increases the energy of the molecules - Because heat is transferred from the surroundings - Because the system is in equilibrium - Because the volume does not change	Item 8: Cyclic Transformations Second Level (Reasoning): - Because $\Delta U = 0$ after a complete cycle - Because heat does not transfer - Because the work equals zero - Because H is always constant
Item 4: Heat Capacity of the Gas Second Level (Reasoning): - Because heat capacity is defined as $C = Q/\Delta T$ - Because it measures the change in volume - Because it measures the change in pressure - Because it measures only the mechanical energy	Item 9: Adiabatic Transformation (Heat Exchange) Second Level (Reasoning): - Because the adiabatic transformation does not allow heat transfer - Because the heat is constant - Because the pressure does not change - Because the volume is constant
Item 5: Enthalpy ΔH Second Level (Reasoning): - Enthalpy is defined as $H = U + PV$ and is measured experimentally at constant P - Because it always equals ΔU - Because it does not depend on the type of process - Because it equals heat under any condition	Item 10: Isothermal Transformations Second Level (Reasoning): - Because $\Delta U = nC_v\Delta T$ and T is constant - Because the pressure is constant - Because the volume is constant - Because the work is zero

Item 11: Second Level (Reasoning): - Because the ideal gas depends only on T - Because pressure determines the energy - Because H and U do not depend only on T - Because volume always affects	Item 14: Compound Formation Energy Second Level (Reasoning): - Because bond formation releases energy - Because ΔH depends only on the elements of the compound - Because the energy does not change - Because the heat used only changes the state
Item 12: Change in Temperature During the Physical Change Second Level (Reasoning): - Because heat is used to change the state rather than to raise the temperature - Because energy is annihilated - Because pressure increases - Because work leads to the change	Item 15: State Functions Second Level (Reasoning): - Because its value depends on the path, not only on the initial and final states - Because it is related only to temperature - Because it is always a conserved quantity - Because it is constant in all transformations

Item 13: Bond Energy Second Level (Reasoning): - Because it represents the amount of energy that must be supplied to separate the atoms - Because it is measured at constant temperature - Because it expresses the heat of formation - Because it depends only on the physical state	Item 16: Work Done by the Ideal Gas Second Level (Reasoning): - Because $W = \int P dV$ and it depends only on the transformation - Because work does not depend only on the type of system - Because the gas has different properties - Because time does not determine the amount of work
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- **Ethical approval:** The conducted research is not related to either human or animal use.
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