# Exploring Prospective Teachers' Conceptions in Thermal Physics

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**Abstract**

*A substantial body of research has documented the prevalence of naïve understandings of scientific concepts among students. These misconceptions can impede learning and persist despite classroom instruction. This study examined the understanding of fundamental thermal concepts, such as heat transfer, specific heat, the relationship between boiling point and pressure, and phase changes, among 170 prospective teachers from various colleges. The data revealed that a significant number of participants held conceptions that deviated from established scientific principles. Additionally, the study identified a variety of reasoning employed by prospective teachers to explain these concepts. Building on these findings, the researcher developed a range of strategies to address the identified alternative conceptions.*

***Keywords:*** *Alternative conceptions, thermal physics, heat transfer, specific heat, boiling, phase change, prospective teachers*

## Introduction

Students often hold preconceived notions about various concepts and phenomena. It is challenging to address their ideas as they are deeply ingrained. Students develop alternative beliefs through interactions with their physical and social environments, including the use of imprecise language. They conceptualise a concept or phenomenon based on their understanding or previous experiences. It is widely acknowledged that traditional teaching methods that ignore students' pre-existing views are largely ineffective in altering their naïve ideas. According to Wenning(2008),"Students come to school with alternative conceptions that deal with the natural world that are highly resistant to change and strongly influence new learning. These improper interpretations are collectively known as alternative conceptions."

Teachers play a crucial role in shaping the cognitive framework of students. So, it is imperative for teachers to recognise the alternative conceptions students hold and assist in aligning them with scientific principles. Prospective teachers are in the initial phase of their teaching careers. During this stage, it is essential for them to transition from a learner's perspective to that of a teacher, and reflect on their depth of subject knowledge. This transformation typically takes place while they are engaged in practical teaching sessions. Prospective teachers enter teacher education programmes with their own conceptions, ideas and beliefs, shaped by formal and informal experiences. If prospective teachers carry alternative conceptions, they may inadvertently communicate them to their students. Research findings suggest a strong resemblance between alternative conceptions of prospective teachers and those of their students (Fredreik, et al.,1999).

Concepts related to thermal physics pose significant challenges for both students and educators. At times, prospective teachers themselves tend to use terms like 'heat' and 'temperature' interchangeably (Kartal, et al., 2011; Sari, 2017; and Keleş et al., 2010). Students found it difficult to relate temperature change with the specific heat of a substance (Niaz,2000; Kruatong, et al., 2006). Many believe that heating always leads to an increase in temperature (Yeo and Zadnik,2001; and Chu, et al.,2012). Some students assume that food gets cooked in a pressure cooker due to extra heat generated inside it (Kruatong, et al., 2006).

There is an urgent need for more comprehensive teacher training programmes that emphasise conceptual development alongside pedagogical instruction. The cognitive development of students can be enhanced when educators actively engage in the process of knowledge construction alongside their students.

A structured framework must be in place to facilitate the professional growth of educators (National Curriculum Framework, 2005). Revisions in the teacher preparation curricula are essential to address these concerns. Special attention must be placed on fostering the conceptual understanding of prospective teachers during their course of study. Various theoretical frameworks within the realm of teacher education need to be re-examined and reconstructed (NCFTE, 2009).

Teachers should be well-informed about the preconceptions and misconceptions their students hold. They must be supported in using a variety of teaching–learning strategies to address individual student's understanding ('Constructivist Approaches to Teaching and Learning', NCERT, 2006). If these misconceptions ideas are not adequately countered and challenged through research-based methods by research, they may evolve into persistent alternate conceptions that students carry throughout their education (NCFSE, 2023).

## Research Questions

What are the alternative conceptions of prospective teachers in thermal physics?

2.What strategies could be adopted to deal with those alternative conceptions?

