# PER Study of Fundamental Concepts in Statistical Physics-I: Concept inventory on Microstate, Macrostate and Steady State

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## Abstract

**Background** Conceptual knowledge of microstate, macrostate and steady state is crucial to understanding Statistical Physics.

**Purpose** The objectives of present paper are:
(i) To assess students' conceptual understanding/ difficulties on the ideas of microstate, macrostate and steady state using methodology of physics education research (PER), and
(ii) To create a concept inventory, based on the above, to act as a validating tool

**Method** A total of 341 students at undergraduate and postgraduate level participated in this study. Based on the students' responses to the interviews, open ended questions and semi-structured multiple choice questions, alternative conceptions were identified. These alternative conceptions were used as distractors in certain items of the concept inventory. Authors have created the concept inventory items keeping in mind the cognitive process knowledge dimensions of Revised Bloom Taxonomy. To minimize gains due to random guessing, a scoring key was devised via conceptual chronology of items. The concept inventory has been validated via face and content validation, item analysis and reliability tests performed on all the items.

**Result** A total of 18 items, in the form of multiple choice questions, were prepared and validated to form the original concept inventory. Then, it was divided into two equivalent concept inventories with 13 items in each. The five items which differ in two inventories were equivalent in terms of content relevance and difficulty level. Any of them could be used as pre-test or post-test.

**Conclusion** The PER based concept inventory can be used as a tool to measure students' difficulties on the chosen topics of microstate, macrostate and steady state. It can be utilised to evalute relative effectiveness of different instructional strategies.

**Keywords** concept inventories; microstate; macrostate; steady state; thermodynamic; statistical physics. Physics Education Research(PER)

## 1 Introduction

Physics education researchers have considered various aspects of student reasoning that result in misconceptions and alternate conceptions of various physics concepts. Here, are a few important research based observations:

- "Students do not only bring ideas about how the physical world works into our classrooms. They also bring ideas about the nature of learning, the nature of science, and what it is they think they are expected to do in our class."(pp.51). Redish opines that students knowledge and reasoning could be analysed in terms of their common naive conceptions, primitive reasoning and the way it has been connected with real life situations.[1].

- According to Andrea Disessa, misconceptions are "fragmaneted collection of ideas, loosely connected and reinforcing"(pp.50). This can be viewed as intutive physics, as it consists of large number of fragments called as phenomenological primitives, a simple abstraction of common experience [2].

- Moore in his book, *Science teaching reconsidered : A handbook*, categorized misconceptions as pre-conceived notions, nonscientific beliefs, conceptual misunderstanding, vernacular misconceptions and factual misconceptions[3].

- Berman figured out that, sometimes, elementary textbooks lead to misconceptions among students. This could be either due to inappropriate graphical presentation, communication gap or inappropriate use of words in a particular context. Fifteen misconceptions in elementary physics textbooks involving relativity, gravitation and cosmology have been identified[4]. Our own review of content on microstate, macrostate and steadystate has confirmed this finding.

- Weiman[5] pointed out that, students' beliefs are crucial in teaching physics.

- Hamza[6] figured out that, Misconceptions emerged as alternatives due to questions that are not actively defended. Students' reasoning evolved as a result of such specific situations.

- Docktor and Mestre described misconceptions traits as constructive in nature, oppose changes and interfere with scientific conceptions[7].

Then, the questions arose, as to how to identify misconceptions and the researchers have put a lot of effort and time into it. Here, we cite a few works:

- In a study by Morrison[8], the most experienced teacher was able to mention many examples of common preconceptions among students, where as, least experienced teacher provided examples which shows students' confusion among two terms. The study opined that, "In order to diagnose students' preconceptions, one needs to train students to participate in classroom discussion from very beginning when they start attending the lectures. Teacher must not only pose questions but should wait until students provide their answers. Given strategy requires sufficient amount of time and training of students as well as teachers".
- Researchers[9][10] [11] took interviews, paper and pencil test, used think aloud protocol and surveys to identify their misconceptions. .
- D.F. Styer has identified misconceptions based on the observations of students and colleagues write ups[12].

Finally, researchers have also put efforts into understanding how to handle these misconceptions:

- Gil[13] have shown that, constructivist model of science learning must be adopted to overcome misconceptions in science and other important problems of science learning.
- Stavy[14] identified that, in science, teaching by analogy is an effective tool in modifying misconceptions and learning new information.
- Thijis[15]specifically realised that, constructivist approach leads to the reduction in students misconceptions on the concept of force.
- Ryan and Aikenhead[16] have developed an instrument VOSTS in science education, that shows how science, technology, and society interact, school characterization of science and scientists, the social construction of scientific knowledge, and the epistemology of science.

## 2 Background

One of the foremost steps in identifying students naive conceptions is the creation of concept inventory. In science, the first diagnostic test as a multiple choice alternatives that has been applied to a large sample was by Halloun and Hestenes in 1985[17], in their paper, 'Common sense concepts about motion'. In 1992, they formulated the Force concept inventory(FCI)[18], which became a benchmark in science education as it elaborated the whole process of development and validation of concept inventory. Till now, several concept inventories have already been formulated in science education. In Physics, concept inventories have already been developed for the foundation courses such as mechanics [19]; [20] electricity and magnetism [21];[22]; [23], quantum mechanics [24]; [25] and astronomy[26] [27];[28]; [29].

This is for the first time that we have developed a multiple choice concept inventory on microstate, macrostate and steady state for the specialization course *"Statistical Physics"*. Before that, concept inventories on heat, temperature and thermodynamics have been developed for the students at $11^{\text{th}}$ grade[30], at high school, college and University level[31]; [32], and at undergraduate engineering level [33];[34];[35]; [36]. They cover the basic concepts such as heat and temperature, thermodynamic laws, heat engines, heat pumps, Carnot cycles, thermal properties, entropy, reversibility, impossibility, Kelvin-Planck and Clausius statements.

