DIAGNOSING ALTERNATIVE CONCEPTIONS IN THE NATURE OF THERMODYNAMIC VARIABLES AND ENTROPY

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Alternative conceptions play a pivotal role in learning physics. Students either consciously or subconsciously construct their concepts by experience. For them it becomes difficult to accept new information, which contradicts their alternative conceptions. Knowledge of students' alternative conceptions can provide instructors a window into their students' thinking. To assess alternative conceptions, diagnostic tools such as concept inventories or survey, are often used. In this paper, the development of a tool based on two themes, thermodynamic state variables and entropy, which are encountered at undergraduate level, is discussed and further used for analysis. This tool discussed here is a subpart of the concept inventory developed by authors on statistical physics at undergraduate level. This analysis helped us to identify some of the alternative conceptions prevailing among students on these two themes.
Key words: statistical physics, concept inventory, alternative conceptions

INTRODUCTION

For the last two decades there has been a lot of focus on the implementation of new theories of learning and teaching in the field of science, engineering and technology, to increase students' knowledge and conceptual understanding of the subject matter and to make teaching learner centered, rather than teacher centered (Halloun & Hestens, 1985; Hake, 1987). To evaluate conceptual knowledge of learners, assessment or diagnostic tools such as concept inventories, usually built in a format to ensure that they can be readily administered in large classes, and scored in an objective manner have been designed (Anderson, Fisher & Norman, 2002; Martin, Mitchell & Newell, 2003; Midkiff, Litzinger & Evans, 2001). These inventories help the instructors to identify concepts, which students find hard to understand, and let them know alternative conceptions in their minds about those concepts. This also provides instructors an opportunity to know the learning gaps and assist in chalking out research-based strategies to bridge these gaps, enhance and measure learning (Adam & Wieman, 2010). A lot of work has already been done on the development of such concept inventories. The Force Concept Inventory (FCI), is one of the important and mostly used research based standard instrument for assessing the conceptual understanding and probing the alternative conceptions of basic mechanics (Hestenes, Wells & Schwackhammer, 1992).

Thermodynamic state variables and entropy are two important concept domains, which crop up in the study of statistical mechanics and solid-state physics as given in Table1. However, sometimes these concepts are considered very difficult and abstract by the students.

In this paper, the process of development of a concept inventory related to the above mentioned two basic concept domains, "thermodynamic state variables" and "entropy", needed in the study and understanding of statistical physics and solid state physics courses for undergraduate, Bachelor of Science (B.Sc.) three years degree course, have been discussed.

Further, the paper summarizes some general information about students' alternative conceptions emerging from this study. This knowledge of alternative conceptions can be helpful for instructors in deciding where to start and what to cover.

METHODOLOGY

The authors have developed a concept inventory on statistical physics. The complete methodology adopted for the development of concept inventory version 1.0 is shown in Figure1. The tool (consisting of two themes) discussed in this paper is a subpart of that concept inventory (Kaistha, 2014).
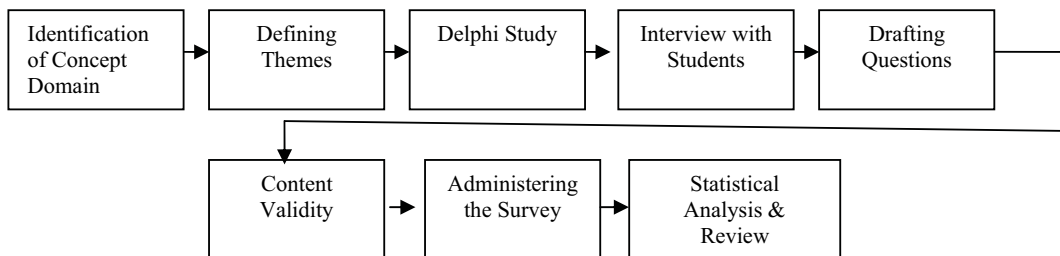
Identification of Concept Domain → Defining Themes → Delphi Study → Interview with Students → Drafting Questions → Content Validity → Administering the Survey → Statistical Analysis & Review

Figure 1: Algorithm used for the development of tool

Defining of Themes for the Development of Concept Inventory

Looking at the content of solid state physics course, the list of statistical physics concepts applied in different topics of this course was identified. Thermodynamic state variables and Entropy were two such identified themes in the statistical physics course as given in Table 1.