## Methodology

This article is part of a broader investigation titled Analysing and Addressing Pre-Service Teachers' Conceptions in Heat and Thermodynamic Phenomena, which was conducted in five phases—Prior-Interventional, Piloting, Pre-Interventional, Interventional and Post-Interventional. The study aimed to identify the alternative conceptions prevalent among pre-service science teachers, develop research-informed teaching modules and conduct sessions to implement these modules to engage with the alternative conceptions. The study sought to facilitate a transition in pre-service teachers' conceptual understanding, helping them shift from their existing alternative conceptions to scientifically accepted ones. A detailed literature review and informal discussions with pre-service teachers were conducted to explore the causes of these alternative conceptions.

This article elaborates on only the first three phases of the broader study. In the Prior-Interventional Phase, a test was developed after reviewing the literature on students' alternative conceptions in heat and thermodynamics, and making various off-hand observations of pre-service teachers' teaching. The test consisted of 25 questions, including both open and close-ended questions. The objective was to assess the possible prevalence of alternative ideas among teachers. Some test questions were adapted from standardised, well-known inventories. Experts in the field validated the questionnaire and their suggestions were incorporated.

During the Piloting Phase, the developed test was administered to 30 pre-service science teachers to check its feasibility and effectiveness. Based on the responses received, the questions were analysed and some modifications were made. The final test consisted of 25 questions, primarily multiple-choice questions (MCQs) along with some open-ended questions. The MCQs included one scientifically correct option (answer), while the other options (distractors) reflected common alternative conceptions identified in the literature and responses received during pilot testing.

In the Pre-Interventional Phase, the final test was administered to a larger sample of 170 pre-service teachers from different colleges in Delhi. These participants were enrolled in a B.Ed. programme and had already obtained a degree in science, having studied physics in their undergraduate courses. The primary objective of the study was to identify pre-service teachers' conceptions about thermal concepts across four domains—heat transfer, specific heat, the relationship between boiling and pressure, and phase change phenomena. From the beginning, it was clarified to the participants that the assessment was solely being conducted for research purposes and would not affect their grades. They were instructed to respond to each question and were encouraged to express their opinions individually if they disagreed with any of the given multiple-choice options.

Based on the responses received through a test, intervention modules were developed to address the identified alternative conceptions. The researcher devised a strategy, in which some teaching interventions were implemented using these developed modules to counter the misconceptions identified alternative ideas. In this study, only an outline of the developed modules was provided. The details of their transaction and implementation procedures are elaborated in the main study, specifically in the interventional and the post-interventional phases.

## Discussion on Thermal Concepts

**Heat transfer**: Heat is the energy that travels from a hotter body to a cooler one. Once energy is transferred, it is no longer considered heat. The change in temperature $\Delta t$ depends on the amount of heat transferred (Q), the specific heat of a substance(c), and the mass of the substance(m), and is calculated by the formula $Q=mc\Delta t$.

**Specific heat**: It is the amount of heat required to raise the temperature of one gram of a substance by one degree Celsius. The change in the temperature of a substance depends on its specific heat. A substance with a lower specific heat will heat up or cool down faster than one with a higher specific heat.

**Boiling and its relationship with pressure**: Boiling occurs when a liquid is heated to its boiling point and transforms into vapour. The boiling point of a liquid is determined by its temperature, air pressure and vapour pressure. Boiling takes place when the air pressure equals the liquid's vapour pressure. The vapour pressure created by water vapour molecules in bubbles collides with air molecules. Different substances have different boiling points because of variations in their vapour pressures. Lowering the pressure reduces the energy required for a liquid to transition to the gaseous phase, causing it to boil at a lower temperature.

Boiling can be achieved either by increasing the vapour pressure or by decreasing the atmospheric pressure. This paper discusses the boiling of water. Water can boil both below100 degrees Celsius and above 100 degrees Celsius. At higher altitudes, water boils below 100 degrees Celsius, whereas increasing the pressure causes water to boil above 100 degrees Celsius. Additionally, the temperature of a substance can exceed its boiling point.

**Phase change**: It is a process in which matter transitions from one state (solid, liquid, gas or plasma) to another. During a phase change, the temperature of a substance remains constant for some time during the change of state. until the transition is complete. During phase change, the heat absorbed or released is used to alter the substance's thermodynamic state or phase.