Loverude and his students have done a lot of work in the field of Thermal and Statistical Physics. Diagnostic questions were formulated to probe students understanding of basic probability concepts. It was found that students find difficultly in distinguishing the concepts of microstate and macrostate of a system, and in relating mathematical relationships for multiplicity [37]. Students of upper-division courses in Thermal and Statistical Physics were examined to inquire their reasoning about entropy and the second law of thermodynamics. The finding suggested that students use a variety of conceptual resources rather than single simple resource of entropy which leads to contradiction in some cases. [38]. Smith et.al. have created a guided Inquiry worksheet tutorial to help students in understanding the concepts of Boltzmann distribution and Canonical partition function. It was found that students were benefitted from the tutorial[39]. The guided inquiry worksheet has also been created for the tutorial on the concepts of Carnot efficiency and Carnot cycle as an upper level thermodynamical course. Results have shown that most of the students gained clarity on the concepts taught[40]. Simulations in Scilab were created to explain the concepts of the Maxwell Boltzmann speed and velocity distribution, and Joule's free expansion of a gas[41]. Two inquiry based activities have been formulated for concepts: entropy, reversibility, confusion between enthalpy and internal energy, confusion between equilibrium and steady state, and confusion over factors impacting chemical equilibrium and rate[42]. Open source physics java programs were formulated on coin flip equilibrium and ideal gas expansion to demonstrate the concepts of probability, entropy and second law of thermodynamics[43]. The demon algorithm was created to help students understand the concepts of temperature and chemical potential[44]. We have developed a worksheet based simulation activity for teaching steady-state equilibrium.[45]

Methodology adopted in this paper is described in the next section. It involves the process of shortlisting the concepts as well as building the research questions for the paper. Further, formulation and validation of concept inventory is discussed in two separate subsections. Finally, we conclude and recommend some suggestions for further research.

## 3 Methodology

In the present paper, methodology given by Wendy K. Adams and Carl E. Wieman has been adopted[46].

### 3.1 Shortlisting the Basic concepts of Thermodynamic and Statistical Physics

The experts teaching ‘Thermodynamics and Statistical Physics’ or ‘Statistical Physics’ at undergraduate or postgraduate level were requested to list the five most important concepts which they would like their students to have firm knowledge after they have completed the course. Moreover, the syllabus of chosen subject at undergraduate course content of various Universities have also been examined. Thence, the shortlisted basic concepts of Thermodynamics and Statistical Physics are as follows:

- Kinetic Theory of Gases
- Laws of Thermodynamics
- Probability Calculations and Statistical distributions
- Microstate and Macrostate of a system
- Entropy

### 3.2 Identification of Alternative Conceptions/ Misconceptions

To identify alternative conceptions, the first step is to interview students or one may use think aloud protocol to explore their thought process[46]. Five students were randomly chosen from 2$^{\text{nd}}$ year M.Sc.(Specialization in Theoretical Physics, batch 2012- 2014), Central university of Himachal Pradesh(CUHP). These students have studied the course on ‘Thermodynamics and Statistical Physics’ in their B.Sc. and ‘Statistical Physics’ in M.Sc. $2^{nd}$ semester(two to three months back). Students were known to the interviewer, as interviewer had been a P.hD. scholar in those days in the same University. Students gave their verbal consent to open up their view in front of interviewer without any hesitation. Various concepts probed in the interview were microstate, macrostate, ensemble, ergodic hypothesis, extensive and intensive variables, equilibrium and entropy. These interviews did not follow any predetermined sequence. Students interviews were audio as well as audio-video recorded, transcribed and analyzed. From these interviews, we directed our research into understanding students difficulties on the concepts of microstate, macrostate and steady state. We have analysed that

- Students were intermixing the concepts of micro-dimensions and micro-state of system, and macro-dimensions and macro-state of a system. Students associate the term micro with *‘less’* or *‘small’* and microstate with*‘less number of particles’*, *‘less’* or *‘small size’*. They relate the term macro with *‘large’* and macrostate as a state of a system consisting of *‘large number of particles’* or *‘large size’*.
- Students actually skip the basic meaning of the word *‘state’* associated with microstate

and macrostate. This shows their lack of understanding in defining the term *'state'* in the concerned subject.

- They were unable to associate the number of micro-states corresponding to the macrostate of a particular system.

When they were asked "Why Thermodynamic and Statistical Physics is taught as a combined subject", students responses were :

- In Statistical mechanics, we read microstates to get to know about macrostate.
- Because statistical deals with thermodynamics.
- Because statistics contains little bit of thermodynamics too. We studied thermodynamic laws in studies.
- Some of the properties match.

When asked the question: What do you know about microstate and macrostate? Two students responded saying

- *"I remember, but now I feel that I have forgotten."*
- *"No idea "*

. It is unexpected, as they have studied these concepts just in their previous semester.

Apart from these formal interviews, we had informal chats/ conversations and discussions on the same topic with other students of the same class. Most of the students' responses were *'I don't know anything about Thermodynamic and Statistical Physics, madam please don't take our interview or ask questions'*. These students were either not open to express their thoughts or they might have had a fear in speaking in front of the camera.

To probe students thinking pattern further, open ended questions on the concept of state, system, surrounding, intensive and extensive variable were framed and administered on another group of 22 students of 1$^{st}$ year M.Sc.(Specialization in Theoretical Physics, batch 2013- 2015) of the same University. Yet, we focused on one basic open ended question : **"What do you mean by microstate and macrostate of a system?"** Students were requested to avoid answers like *'I don't remember/ I don't know/ No idea'*. If possible, write your answer with examples. The responses to the open ended question were the part of their tutorial sessions of Statistical Physics class.

