

**Ph.D. Title-Analysing and Addressing Prospective Teachers'
Conceptions of Heat and Thermodynamic Phenomena**

Findings of Ph.D.

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Findings of the study: -

Based on the objectives of the study, findings are compiled as follows: - *Objective 1: - To explore prospective teachers' conceptions of heat and thermodynamics phenomena.*

Based on various off-hand observations as a teacher educator, literature review, pilot testing and pre-test analysis, 25 alternative conceptions were identified. (Detail in chapter 4).

Objective 2: -To identify prospective teachers' those ideas which differ significantly from scientific conceptions.

The following prominent alternative conceptions (demonstrated by more than 50% of the prospective teachers) were identified based on a pre-test analysis of 170 pre-service teachers:

- ***Alternative Conception: Temperature is an extensive quantity, and the final temperature of two mixtures at different temperatures is the average of two temperatures.***

Pre-service teachers could not relate the concept of heat transfer to predict the change in temperature of the mixture. They failed to interpret the formula of heat transfer, i.e., $Q = mc\Delta T$, in predicting the final temperature. Moreover, they inappropriately applied an additive strategy by adding two different temperatures and averaging out to calculate the final temperature, considering temperature as an extensive variable.

- ***Alternative Conception: More heat is transferred to a lesser volume of water than a larger volume of water (at the same temperature difference), or the same amount of heat will transfer to a different volume of water when water in both vessels reaches 100 degrees Celsius.***

Pre-service teachers held the alternative conception that the same material would receive the same amount of heat from the same source irrespective of the volume (keeping the temperature constant). They did not acknowledge the fact that heat transfer also depends upon the mass of the substance according to the formula $Q = mc\Delta T$.

- ***Alternative Conception: A substance contains heat, or heat is a substance.***

Result analysis also highlighted the PSTs' lack of sound understanding of concept heat. They were found to be considering heat as a substance which was contained in a matter. They did not recognize the difference between heat and internal energy.

- ***Alternative Conception: Different objects possess different temperatures when kept at the same room temperature or in the same surroundings.***

A large number of pre-service teachers were of the opinion that different objects possessed different temperatures even when kept in the same surroundings over an extended period of time. They seemed to be relying on their senses through touch or feel in predicting the degree of hotness or coldness of the substance.

- ***Alternative Conception: For a given amount of heat provided, there is no relation between an increase in the temperature of the substance and the specific heat of the substance.***

Pre-service teachers could not relate that change in temperature depends upon the specific heat of the substance. The concept of specific heat was not completely understood by the pre-service teachers. Although many pre-service teachers marked the correct answer, but their reason was incorrect.

- ***Alternative Conception: Water boils only at 100°C under all conditions, or the boiling point is the maximum temperature a substance can reach***

Most of the pre-service teachers assumed that boiling point is the maximum temperature a substance could reach and boiling cannot occur above or below 100°C degrees Celsius. They did not comprehend the relation between pressure and boiling point and could not describe how boiling point varies with change in pressure.

- ***Alternative Conception: Temperature of the ideal gas will increase as the pressure increases, and pressure is directly proportional to the temperature as per the ideal gas law. Or Temperature of the ideal gas will decrease as the volume decreases, and volume is directly proportional to the temperature as per the ideal gas law. Or No change in the temperature occurs in the adiabatic process because there is no heat transfer between the system and surroundings.***

Pre-service teachers demonstrated an inability to recognize the applicability of first law in adiabatic process to determine the temperature change. They wrongly interpreted the given condition and applied ideal gas law, i.e. $PV=nRT$, in predicting the temperature in a given adiabatic process. They found it difficult to relate the multivariate variables in the process and related only pressure or volume in the process to find the temperature.

- ***Alternative Conception: During the isothermal process, the internal energy of the system changes.***

Most of the pre-service teachers failed to recognize that the given process was isothermal hence there would be no change in the internal energy of the ideal gas. They wrongly associated the change in internal energy with the collision between the gas particles.

- ***Alternative Conception: No heat transfer takes place during an isothermal process because the temperature is constant within the system.***

It was found that many of the pre-service teachers wrongly assumed that in isothermal process as, temperature remains constant; hence, no heat transfer could take place because of no temperature difference. There was a failure on the part of pre-service teachers to recognize the temperature difference within the system.

- ***Alternative Conception: In a cyclic process, work done is zero or work is a state variable and is path independent***

The most prominent alternative conception in the PV process was that work and heat are path independent variables. They wrongly interpreted the state variables and could not differentiate correctly between path dependent and path independent variables.

- ***Alternative Conception: Heating always results in increasing the temperature of a substance.***

Data analysis revealed that many of the pre-service teachers had difficulty in recalling the instances where the temperature of the substance remains the same even after heating the substance for some time. They were not able to link the context with the phase change process.

Objective 3: To reflect upon the causes of prospective teachers' alternative ideas.

Inappropriate use of scientific concepts in everyday conversation, scientific terminologies mentioned in the textbooks, lecture based classrooms with little or no scope for brainstorming exercises and practical aspects of the concept, language constraints, more emphasis on numerical solving and derivations as compared to conceptual understanding were the prominent causes of occurrence of alternative conceptions.