## Findings and Data Analysis

The data were analysed and interpreted. The multiple-choice items were assessed based on the correctness of responses, while subjective items were evaluated qualitatively. The data were also analysed quantitatively using percentage analysis. In a qualitative study, data analysis involves preparing and organising the data, reducing it to certain themes, and finally presenting and comparing it through tables, charts and graphs. The data were categorised into the following four themes based on the identified alternative conceptions of 170 prospective teachers.

## Predicting the Final Temperature of the Mixture after Heat Transfer

In this question, the prospective teachers were asked to determine the final temperature of a water mixture after combining two different quantities of water at different temperatures, neglecting the heat transfer during mixing.

This question is based on the concept of heat transfer, represented by the equation Q =**mcΔT** where Q is the heat transfer, mis the mass of the substance, c is the specific heat of the substance and **ΔT** is the change in temperature of the substance.

As shown in Figure 1,62% of the prospective teachers correctly predicted that the temperature of the mixture would be between 25 and 50 degrees Celsius. However, after reviewing and analysing their responses, it was found that only a few of these 62% prospective teachers provided the right reasoning by accurately applying the formula Q= **mcΔT** to calculate the final temperature.

Some of the incorrect explanations provided by prospective teachers who marked the correct option included the following.

- "The larger volume of water had a higher temperature, so even after mixing with cold water, the temperature won't drop beyond 25 degrees Celsius."
- "Energy dissipation will occur due to mixing."
- "The average temperature of the container is greater than 25 degrees Celsius as the amount of water, which is at 50 degrees Celsius, is 200 gm, while the other is only 100 gm."

Additionally, some prospective teachers even applied the ideal gas law (PV = nRT) in this question to calculate the temperature, which was not appropriate.

These responses indicate that many prospective teachers hold alternative conception, such as believing that after reaching equilibrium, the final temperature is simply the average of two liquids after mixing or that increasing the amount of a substance increases the final temperature.

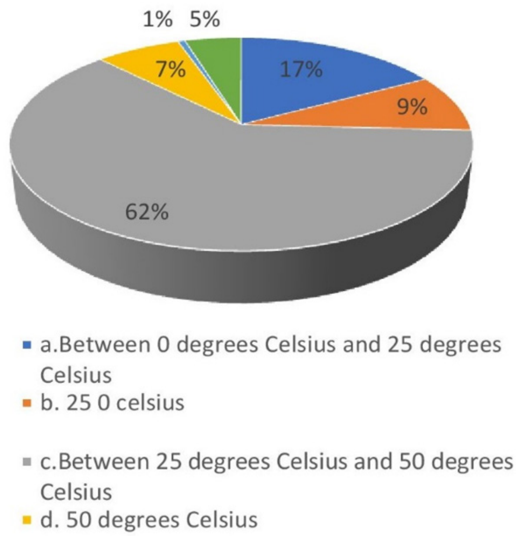


*Figure 1: Prospective teachers' responses on predicting the final temperature of the mixture*

## Prospective Teachers' Understanding about Specific Heat and Temperature

The conceptual knowledge of prospective teachers regarding temperature and its relationship with the specific heat of a substance was assessed through this test question. In this question, a situation was given, in which equal quantities of iron and water were heated by the same source for the same duration. The prospective teachers were asked to determine which substance would undergo a greater change in temperature and why.