Out of 22 students, only 4 students were able to define microstate and macrostate of a system. Rest of them considered microstate and macrostate of a system as *'small number of particles/ large number of particles'*. These students were periodically studying Statistical Physics concepts in their regular class. Still, their conceptual understanding is fallacious. Moreover, these are not merely definitions but an important kernel for the whole syllabus of 'Statistical Physics'. Among 4 students who were able to define macrostate and microstate clearly, only one student was willing to further clarify their response for the written answer. In addition to that we had informal discussions with students of the same class.

To check whether these misconceptions are common among students, unfurnished and yet not validated MCQs were framed and administered on two colleges of Punjab, Jalandhar. Total of 119 students of B.Sc. from HMV and DAV Jalandhar, M.Sc. from DAV Jalandhar and only 8 students from Amity University NOIDA (Uttar Pradesh) participated in this task. MCQs based on microstate and macrostate with percentage of students who chose a particular option are as below in Table 1. Although, it was made clear that students should choose only one option in the MCQs, still some students opted for more than one option in MCQs. The results have shown the same pattern which were previously analysed in interviews and open ended questions.

Hence, we have concluded based on our analysis, that students had a vague/ little knowledge regarding the concepts of microstate and macrostate of a system.

### 3.3 Research Questions

The research questions, which have been formulated are as follows :

- Whether students are able to describe and identify thermodynamic state of a system/ macrostate of a system?
- Whether students are able to describe and identify statistical state of a system/ microstate of a system ?
- Whether students are able to distinguish between microstate and macrostate for a given system?
- Whether students are able to build the relationship between the number of micro-states belonging to a particular macro-state, for a given system?
- For a given example of a concrete and an abstract system, whether students are able to identify and apply the concepts of probability to the microstates, macrostates and multiplicity of a system?
- Whether students are able to interpret the concept of steady state and thermodynamic limit for a thermodynamic statistical system?

### 3.4 Formulation of Concept Inventory

#### 3.4.1 Content Map of Concept Inventory

The identified alternative conceptions has made it clear that in order to create a concept inventory on microstate and macrostate, one must also create items on microscopic and macroscopic system. This shall clarify students conception regarding the dimensions of the system and the dimensions of the constituents with in the system. Students needs to understand that microscopic and macroscopic system has nothing to do with the state of the system and the state of the constituents with in the system. We have also observed that students find difficulty in defining the system in terms of microstate i.e. in terms of the position and momentum of individual particles present in the system at time t and in defining macroscopic state of a system, at equilibrium. Again, the concept of multiplicity is utmost important to bind the concept of microstate

Table 1: Showing the percentage of students($P_s$) who chose a particular option in the MCQs

| **While considering a Thermodynamic system, Microstate of a system may be described as (Option)** | **$P_s$** |
|---|---|
| 1. State of a system in which particles have microscopic dimensions. | 28.35% |
| 2. State of a system consisting of less number of particles. | 33.07% |
| 3. State of a system in which individual position and velocity of particles are specified. | 34.65% |
| **While considering a Thermodynamic system, Macrostate of a system may be describe as (Option)** | **$P_s$** |
| 1. State of a system in which particles are not of microscopic dimension. | 13.39% |
| 2. State of a system containing large number of particles. | 59.84% |
| 3. State of a system in which Thermodynamic variables such as P, T or V do not vary with time. | 32.28% |

and macrostate. The students need to understand that a system will appear to choose a macroscopic configuration that maximizes the number of microstates.[47]. To do so, one should have clear understanding of steady state and thermodynamic limit. Content mapping of the concept inventory is shown in figure 1.

### 3.4.2 Concept inventory Items based on Revised Bloom Taxonomy

Revised Bloom taxonomy(RBT)[48][25] is a $4 \times 6$ matrix of the knowledge dimension and the cognitive process dimension. The item numbers 1 and 2 are based on factual understanding of microscopic and macroscopic system. The item numbers 3 and 4 are based on the examples of microscopic and macroscopic system. The item numbers 5 and 6 are definition based questions on microstate and macrostate, formulated to identify students conceptual understanding. Item numbers 7, 8 and 9 are application procedural based concrete examples of microstate and macrostate. Item number 11 and 12 are analysed procedural based abstract examples of microstate and macrostate. Item numbers 10 and 13 are based on evaluative procedural knowledge dimension of RBT. The concept inventory items with RBT knowledge dimension is shown in table 2

### 3.4.3 Items based on the concepts of Microscopic and Macroscopic System

The first four items have been formulated to check whether students are able to define and identify microscopic and macroscopic system. Microscopic means small, of the order of atomic dimensions or less and macroscopic means very large compared to atomic dimension[49]. Description of these items with revised bloom taxonomy (RBT) component and rationale for distractors are shown in table3.

