Study on the difficulties in learning fundamental concepts of thermodynamics in the initial training of physics teachers: the case of analogical scientific reasoning

Tarcilo TORRES, Laura ÁLVAREZ, Sebastián MORENO, María José RUIZ, Víctor CALVO, Bibiana Cuervo, Katerin VALENCIA

Faculty of Education, University of Antioquia, Medellín, Colombia.

Abstract. An exploratory study on urban thermodynamics with 24 participants compared their responses in interviews with those of an artificial intelligence. Results showed varied responses, with some moderate agreement. The study suggests interdisciplinary educational strategies are crucial for addressing urban thermal challenges, promoting deeper understanding and concrete actions in urban environments.

Introduction and problem statement

Thermodynamics, a foundational aspect of physics, delves into the laws governing energy exchange and transformation in physical systems (Smith, 2010). A central challenge in this field, known as the Kelvin-Planck statement, asserts the impossibility of creating a heat engine that transfers heat from a cold body to a hot one without external work, constraining machine efficiency.

Understanding thermodynamics is vital in training physics teachers, providing the groundwork for teaching key concepts like energy conservation and the second law of thermodynamics. Its significance spans from engineering to medicine (Brown, 2015).

Addressing the challenge of comprehending thermodynamics in teacher training necessitates concrete examples and practical activities linking theoretical concepts to real-world scenarios. Interdisciplinary pedagogical approaches encourage collaboration with other fields, broadening educators' perspectives on its relevance.

Research on this issue in Colombian universities aims to enhance educational quality and prepare students for real-world challenges, promoting interdisciplinary collaboration Innovative teaching strategies improve thermodynamics comprehension, benefiting science and technology professionals.

Efforts are directed towards designing effective pedagogical strategies for teaching thermodynamics in Colombian universities, aiming to enhance teaching quality, strengthen professional training, and advance science education in the country.

Analogical reasoning emerges as a rigorous teaching strategy, facilitating the connection of abstract concepts to everyday phenomena. Educators must guide students to use accurate analogies reflecting underlying physical principles, aligning with the notion of coherent mental model development (Gentner & Holyoak, 1997).

Prior research demonstrates the efficacy of analogical reasoning in physics learning, aiding problem-solving and deep comprehension. Analogies help overcome student misconceptions and build accurate models of thermal processes in thermodynamics teaching (Clement, 1982).

Challenges persist in understanding concepts like the second law of thermodynamics, crucial in various fields including climate science. Maxwell's "Angel" experiment illustrates the law's significance, showcasing the incompatibility of violating thermodynamic equilibrium (Singh & O'Neill, 2022).

Research methodology

A qualitative study with a convergent mixed methods design (Creswell and Creswell, 2018) will be implemented to address the research questions. The sample included 12 students of a Bachelor's Degree in Physics from the University of Antioquia, Medellín-Colombia. Individual interviews were conducted " face to face " (n1=12) and the students solved Maxwell's " Angel " (n2=12) with artificial intelligence. During the interviews, 2 physics problems were presented, requesting analogies for their resolution. The data were analyzed with statistical techniques and tools such as R studio and Jasp , identifying emerging patterns and themes.

Results

Individual Interview Analysis: Comparing Concepts Between Humans and AI

Research in physics, particularly thermodynamics, uncovers insights into heat, environment, and energy (see Figure 1). Urbanization's impact on "heat islands" is noted, with trees acting as heat sinks, illustrating thermodynamic principles. IPCC reports on climate change in urban areas align with findings. Solutions like green roofs and reflective materials are proposed to counteract heat islands. Thermodynamics-focused research highlights concepts such as "heat islands" and vegetation's role in urban thermal regulation. The significance of construction materials and ventilation in mitigating heat accumulation is emphasized. Interdisciplinary approaches are advocated through analogies integrating physical principles with environmental and urban considerations (see Figure 2). An analysis compared students' and artificial intelligence's (AI) responses, revealing variable consistency. Cohen's kappa ranges from 0 to 0.625, indicating moderate to substantial agreement for some concepts, while slight or poor agreement for others. Percentage of agreement varies from 50.0% to 92.0%, suggesting inconsistency in responses between students and AI.

Provisional conclusions

The findings highlight the importance of considering sociodemographic and academic aspects in effective educational strategies. Participants propose solutions to urban thermal challenges based on thermodynamic and environmental principles. The need for an interdisciplinary approach is underlined when addressing heat islands. The variability in responses, highlighted by the analysis, highlights the importance of assessing consistency and using multiple measures. This study offers a comprehensive view of urban challenges and highlights the need for collaborative and multifaceted action for environmental sustainability.

References

[1] E. Brown, *Procesos Termodinámicos y las leyes primera y segunda (STPFaSL).* Tesis Doctoral. University of Pittsburgh, 2015.

[2] J. W. Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches,* Sage Publications, 2018.

[3] D. Gentner and K. J. Holyoak, Reasoning and learning by analogy: Introduction, *American Psychologist* **52**(1) (1997) 32-34.

[4] J. Smith, *Thermodynamics: Fundamentals and Applications*, Pearson Publishing, 2010.

[5] M. S. Singh and M. E. O'Neill, Thermodynamics of the climate system, *Physics Today* **75**(7) (2022) 30-37. https://doi.org/10.1063/pt.3.5038