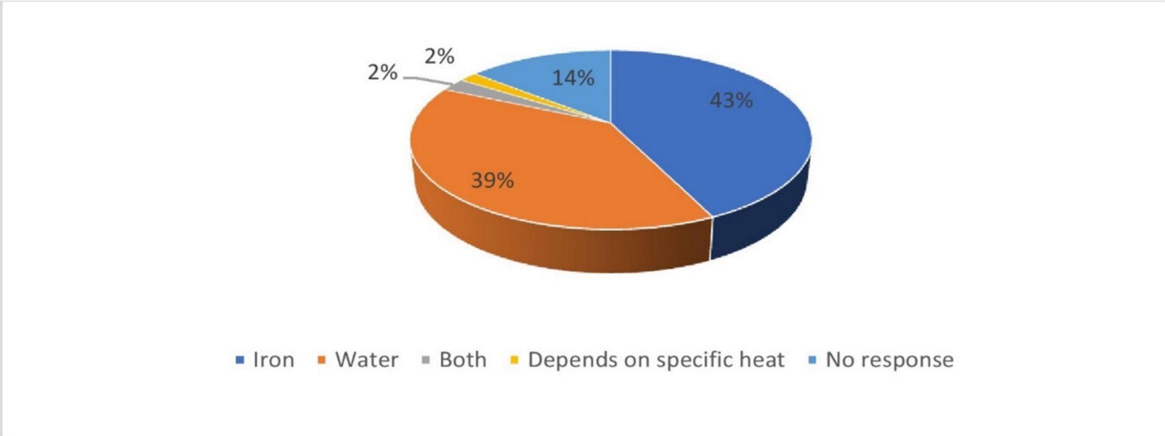


*Figure 2: Prospective teachers' responses for selecting iron, or water, or both for undergoing greater change in temperature*

As illustrated by their responses in Figure 2, 43% of the prospective teachers correctly stated that iron would undergo a greater change in temperature. However, only 26% provided the correct reason, explaining that iron has a lower specific heat than water, and therefore, it experiences a greater change in temperature.

Some prospective teachers gave incorrect reasons, such as:

- "The change in temperature would be greater in iron because iron is solid, so its particles are tightly packed."
- "Iron is a good conductor; therefore, heat transfer will occur rapidly."
- "Water will undergo a greater change in temperature because, as a liquid, its atoms move freely as compared to iron."

After a qualitative analysis of their responses, the prospective teachers' explanations were categorised into various themes. Their responses indicate that an alternative conception—that for a given amount of heat, there is no relationship between the increase in a substance's temperature and its specific heat. The diverse range of responses, as shown in Table 1(a), Table 1(b),Table 1(c),Table 1(d) and Table 1(d), suggest a weak conceptual understanding of this concept among prospective teachers.

**Table1: Reasons cited by Prospective Teachers for opting substance undergoing Greater Change in Temperature**

| Iron | |
|---|---|
| **Reasons for Choosing Iron** | **No. of Prospective Teachers** |
| Iron (no reason) | 13 |
| Iron is a good conductor of heat. | 18 |
| The specific heat of iron is less than water. | 19 |
| Solid particles are tightly packed in iron. | 12 |
| Iron has high thermal conductivity. | 3 |

| | |
|---|---|
| Iron is more effective. | 1 |
| Iron stores more heat. | 2 |
| Iron will take more time to heat. | 2 |
| Iron has high melting and boiling points. | 3 |

**Table 1(a): Reasons cited by PT for opting iron for undergoing greater change in temperature**

| Water | |
|---|---|
| **Reasons for Choosing Water** | **No. of Prospective Teachers** |
| Water (no reason) | 20 |
| Low melting and boiling points | 13 |
| Water has High boiling point | 1 |
| Liquid state atoms are loosely packed. | 12 |
| High internal energy | 1 |
| Water takes less time to get heated | 1 |
| Water has High calorific value | 1 |
| Water starts to evaporate after reaching its boiling point. | 4 |
| Water has less specific heat than iron. | 1 |
| It has less intermolecular force. | 3 |
| Molecules in water move freely. | 1 |
| Water has high energy or thermal conductivity | 2 |
| Water has low density, so its molecules move fast. | 4 |
| Water has High entropy | 1 |
| Specific heat of water is more than iron | 2 |

**Table 1(b) : Reasons cited by PT for opting water for undergoing greater change in temperature**

| Reason Given by Prospective Teachers | No. of Prospective Teachers |
|---|---|
| The change in temperature depends on specific heat. | 4 |

**Table 1(c) :Reasons cited by PT for change in temperature**

| Reason Given by Prospective Teachers | No. of Prospective Teachers |
|---|---|
| The change in temperature would be same in both iron and water. | 3 |

**Table 1(d) :Reasons cited by PT for change in temperature**

| No Responses given by Prospective Teachers | No. of Prospective Teachers |
|---|---|
| No responses | 23 |