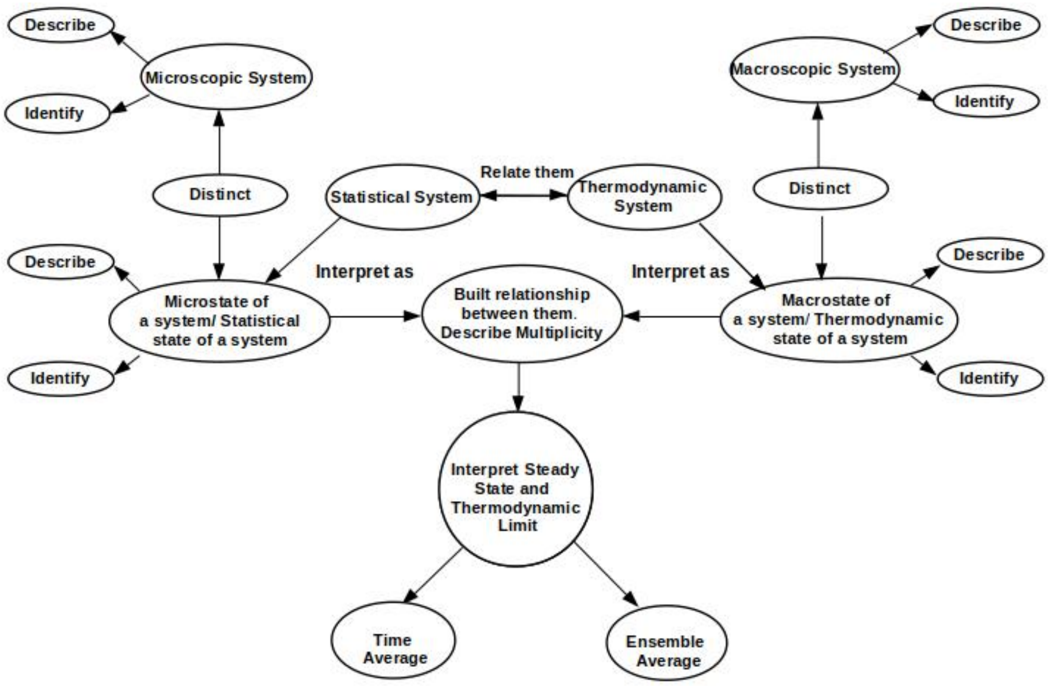



Figure 1: Content Mapping of Concept inventory

#### 3.4.4 Items based on the concepts of Microstate, Macrostate, and Steady State of a system

Item numbers 5 and 6 are statement based questions on conceptual understanding of microstate and macrostate. Students find it difficult to define the system in terms of state of all the particles present in the system from statistical point of view and macrostate of a system as a whole, while defining steady state. While administering item numbers 5 and 6, option (a) of an item is a distractor related to microscopic and macroscopic system respectively. While, option (b) corresponds to the definition of microstate and macrostate respectively. The option (c) is both (a) and (b), and is crucial as some of the students mark both (a) and (b) as an answer.

Given the $5^{th}$ item shown in fig 2, administered on 187 students, in a pre-test. 33% students mark option (a) as a response while 25% students mark option (c) as a response. Microscopic state of a system[49] "described in microscopic detail by the most complete specification, according to the laws of mechanics, of all the atoms of the system."This shows that even though the students have learnt these concepts, they still lack clarity in their conceptual definitions.

Item numbers 7, 8 and 9 are based on procedural application of microstate and macrostate. They have been designed to check whether students are able to identify microstates, macrostates and build the relationship between them. $9^{th}$ item is formulated to access the probability of choosing a microstate associated with

Table 2: The items of Concept Inventory with Revised Bloom's Taxonomy Knowledge Dimension

| The Knowledge Dimension | The Cognitive Process Dimension | | | | | |
|---|---|---|---|---|---|---|
| | Remember | Understand | Apply | Analyze | Evaluate | Create |
| Factual | | 1 and 2 | 3 and 4 | | | |
| Conceptual | | 5 and 6 | | | | |
| Procedural | | | 7, 8 and 9 | 11 and 12 | 10 and 13 | |
| Meta-Cognitive | | | | | | |

Table 3: Description of Items of concept inventory based on microscopic and macroscopic system

| I.No. | Description of Question(**RBT Aspect**) | Distractors | Rationale for Distractors |
|---|---|---|---|
| 1 & 2 | Factual definition of Microscopic and Macroscopic system **(Factual Understanding)** | System consisting of few/ large number of particles | Unable to define microscopic and macroscopic system. |
| 3 & 4 | Identification of Microscopic and Macroscopic system **(Factual Application)** | No Distractor; as all of them are correct responses. | Unable of identify all of them as correct option. |

a given macrostate. Item number 10 is designed to incorporate the concept of ensemble average. It represents a system which is not in thermodynamic equilibrium. Further, to ensure that whether students are able to apply and analyse the knowledge of steady state to a new imaginary system, last three items have been devised. These items incorporate a statistical system consisting of $10^{24}$ particles. The system is being observed after a sufficiently large amount of time. Description of each item with RBT aspect, corresponding distractors and rationale for each distractor are shown in Table 4 and 5.

#### 3.4.5 Scoring Key for the Concept Inventory

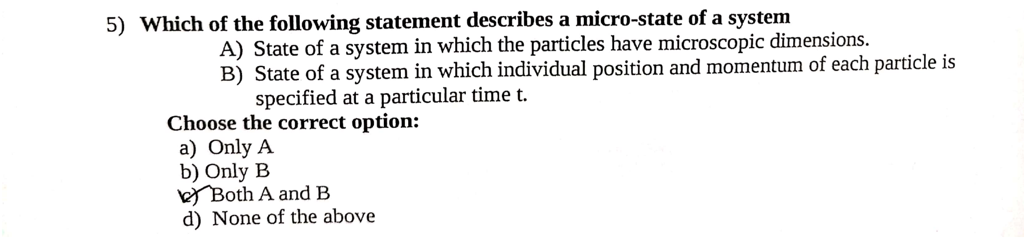
The scoring key for the concept inventory has been designed in accordance with the conceptual chronology of the items and cognitive process dimensions of revised bloom taxonomy. The conceptual chronology of scoring key means that the items of the concept inventory would be checked in the sequential order of the concepts. The checking of subsequent item within the concepts and among the various concepts depends on the correct response of the previous item(s)[25]. An example of actual post test response of a student is shown in figure 3. Given items are based on