Themes	Concept Profile	Topics of Solid State Physics course in which concept(s) is/are used
Theme 1	Thermodynamic state variables	Provides a macroscopic backdrop for innate understanding. e.g. Superconductivity; Critical field of superconductors, Variation of specific heat, entropy and thermal conductivity of superconductors with temperature.
Theme 2	Entropy	Superconductivity

Table1: Concept profile of themes-thermodynamic state variables and entropy

Delphi Study

After identifying, the concept profile of these two themes (thermodynamic state variables and entropy), a widely used research technique called Delphi Study was carried out. This technique provides an interactive communication between researcher and experts in a field to develop themes and directions about a particular topic. This method was followed, to reach a consensus among a group of experienced teaching faculty of physics involved in teaching undergraduate B.Sc. physics courses about the difficulty and importance of these concepts. Peer group of teachers was drawn from faculty members of physics department of local

undergraduate colleges in Shimla, University Institute of Information Technology, Summerhill, Shimla and Himachal Pradesh University, Shimla.

Interviews with Students

Delphi study was followed by an extensive brain storming session with the students who had gone through solid-state physics course and who conveyed a general dissatisfaction with the course with the responses like: Solid State Physics course is confusing; Solid State Physics expects an in depth understanding of concepts of both Statistical Physics and Quantum Mechanics etc.

These interviews helped us to understand the thinking process of the students, identification of the missing linkages or alternative conceptions and mental barriers, impeding the learning of solid-state physics. We observed that they were finding it difficult to articulate their experience or feelings in picking up and underlining the conceptual difficulties.

Drafting of Multi Choice Type Questions for Each Sub Theme

The question items for the present tool were developed by consulting widely used textbooks (Bhatia, 2002; Lal, Subrahmanyam & Hemne, 1994; Hugh & Roger, 2008) and web sites. To get structural validity a draft of concept inventory was sent to 15 experts all over the country to check mark and point out any

1. deviation from concept specificity of the question item

2. ambiguity as regards physical concept involved

3. ambiguity of wording and diagrams in the sent items

4. choices/alternative options which in their opinion are not good distracters etc.

After the content validity, statistical analysis was carried out for validity and reliability of the tool.

Validity (Item Analysis)

Validity tells how well the test is able to measure the things, which it is supposed to measure. To check that items of the test are functioning well, item analysis was performed. Item analysis is a set of three tests: *item discrimination test, item difficulty test and point biserial coefficient test.* This analysis, as the name suggests, was done for each individual item of the test developed and results are given in Table 2 and Table 3.

Reliability (Test Analysis)

Cronbach Alpha coefficient test to measure reliability, and Ferguson Delta test to measure the discriminatory power, were performed on the developed statistical physics concept inventory (present tool is a subpart of it). Some sources consider a test reliable if alpha value is 0.60-0.80 (Nunnally, 1978). The instrument developed on statistical physics was having Cronbach alpha value above 0.6 and Ferguson delta coefficient 0.9., which were reasonably good.

Mode Adopted

The tool consisting of five questions (refer Appendix A) based upon the themes thermodynamic state variables and entropy was administered to 152 students at the beginning of the course (pre-test), and to 134 students at the completion of the course (post-test). This provided us data of 134 common students (37 postgraduate (PG) and 97 undergraduate (UG)), from June 2010 to March 2011 for further study and statistical analysis. The test was also

administered to 55 teachers teaching undergraduate physics in different colleges or universities all over the country. These teachers had come to attend a refresher course conducted by the Physics Department, Himachal Pradesh University, on Physics Education Research, at University Grants Commission Academic Staff College (ASC). Therefore, post test could not be conducted for them. Ten days advance intimation for administering the test was given to all the target group members. Both teachers and students took time between forty-five minutes to an hour to complete the test, stipulated time given was an hour.

DISCUSSION AND ANALYSIS

Research has shown that every individual holds some prior beliefs/alternative conceptions, and even greatest scientists like Galileo and Newton had some firm beliefs/alternative conceptions (Steinberg, Brown & Clement, 1990). The exploration and research of such alternative conceptions can help teachers and researchers to know how learners perceive particular knowledge and justify their inferences (Sharma & Ahluwalia, 2012).

For this purpose after the administration of the tool, interviews were conducted with B.Sc. students at one of the undergraduate colleges and students of M.Sc., at Physics Department, Himachal Pradesh University. The effort was made to know, how these students have arrived at the ticked options in their attempt of the question items of the inventory and what were the alternative conceptions occurring in their minds.