**Table 1(e):PT not responded for this question**

## Analysing Prospective Teachers' Understanding of Boiling Point and Pressure

A common alternative conception among prospective teachers was that water always boils at 100 degrees Celsius. According to them, water could neither boil below nor above 100 degrees Celsius, as reflected in their responses. Figure 3shows that only 22% of the prospective teachers correctly stated that increasing pressure raises the boiling point. So, in a pressure cooker, water boils above 100 degrees Celsius due to increased pressure, allowing food to cook faster. However, 25% of the prospective teachers incorrectly perceived that increasing pressure lowers the boiling point of water. Additionally, 30% cited that increasing pressure generated extra heat. An analysis of their responses reveals misconceptions, such as the belief that water always boils at 100 degrees Celsius under all conditions, that the boiling point is the maximum temperature a substance can reach, that there is no relationship between boiling and pressure, or that extra pressure generates extra heat.

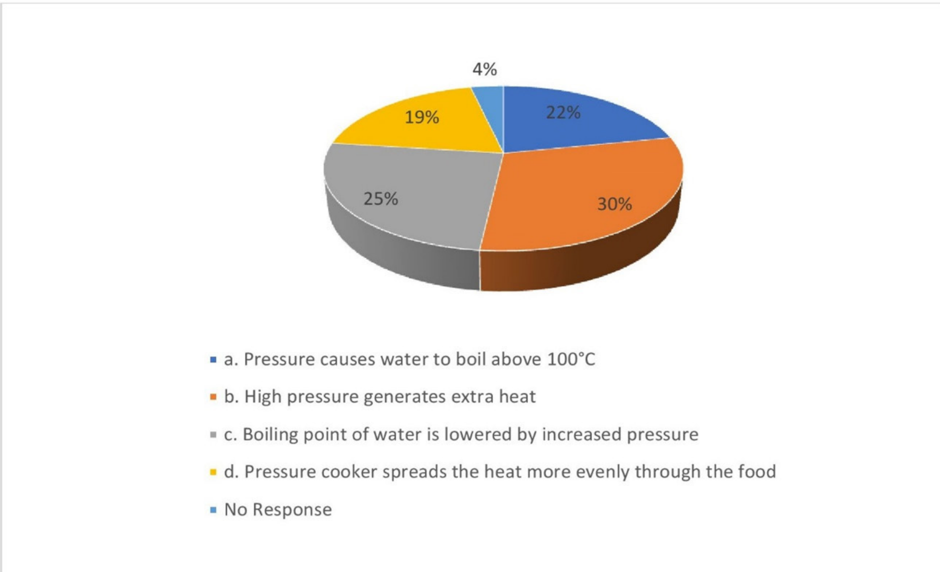


*Figure 3:Prospective Teachers' responses for the relationship between boiling point and pressure*

## Analysing Prospective Teachers' Interpretation of Phase Change

This question assessed the prospective teachers' knowledge of phase change. It was open-ended, requiring them to mention instances where they had observed no change in the temperature of a substance despite heat being supplied. Many responses were recorded, as shown in Figure 4. A total of 15% of the prospective teachers answered correctly, stating that during a phase change or change of state (from solid to liquid or liquid to gas), the temperature of a substance does not change, i.e., it remains constant. Additionally, 19% correctly mentioned that the temperature of ice does not change during melting, while 6% stated that the temperature remains unchanged during the boiling of water. However, some prospective teachers incorrectly stated that the temperature of materials like metal, paint, wood, glass, oil, insulator, diamond, gold, mercury, railway track, etc., would not change on heating. Moreover, 2% of the prospective teachers held the misconception that the temperature of a substance always changes when heated. These findings indicate that most prospective teachers struggled to recall correct instances and lacked understanding of the concept of phase change.