Table 4: Description of items of concept inventory based on the concepts of microstate, macrostate, probable microstates and macrostate, and Steady State

| I. No. | Description of Question(**RBT Aspect**) | Distractors | Rationale for Distractors |
|---|---|---|---|
| 5 & 6 | Conceptual definition of Microstate and Macrostate of a system **(Conceptual Understanding)** | 1. State of system consisting of few/ large no. of particles.<br>2. State of system in which particles have microscopic dimension. | Associated alternative conceptions are Microscopic and Macroscopic System.<br>1.Confused. As they define microstate and macrostate in terms of size and number of particles.<br>2. Unable to define microstate at an instant t.<br>3.Unable to define system as a whole, which is in thermodynamic equilibrium. |
| 7, 8 & 9 | System of 2-fair coins/ 2-fair dice **(Procedural Application)**<br>1. Identify the possible microstates/ macrostates of a system.<br>2. How microstates and macrostates are associated with the outcomes.<br>3. Probability (P) of choosing a microstate associated with a given macrostate if microstates are selected at random. | 1. Outcome of a system.<br>2. P = Number of microstates associated with a particular macrostate. | Unable to identify microstate and macrostate for a concrete system and build the relationship between possible number of microstates belonging to a particular macrostate. |
| 10 | Ensemble Average**(Procedural Evaluate)**<br>This question focuses on Probability distribution<br>1. All microstates of a system are equally probable.<br>2. Microstates corresponding to particular macrostate are equally probable.<br>3. System will tend towards a particular macrostate which has maximum number of microstates. | All responses are correct(No Distractor). | We would like to see whether students realize and comprehend all the answer to be correct or not. According to Thoads & Roedel [25] choosing more than one correct answer correlates with an increased understanding of the material. Moreover, creating an absurd distractor might mislead them. Our motive is not to confuse or distract them rather to check their conceptual understanding behind the concepts. |

Table 5: Description of items of the concept inventory based on the concepts of microstate, macrostate, probable microstates and macrostate, and Steady State

| I.No. | Description of Question(**RBT Aspect**) | Distractors | Rationale for Distractors |
|---|---|---|---|
| 11, 12 & 13 | A box containing N (non-interacting and independent) $10^{24}$ particles, divided by semi impermeable membrane, into two equal halves. Let n and m denotes the number of particles on the left and right side of the box respectively, such that n + m = N. Particles are randomly moving throughout the box, colliding with each other and with the walls of the box. Some of the particles from the right side of the box enter the left side of the box and vice versa. This process continues for a sufficiently large interval of time and then the newly formed system is observed.<br>1. Identify the microstate(s) of a newly formed system(**Procedural Analyze**) .<br>2. Identify the macrostate(s) of a newly formed system(**Procedural Analyze**) .<br>3. Steady State(**Procedural Evaluate**) | 1.Individual states corresponding to each particle of the system could be considered as **its all possible micro-states** at a particular time t.<br>2.Individual state of each particle on the left side of the box at a particular time t. could be considered as **some of the micro-states/ one of the possible macrostate** of a system.<br>3.Total number of particles on the left side of box is significantly varying. | 1.Unable to define system as a whole, at equilibrium.<br>2.Confused to understand whether **each particle in a box**, considered as its all possible microstate OR **state of all particles in a box considered collectively** as one of the microstate at a particular time t.<br>3.At equilibrium, microstates of a system are continuously changing but macrostates of a system are approximately constant w.r.t time.<br>4.Unable to interpret steady state in terms of number of particles and time period of observation of the system.<br>(bold words are the keywords) |



5) **Which of the following statement describes a micro-state of a system**

A) State of a system in which the particles have microscopic dimensions.

B) State of a system in which individual position and momentum of each particle is specified at a particular time t.

**Choose the correct option:**

a) Only A
b) Only B
c) Both A and B
d) None of the above

Figure 2: Showing original pre-test response of a student

identifying the possible microstates of a system and in relating the multiple microstates belonging to a particular macrostate of a system. For item number 7 and 8 option (c) and (a) are correct responses respectively. 1 mark shall be given for correct response of an item. As seen in figure 3, student marked (a) as correct option in $7^{th}$ item but answer is option number (c) : Both (a) and (b). Therefore, we count zero mark for item 7. Again, all other subsequent items have been marked zero, as per conceptual chronology based scoring key. This whole process has been followed to minimize random guessing. For items 1, 2, 5, 6; concept inventory has no random check, as they are the first and definition based questions on the concepts of microscopic and macroscopic system, microstate and macrostate of a system. The marking scheme has been discussed in the Table 6.

## 3.5 Validation of Concept Inventory

The validation of concept inventory is based on face and content validity, item analysis and reliability[46].