Objective 5: To study the effectiveness of the developed material.

1. Module 2 was found to be the most effective module, as all the pre-service teachers attempted all the questions of the module and scored above 80%.
2. In module 1, 23 pre-service teachers scored 80% and above to the queries raised in the module.
3. In module 3, only 16 pre-service teachers scored 80% and above to the questions asked in the module.
4. In module 4 and module 5, 20 pre-service teachers scored 80% and above to the queries.

5.3.2 Question-wise findings:

Findings of Q1.

Out of 25 PSTs, 21 PSTs subscribed to the alternative conception that the final temperature would be average of two temperatures or double of the initial temperature. After an intervention, out of these 21 PSTs, 19 PSTs made a shift to the scientific conception that change in temperature depends upon the heat transfer and mass of the substance, i.e., $Q=mc\Delta t$. 3 PSTs retained their alternative conception.

Findings of Q2

Out of 25 PSTs, 13 PSTs subscribed to the most prominent alternative conception that the final temperature of the mixture would be the average of two temperatures after mixing. Post-intervention result shows that all of these 13 PSTs made a shift to the scientific conception that the temperature of the mixture will remain the same even after mixing or dividing the mixture because the temperature is an intensive variable which does not depend upon the size or volume of the substance.

Findings of Q3

8 PSTs held to alternative conceptions, of which 3 PSTs thought that temperature is transferred from one object to another, 3 PSTs thought that due to metal, the temperature rises, and 2 PSTs thought that heat flows from hand to metal. All these 8 PSTs showed a transition from alternative conception to scientific conception, that energy is being transferred from one object to another due to temperature difference.

Findings of Q4

10 PSTs subscribed to the related alternative conception prior to intervention; out of 10, 6 PSTs believed that the same amount of heat would be transferred to both cups irrespective of their volumes, and 4 thought that less amount of water would receive more heat. 8 PSTs showed a transition from alternative conception to scientific conception post intervention that the vessel containing more volume of water will receive more heat because heat transfer depends upon the volume of substance ($Q=mc\Delta t$) (at same temperature difference and same specific heat).

Findings of Q5

8 PSTs subscribed to the alternative conception that heat is a substance, post-intervention results showed that all of these 8 PSTs shifted to a scientific conception that heat is not a substance. A substance does not contain heat; it contains internal energy.

Findings of Q6

5 PSTs subscribed to the alternative conception that heat is generated through material or insulators. Post-intervention results showed that all these 5 PSTs made a shift to the scientific conception that poor conductors slow down the heat transfer.

Findings of Q7

Out of 25 PSTs, 23 PSTs subscribed to the alternative conception that different objects possess different temperatures when kept at the same room temperature or in the same surroundings. Out of these 23, 19 PSTs made a transition to a scientific conception that different objects kept in the same surroundings for a long time would be at the same temperature as they reached to thermal equilibrium.

Findings of Q8

Out of 25 PSTs, 17 PSTs subscribed to the alternative conception that for a given amount of heat provided, there is no relation between an increase in the temperature of the substance and the specific heat of the substance. After intervention, all these 17 PSTs made a shift to a scientific conception that change in the temperature of a substance depends upon the specific heat of that substance. A substance with low specific heat will warm/cool faster than a substance with high specific heat.

Findings of Q9

Out of 25 PSTs, 21 PSTs were found to subscribe to the related alternative conceptions. The most prominent one was that the boiling point of water can be decreased by increasing the pressure, or water boils only at 100⁰C under all conditions. Out of these 21 PSTs, 18 PSTs made a shift to a scientific conception that water can boil below 100⁰C and above 100⁰C. Boiling point is directly proportional to the pressure.

Findings of Q10

Out of 25 PSTs, 14 PSTs were found to subscribe to the alternative conceptions that during the adiabatic process, the change in temperature of the ideal gas would be calculated by applying ideal gas law ($PV=nRT$), or no change in the temperature occurs in the adiabatic process because there is no heat transfer between the system and surroundings. 11 PSTs made a shift to a scientific conception that change in temperature could be predicted by applying first law of thermodynamics.

Findings of Q11

7 PSTs subscribed to the alternative conceptions that in adiabatic compression no work is done because no heat is transferred or the sign of the work done is decided by change in pressure. Post-intervention result shows that all these 7 PSTs made a shift to a

scientific conception that 'in adiabatic compression/expansion, the sign of the work done depends upon the change in the volume of the gas in the system, because in adiabatic process heat transfer, $dQ=0$, therefore according to first law of thermodynamics, $dQ=dW+dU$.

Findings of Q12

Out of 25 PSTs,9 PSTs were found to subscribe to the alternative conceptions that work cannot bring a change in the internal energy of a system or internal energy remains unchanged in the adiabatic process. Post-intervention result shows that all these 9 PSTs made a shift to a scientific conception that work can bring a change in the internal energy of the system. In an adiabatic process, internal energy changes and depends upon the nature of the work done.