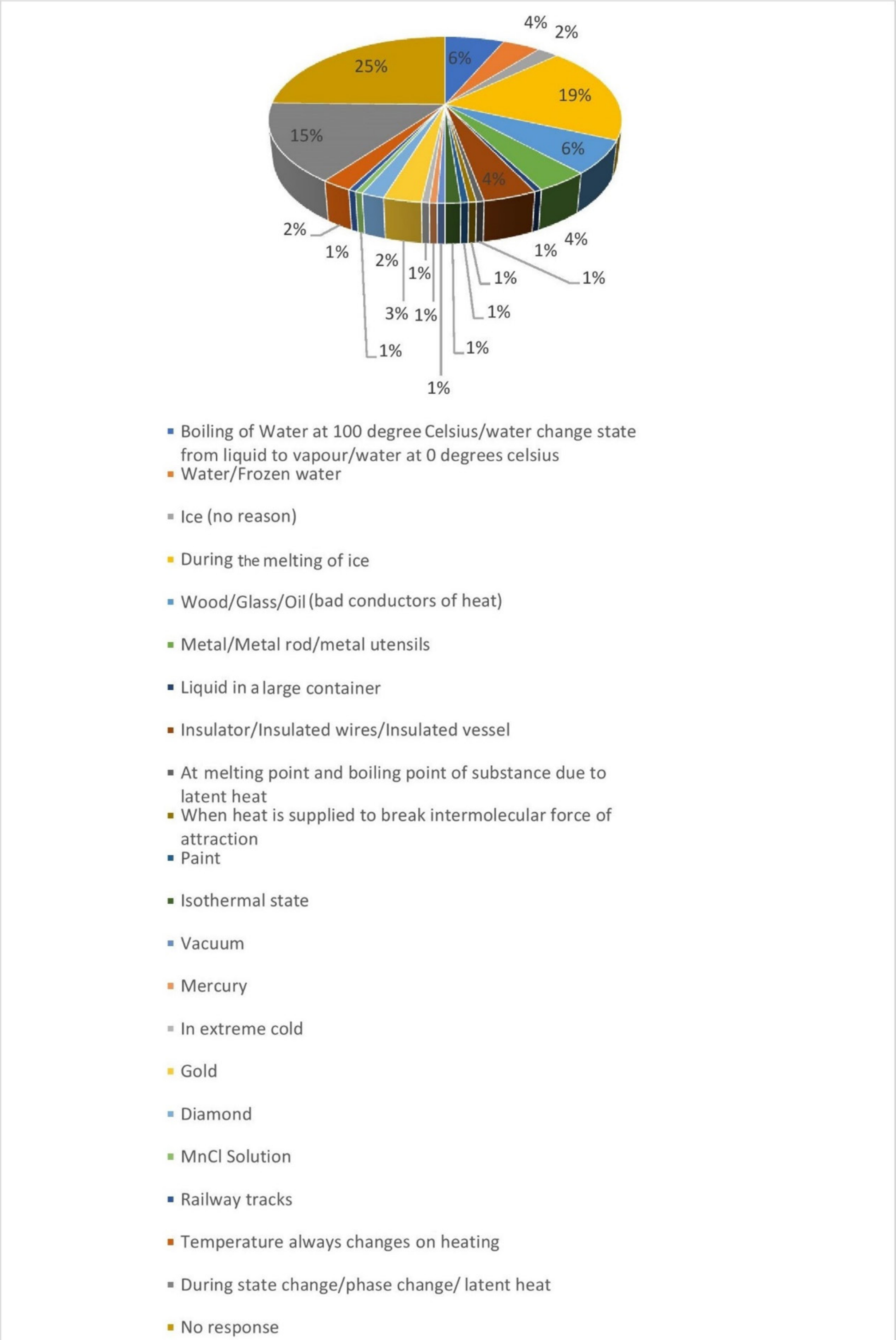


*Figure 4: Various substances mentioned by prospective teachers as having constant temperature during phase change*

## Rationale for Developed Modules to Address Alternative Conceptions

Interventional teaching modules were designed using various instructional strategies, such as the demonstration method, analogy-based teaching, the POE(Predict-Observe-Explain) method, cognitive conflict-based instructions and ICT-based simulations. As established by numerous researches, these strategies have proved effective in bringing about the desired conceptual change among learners.