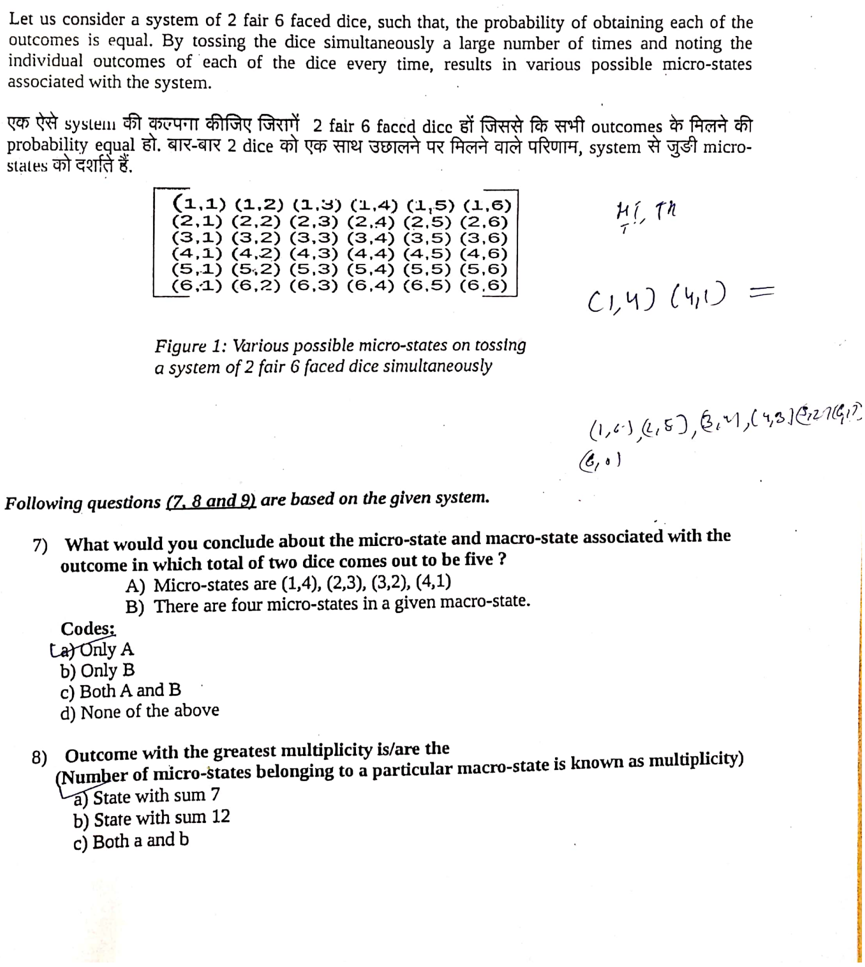
### 3.5.1 Face Validity

Face validity is a measure of subjective judgement of the content in terms of examinee[50]; [51]. Students responses are essential to check whether the content or the language of the multiple choice questions (MCQs)/ items are clear to them. The sample size for the administration of three drafts of MCQs in terms of face validity has been shown in Table 7. In each draft, suggestions given by the students have been incorporated.

### 3.5.2 Content Validity

Three phase content validation process has been adopted. This has been done by examining the contents of topics by the experts/ faculty members, who have been teaching and who had taught the subject 'Thermodynamic and Statistical Physics' or 'Statistical Physics' , at undergraduate or postgraduate level[46]. In each phase, different set of experts have been chosen. For each item, three point rating scale i.e. Good, Average or Poor has been designed. Experts gave their valuable remarks and suggestions in terms of :

- content relevance (the content of the question is relevant to the topics)
- content clarity (the content being asked in the question is clear to the respondent)



Let us consider a system of 2 fair 6 faced dice, such that, the probability of obtaining each of the outcomes is equal. By tossing the dice simultaneously a large number of times and noting the individual outcomes of each of the dice every time, results in various possible micro-states associated with the system.

एक ऐसे system की कल्पना कीजिए जिसमें 2 fair 6 faced dice हों जिससे कि सभी outcomes के मिलने की probability equal हो. बार-बार 2 dice को एक साथ उछालने पर मिलने वाले परिणाम, system से जुड़ी micro-states को दर्शाते हैं.

| | | | | | |
|---|---|---|---|---|---|
| (1,1) | (1,2) | (1,3) | (1,4) | (1,5) | (1,6) |
| (2,1) | (2,2) | (2,3) | (2,4) | (2,5) | (2,6) |
| (3,1) | (3,2) | (3,3) | (3,4) | (3,5) | (3,6) |
| (4,1) | (4,2) | (4,3) | (4,4) | (4,5) | (4,6) |
| (5,1) | (5,2) | (5,3) | (5,4) | (5,5) | (5,6) |
| (6,1) | (6,2) | (6,3) | (6,4) | (6,5) | (6,6) |

(1,4) (4,1) =

*Figure 1: Various possible micro-states on tossing a system of 2 fair 6 faced dice simultaneously*

(1,6),(2,5),(3,4),(4,3)(5,2)(6,1)
(6,1)

***Following questions (7, 8 and 9) are based on the given system.***

7) **What would you conclude about the micro-state and macro-state associated with the outcome in which total of two dice comes out to be five ?**
   A) Micro-states are (1,4), (2,3), (3,2), (4,1)
   B) There are four micro-states in a given macro-state.

**Codes:**
a) Only A
b) Only B
c) Both A and B
d) None of the above

8) **Outcome with the greatest multiplicity is/are the**
**(Number of micro-states belonging to a particular macro-state is known as multiplicity)**
a) State with sum 7
b) State with sum 12
c) Both a and b

Figure 3: Showing original post-test response of a student

- language clarity (the language clearly conveys what is being asked in the question)

Suggestions given by the experts in the third phase of content validation process are as below: According to one of our experts, “Q’s have been designed for the purpose of bringing out the level of conceptual understanding of a basic problem in statistical mechanics- the meaning of microstates and its correlation with the thermodynamic probability of the corresponding macrostate of a thermodynamic system”. “Thermodynamic probability of a system is defined as the number of microstates associated with the system. It is not normalized. The system has no choice, it can remain in any microstate with probability which is equal to the reciprocal of number of microstate.”. Expert suggested us to change the options of item number 9. This suggestion has been taken care of while modifying item number 9. Therefore, in formulating items, the concepts of probability and thermodynamic probability must be taken care off. This may lead to the confusion among students. Same expert suggested us to create short objective questions