Findings of Q13

7 PSTs subscribed to the alternative conception that whenever work is done, heat will be generated, or work refers to the heating process or no work is done during the heating process. All of these 7 PSTs made a shift to a scientific conception that both work and heat are independent means of energy transfer.

Findings of Q14

Out of 25 PSTs,16 PSTs were found to subscribe to the alternative conception that the internal energy of the system changes during isothermal process. Post-intervention results show that all of these 16 PSTs exhibited a transition from an alternative conception to a scientific conception that the internal energy of the system remains constant during the isothermal process because the temperature remains the same.

Findings of Q15

12 PSTs subscribed to the alternative conception that no heat transfer takes place during an isothermal process because the temperature is constant within the system. Post-intervention result shows that all of these 12 PSTs made a shift to scientific conception that heat transfer occurs in an isothermal process due to temperature differences within the system.

Findings of Q16

Out of 25 PSTs,6 PSTs were found to subscribe to the alternative conception that 'temperature changes during the melting of ice or boiling of water (isothermal process). Post-intervention results show that all of these 6 PSTs made a shift to a scientific conception that the temperature remains constant during melting or boiling because,

during melting or boiling, phase change occurs. Hence, melting of ice or boiling of water is an isothermal process.

Findings of Q17

13 PSTs subscribed to the alternative conception that in a cyclic process, work done is zero. After intervention, out of these 13 PSTs, 12 PSTs exhibited a transition from alternative conception to a scientific conception that work is area under the PV curve.

Findings of Q18

10 PSTs initially subscribed to the alternative conception that in a cyclic process, heat transfer is zero. After intervention, all these 10 PSTs shifted to the scientific conception that heat transfer is calculated through work done in a cyclic process.

Findings of Q19

6 PSTs were found to subscribe to the alternative conception that internal energy is path independent prior to the intervention. After intervention, all these 6 PSTs transitioned from the alternative to the scientific conception that internal energy is path dependent. In a cyclic process as initial and final points are the same; therefore, change in internal energy is zero/constant.

Findings of Q20

12 PSTs subscribed to the alternative conceptions that work is a state variable and is path independent. Post intervention results show that 11 PSTs shifted to the scientific conception that work is not a state variable and is path dependent.

Findings of Q21

Out of 25 PSTs, 9 PSTs were found to subscribe to the alternative conception that internal energy is path dependent. After intervention, all of these 9 PSTs made a shift to scientific conception that internal energy is path independent. In a cyclic process as initial and final points are the same; therefore, change in internal energy is zero/constant.

Findings of Q22

Out of 25 PSTs, 9 PSTs were found to subscribe to the alternative conception that heat is a state variable and path independent. After intervention, out of these 9, 7 PSTs showed a transition from their alternative conception to a scientific conception that heat is not a state variable and is path dependent.

Findings of Q23

4 PSTs subscribed to the alternative conception that heat engines can work irrespective of the temperature of the source and sink, or Heat engines can work beyond the

efficiency of 100%.3 PSTs showed a transition from alternative conception to scientific conception that the efficiency of a heat engine is always less than 100%, or the working of the heat engine depends on the source and sink temperature.

Findings of Q24

7 PSTs were found to subscribe to the alternative conception that ‘working of a refrigerator violates the second law of thermodynamics as heat is transferred from colder region to hotter region.6 PSTs made a shift to a scientific conception that refrigerators do not violate the second law of thermodynamics because external work is being provided from outside.

Findings of Q25

4 PSTs subscribed to an alternative conception that heating always results in an increase in the temperature of a substance or that the temperature of poor conductors does not rise despite heating it for some time. All of these 4 PSTs showed a transition from their alternative conception to a scientific conception that during phase change, the temperature of the substance does not rise and remains constant for some time until a phase change occurs.

5.3.3. Pre-Service Teachers wise findings:

1. In the pre-test, pre-service teachers (PSTs) T8 and T21 gave maximum correct answers (21 out of 25); this shows that PST 8 and PST 21 have a sound understanding of most of the concepts in heat and thermodynamics, followed by PST T11 (17 correct responses out of 25) and PSTs T1 and T25(16 correct responses out of 25).
2. In the post-test 8 PSTs T1, T8, T10, T11, T12, T14, T17 and T25 gave correct responses in all 25 questions, followed by PSTs T3, T19, T23(24 correct responses out of 25 questions) and T6(23 correct responses out of 25 questions).
- 3.PSTs T12 and T15 showed the maximum number of transitions from their alternative conceptions to scientific conceptions, followed by PSTs T10, T13, T14 and T17.
4. Pre-service teachers T9, T22 and T25 answered less than 80% of the queries correctly in given modules.
5. PST T15 did not respond on maximum questions of pre-test but he/she appeared to give more than 90% of responses in the modules.
6. All 25 PSTs gave correct responses for Q2 and Q6 of the post-test. This showed all the PSTs subscribed to scientific conception in concepts of *intensive nature of*

temperature and heat transfer mechanism in insulators after interventions, followed by Q11 and Q25 (24 out of 25).