Research studies have also shown that learning in science can be best done through hands-on experience (Position Paper, NCERT, 2006). Analogy-based teaching has been found to facilitate conceptual change (Haglund and Jeppsson,2014; James and Scharmann,2007; and Vosniadou, et. al,2001). Several studies have also demonstrated that ICT is an effective tool for addressing alternative conceptions (Demirci,2005; Finkelstein, et, al., 2005; and Aslan and Demircioğlu, 2014). The POE strategy has also been found to foster conceptual change (White and Gunstone,1992; Pathare, et al.,2015; and Radovanović and Sliško,2013).

The identified alternative conceptions were addressed through carefully developed interventional learning modules, incorporating real-life, intriguing examples. For instance, to teach the concept of specific heat, it was discussed that if an equal amount of heat is supplied to equal masses of different substances, the resulting temperature change will not be the same. This was further demonstrated in the module through activities and challenging short-answer questions.

For Example, consider Cup A containing 1litre of water and Cup B containing 2litres of water (both the cups are made up of the same material). Initially, water in both the cups was at room temperature. They were then placed on a hot plate and heated until the water in both the cups started boiling (100°C). The following question was posed to the respondents.

"According to you, in which cup more heat is transferred? Please tick against the appropriate option: Cup A________ or Cup B________."

Engaging demonstrations were also included, such as an activity illustrating the relationship between boiling and pressure. ICT-based simulations and videos further reinforced the concept of specific heat.

Different conceptual change approaches were incorporated in the modules. Alternative conceptions related to heat transfer were addressed through a module that explained the concepts of heat, temperature and heat energy transfer. The module also covered the historical development of the concept of heat, the difference between heat and temperature, and how heat transfer occurs. The amount of heat transferred from one object to another is determined by the heat transfer formula: $Q = mc\Delta T$. Here, 'Q' is the heat transferred, 'm' is the mass of the substance and '$\Delta T$' is the change in temperature. The symbol 'c' stands for specific heat, which depends on the material and its phase.

Analogy-based teaching to explain new concepts has been reported as a helpful strategy in related research literature (James and Scharmann,2007). This strategy has been incorporated in the module where the concept of specific heat was compared with the concept of inertia in mechanics: just as inertia resists changes in an object's state, specific heat resists changes in a substance's temperature. This analogy was further clarified through a demonstration and an online simulation.

The module included a demonstration where equal amounts of water and mustard oil were heated separately in an electric kettle for the same duration. The resulting changes in temperature were recorded, revealing variations in temperature between the two liquids, thereby illustrating the concept of specific heat. Additionally, prospective teachers engaged in an online simulation using the Java Lab application, where they compared a substance with low specific heat to one with high specific heat, as shown in Figure 5.

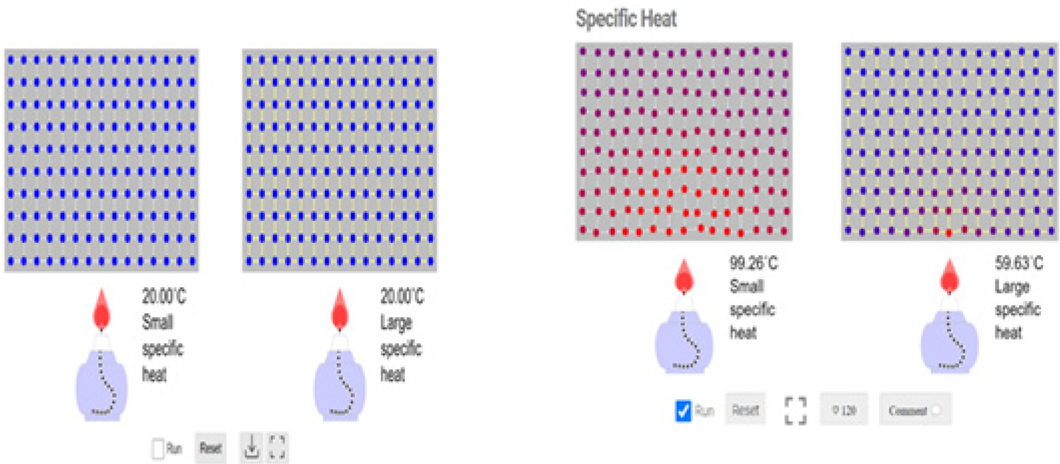


*Figure 5: ICT simulation to demonstrate a substance undergoing change in temperature with large specific heat and small specific heat*