Table 6: Scoring key of concept inventory based on conceptual chronology of topics

| Topic | Item Number (I.No.) | Answer (**A**) : 1 mark for correct answer |
|---|---|---|
| Microscopic and Macroscopic System | 1 and 2 | **c** (Definition based independent questions on *microscopic and macroscopic system*) |
| | 3 | **d** (Identification based *microscopic system*, If I.No. 1 is incorrect then I.No. 3 is incorrect too) |
| | 4 | **d** (Identification based *macroscopic system*, If I.No. 2 is incorrect then I.No. 4 is incorrect too) |
| Microstate, Marcostate and Steady State of a system | 5(a), 5(b) and 6 | **b** (Definition based independent questions on *microstate and macrostate of a system*) |
| | 7 | **b [for 7(a)]**, **c [for 7(b)]** (either I.No. 5 or 6 is incorrect then I.No. 7 is incorrect too) |
| | 8 | **c [for 8(a)], a [for 8(b)]** (If I.No. 7 is incorrect then I.No. 8 is incorrect too) |
| | 9 | **d** (If I.No. 8 is incorrect then I.No. 9 is incorrect too) |
| | 10 | **d** (*Based on Probable microstates and macrostates* ; If 9 is incorrect then I.No. 10 is incorrect too) |
| | 11 | **a** (If either I.No. 11 or 12 is incorrect then both are incorrect. Moreover, if either I.No. 10 is incorrect then 11 and 12 are incorrect too) |
| | 12 | **b (0.5 mark)/ d(1 mark)** |
| | 13 | **d** (If either I.No. 11 or 12 is incorrect then I.No. 13 is incorrect too) |

and MCQ items using the examples of atomic systems, placed in a magnetic field, with total angular quantum number j = 1/2 and j = 5/2. Researchers shall try to create the same later on while formulating the modified version of the concept inventory.

Another group of three experts suggested to us that "Statistical Mechanics deals with large and here(item number 13) fluctuation of thermodynamic parameters for system in thermodynamic equilibrium is practically nil; in that case there is no experimental difference between option b & c. So, correct option should be b & c. There is a difference between physics and mathematics!"
Here, option b and c were

- Total number of particles on the left side of the box is approximately equal to N/2.
- Total number of particles on the left side of the box is exactly equal to N/2.

Suggestion have been taken care of while modifying the answer of item number 13. Again, same group of experts pointed out that for items 11 and 12, the words partial/ fractional states

Table 7: The face validation of the concept inventory in terms of concept and language clarity for various draft is shown

.

| | Name of the Institute | Sample |
|---|---|---|
| $1^{st}$ Draft (Try Out - 1) | H M V, Jalandhar, Punjab | 41 students (B.Sc. $2^{nd}$ year, 2013) |
| | D A V College, Jalandhar, Punjab | 35 students (B.Sc. $2^{nd}$ year, 2013),<br>43 students (M.Sc. Physics $1^{st}$ and $2^{nd}$ year, 2013) |
| | Amity University, Noida, U.P. | 8 students (M.Sc. Physics, 2013) |
| $2^{nd}$ Draft (Try Out - 2) | CUHP, Dharamshala, H.P. | 25 students (M.Sc. Physics $2^{nd}$ year, Batch 2013-2015) |
| $3^{rd}$ Draft (Try Out - 3) | CUHP, Dharamshala, H.P. | 25 students (M.Sc. Physics $2^{nd}$ year, Batch 2014-2016),<br>5 students (Persuing P.hD. in Physics, Batch 2015-2018) |

have been used. They wrote “We do not understand the concept of partial/ fractional states.”. We removed the words : partial and fractional states and the language of these item numbers has been revised and simplified.

One of our experts has suggested to test the knowledge of ensemble using the concept of phase space. To do so, we need to create items on configuration space and phase space. We shall try to create them in our modified version of concept inventory.

To a large extent, suggestions of various experts have been incorporated. It should be noted that some of the items were marked poor in terms of language clarity. Therefore, researchers have simplified and rectified those questions and further converted them into bilingual, English as well as native language(Hindi).

The final version of concept inventory contains 18 items. It is further divided into two equivalent tests, pre test and post test items. Item numbers 3, 4, 5, 7 and 8 are seperate for both tests. Experts in all three phases have checked their equivalence in terms of content relevance and difficulty level. Therefore, we have a total of 13 items in each test and any of them could be used as pre-test or post-test.

#### 3.5.3 Item Analysis : Item difficulty index(P) and Item discrimination index(D)

Item analysis includes item difficulty and item discrimination index. The same has been calculated for concept inventory post test results for the main study.

According to Maloley et.al [22], item analysis should be conducted on post-test scores

Table 8: Description of sample size(N=121 students) for Item analysis is shown

.

| Name of the Institute | Sample |
|---|---|
| GPGC, Una, H.P. | $N_1$ = 59 students (B.Sc. V Semester Major Physics) |
| CUHP, Dharamshala Regional Workshop on PER 'Learning By Doing' | $N_2$ = 38 students<br>SSU,Palampur,H.P. (9 students of M.Sc.Physics $1^{st}$ year)<br>DAV, Kangra, H.P. (15 students of M.Sc. Physics $1^{st}$ year)<br>DCE, Rait, H.P. (15 students of B.Ed. with Teaching of Science) |
| CUHP, Dharamshala, H.P. | $N_3$ = 24 students (M.Sc. Physics $1^{st}$ year) |

because pre-test scores lacks common sense ideas and unfamiliarity with the common terms. Moreover, the concept inventory has been created keeping in mind that students have misconceptions/ alternative conceptions on the chosen concept. Therefore, item difficulty and item discrimination of pretest items is meaningless. We could study the same only after administering an intervention. Researchers have prepared and administered set of modules and an intervention[45] whose finding will be discussed in a subsequent research paper. The description of main study sample size for item analysis is shown in table 8. Main study data constitute those items which were based on the suggestions given by the experts till the second phase of content validation and third drafts of face validity.