The concept of boiling point and the relationship between boiling and pressure were explained through a demonstration. To illustrate this concept, a module was designed to demonstrate that water can boil below 100 degrees Celsius, as shown in Figure 6. Boiling occurs when the atmospheric pressure equals the vapour pressure of the liquid. In the demonstration, a syringe was half-filled with water, and air bubbles were removed by pressing the piston. Then, the mouth of the syringe was sealed, and the piston was pulled outward to reduce the pressure inside. As a result, the water began to boil below 100 degrees Celsius. This demonstration caused cognitive conflict among the prospective teachers, who previously believed that water boils only at 100 degrees Celsius.

*Figure 6: Demonstration of boiling of water below 100 degrees Celsius by reducing pressure*

Heating a substance does not always lead to a rise in its temperature. Therefore, the concept of phase change was validated through an activity. The POE strategy was employed in this module to explain the phase change concept .Prospective Teachers were instructed to constantly watch and record the temperature while the given amount of water was being heated. Before the experiment, they were asked to predict how the temperature would change during the heating process. They were asked to continually observe and note down the temperature as the water was heated. The results of the activity differed from the predictions made by some Prospective Teachers. The contradictions were subsequently explained.

## Conclusion

After collecting and analysing the data, it can be inferred that prospective teachers held alternative conceptions of various concepts in thermal physics. The prevalence of alternative conceptions or misconceptions may be attributed to several factors. Presumed ideas, metaphors, language barriers, conceptual difficulties and teacher-driven approaches are among the predominant causes for the formation of alternative conceptions (Pathare and Pradhan,2010). Additionally, plain definitions without proper explanations in textbooks often cause confusion among students (Sözbilir,2003). Ambiguous terminology and confusing symbols given in the textbooks further contribute to the strengthening of alternative conceptions (Bauman,1992). As a result, prospective teachers lacked a comprehensive understanding of certain concepts.

This study highlights the need for innovative teaching strategies to address these alternative conceptions or misconceptions. Various strategies, including analogy-based teaching strategy, POE strategy, ICT-based simulations, demonstrations and cognitive conflict statements, were employed. The developed modules proved to be effective in addressing the alternative conceptions held by prospective teachers, as established in the larger part of this study.

## Alternative Conceptions Identified from This Research

- After reaching equilibrium, the final temperature is the average of the two mixed liquids, or it increases with the amount of substance.
- For a given amount of heat provided, there is no relationship between the increase in a substance's temperature and its specific heat.
- Water boils only at 100 degrees Celsius under all conditions, or the boiling point is the maximum temperature a substance can reach, or there is no relationship between boiling and pressure, or extra pressure generates extra heat.
- Heating always results in increasing the temperature of a substance.

## Questions of the Test

1. Cup A contains 100 grams of water at 0 degrees Celsius and Cup B contains 200 grams of water at 50 degrees Celsius. The contents of the two cups are mixed in an insulated container (no heat transfer occurs during mixing). When the mixture reaches thermal equilibrium, what is the final temperature of the water in the container? Give reason for your answer.
   (a) Between 00C and 250C
   (b) 250C
   (c) Between 250C and 500C
   (d) 500C
   (e) Higher than 500C

Reason for your answer: ____________________

______________________________________________

______________________________________________

2. If the same quantity of water and iron are heated by the same source and for the same duration, then which substance will undergo a greater change in temperature? Why?
3. Food cooks faster in a pressure cooker than a normal saucepan. What could be the possible reason for this?
   (a) Pressure causes water to boil above 100°C.
   (b) High pressure generates extra heat.
   (c) The boiling point of water is lowered by increased pressure.
   (d) Pressure cooker spreads the heat more evenly through the food.

If you think of any other reason please write.

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4. Can you think of instance, in which the temperature of an object/substance does not change despite heating it for some time?

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