To calculate[52] the item difficulty index and item discrimination index of each of the items in the concept inventory, the test scores of the students were arranged in descending order w.r.t. to students' response to the particular item. The top 27% scores of the data for a particular item represents the upper group. The bottom 27% scores of the data represent lower group. The formula for calculating P and D are as follow : $\mathbf{P} = \frac{\mathbf{(RU+RL)}}{\mathbf{(NU+NL)}}$; $\mathbf{D} = \frac{\mathbf{(RU\text{-}RL)}}{\mathbf{(NU)}}$
where RU and RL are the total number of students who responded correctly in the upper and lower groups respectively. NU and NL are the total number of students in the upper and lower groups respectively. The values of P and D calculated from the post test conceptual chronology scores are shown in Table 9. A difficulty value of 0.5 is usually taken as an ideal value[22]. Item numbers 1 to 10 fall under or near ideal item difficultly. For $11^{th}$, $12^{th}$ and $13^{th}$ item, the difficulty index has quite a low value. This could be possibly because these items belongs to higher cognitive dimensions of RBT. These items have been already pointed out to be bit difficult by the experts in the third phase of content validation. The same have been rectified as discussed in content validation section. The modified items had to be retained, as they illustrate relationship between microstates, macrostates and steady state. A discrimination index 0.40 and above are considered as very good items. Value between 0.30 to 0.39 are considered as reasonably good but possibly subject

to improvement[52](pp. 232). All other items except 1, 12 and 13 fall under very good items. It has been pointed out[24] that, according to authors [46], an item which is important from faculty point of view and at the same time shows a significant gain in the post-test results, needs to be retained in the concept inventory. Hence, every item is important as they have already been validated by the experts. The only solution is one needs to improve the methodology of teaching these concepts to bring about better conceptual clarity among students.

### 3.5.4 Reliability

Reliability is the level of consistency over time. It is to check, as to what extent, whether the tests yield the same results on repeated trials. Reliability has been calculated using test-retest method, to check for stability over time. The formula for calculating reliability using Karl pearson coefficient of correlation is

$$\mathbf{r} = \frac{\Sigma_{i=1}^{n}((x_i - X)(y_i - Y))}{\sqrt{\Sigma_{i=1}^{n}(x_i - X)^2 \, \Sigma_{i=1}^{n}(y_i - Y)^2}}$$

Where n = Sample size

$x_i$ = Sum of the correct responses of students to test item i for a time period say $t_1$.

$y_i$ = Sum of the correct responses of students to test item i for a time period say $t_2$.

X = Mean of variable x.

Y = Mean of variable y.

For one set, say pre-test items, have been administered on B.Sc. V Semester, Major Physics, MPGC, Amb, H.P. (n = 66 students) at two different times. The reliability coefficient for pre-test set is found to be 0.43. The low coefficient value may be due to students misconceptions or tendency to make guesses. Moreover, in test-retest method it is not possible to apply conceptual chronology of scoring key.

The inter reliability of the post-test of main study(N=121 students) has been calculated using Kuder Richardson 20 formula as

$$\mathbf{R} = \frac{\mathbf{(N)}}{\mathbf{(N\text{-}1)}} \left(1 - \frac{(\Sigma_{i=1}^{N}(p_i q_i))}{(\sigma^2)}\right)$$

where variance = $\sigma^2 = \frac{\Sigma_{i=1}^{n}(x_i - X)}{n}$

n = Sample size

N = Number of items

$p_i$ = Sum of correct response of students to test item i.

$q_i$ = Sum of incorrect response of students to test item i.

$p_i + q_i = 1$

$x_i$ = Sum of scores of a student i.

X = Mean of variable x.

The value of R comes out to be **0.87** which is high[22] and falls in the acceptable range[52],(pp. 86).

## Conclusion

The concept inventory on Microstate, Macrostate and Steady State has been developed at a level suitable for students taking undergraduate statistical physics course. These efforts are based on the inputs received through a process of elaborated discussions with experts and identified misconceptions based on the analysis of students' responses to the interview questions, open ended questions and multiple choice questions. It has been validated via face and content validity, item analysis and reliability. The conceptual chronology of scoring key has been applied to minimize random guessing.

Table 9: Calculated value of Item Difficulty(P) and Item Discrimination(D) of Post test concept inventory on N = 121 students.

| I.No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **P-value** | 0.77 | 0.48 | 0.56 | 0.41 | 0.71 | 0.64 | 0.50 | 0.50 | 0.50 | 0.48 | **0.29** | **0.20** | **0.18** |
| **D-value** | 0.39 | 0.67 | 0.52 | 0.64 | 0.58 | 0.73 | 1.00 | 1.00 | 1.00 | 0.91 | 0.58 | 0.39 | 0.36 |

## 4 Suggestions for further research

We intend to create more items for the concept inventory based on suggestions received from various experts. One of our experts has suggested to create short objective questions useful for testing smaller sample size. One could also create items of concept inventories based on microcanonical, canonical and grandcanonical ensemble. These concepts shall further strengthen the basic ideas of microstates and macrostates. One could formulate strategies and test this concept inventory at different institutions across different levels. We found that there is a need to design a constructivist based approach towards teaching of theoretical framework of statistical physics ideas. For this, we must adopt a model in which students, teachers, environment and content interact strongly with each other[53].

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