Theme 1: Thermodynamic State Variables

Thermodynamic state of a macroscopic substance is specified by the macroscopic variables like, temperature, pressure, entropy and do not immediately require knowledge of microscopic structure of the matter. However, one of the fundamental problems of Statistical Physics has been to relate these microscopic parameters to thermodynamics. This theme had three questions. Q1 and Q2 dealt with the difference in intensive and extensive parameters, Q3 dealt with relation between thermodynamic probability and entropy

Figure 2 gives the question wise response of students (pre-post) and teachers (pre) in this theme. Q1 and Q2 both were based on the concept of intensive and extensive parameters of thermodynamics. In Q1:

Consider a homogeneous system in equilibrium. Suppose the system is divided into two parts. If the macroscopic variable x of the system has the values x1 and x2 in each of these parts and x = x1 + x2, then x is said to be

(a) an extensive parameter

(b) an intensive parameter

(c) a local parameter

It was asked, whether the additive property of the variable given, points to it as being an extensive parameter or an intensive parameter. In pre test 49% of UG students gave the correct responses, which reduced to 46% in post test. 76% of PG students gave correct responses in pre-test, which reduced to 54% in posttest. 53% of teachers responded correctly in pre test and there was no post- test for teachers.

In Q2, students were supposed to identify the set of intensive parameters. Very less percentage of UG, PG students as well as teachers gave correct answer to this question. Most of the students were identifying even mass and volume as intensive parameters and temperature as an extensive quantity.

Since both the questions were based on the same concept, we were expecting some consistency in answers to these questions. However, the large difference in percentages shows that the students were not able to differentiate between the extensive and intensive parameters properly and most of them only tried a wild guess. Some of the students were having a misconception in mind that temperature is a property of the material from which a body is made. Majority of students and teachers could answer Q3, which was based upon the relation between thermodynamic probability and entropy. UG, PG students, as well as teachers scored less than 60% in Q1 and Q2, indicating that they also lack in conceptual understanding of the concept domain involved.
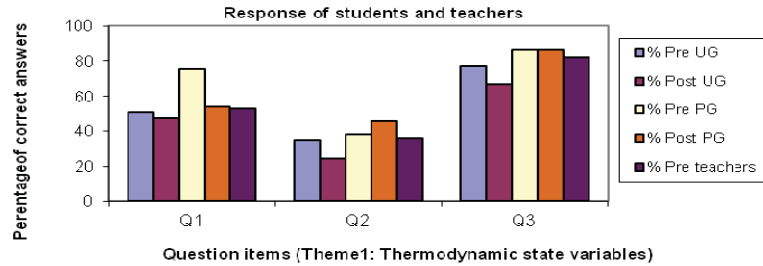

Figure 2: Response of UG, PG students and Teachers on theme 1 (thermodynamic state variables)

Table-2 gives the pre-post values of item discrimination index (D), item difficulty index(d), point biserial coefficient (r_{pb}) of each question item, and alternative conception occurring in the minds of students in that particular question item.

Q. No	Concept	Class	D			d			r_{pb}			Alternative conceptions identified
			Pre	Post	Avg.	Pre	Post	Avg.	Pre	Post	Avg.	
1	Extensive & intensive parameters	UG	0	0.08	0.04	0.51	0.47	0.49	0.41	0.39	0.4	No understanding of the fact that in which physical thermo dynamical quantities total is sum of parts and when not
		PG	0.42	0.67	0.55	0.76	0.54	0.65	0.44	0.47	0.46	
		Teachers	0.27	-	-	0.53	-	-	0.31	-	-	
2	Extensive & intensive parameters	UG	0.06	0.2	0.13	0.35	0.25	0.3	-0.1	-0.5	-0.3	Temperature is a property of the material from which a body is made
		PG	0.25	0.67	0.46	0.38	0.46	0.42	0.36	0.6	0.48	
		Teachers	0.23	-	-	0.36	-	-	0.22	-	-	
3	Thermodyn amic Probability	UG	0.13	0.31	0.22	0.77	0.67	0.72	0.15	0.31	0.23	No alternative conception revealed
		PG	0.08	0.25	0.17	0.86	0.86	0.86	0.12	0.41	0.27	
		Teachers	0.23	-	-	0.82	-	-	0.2	-	-	

Table 2: Item analysis results and alternative conception identified in theme 1 (thermodynamic state variables)

Theme 2: Entropy

Any physical system consisting of large number of particles possesses macroscopic properties such as pressure, volume, and temperature, which are easily measurable, though its microscopic properties, such as positions and momenta of the constituent particles, cannot be measured. Statistical physics relates these microscopic properties to the macroscopic properties and acts as a bridged by providing a relationship between number of different

microstates of a system, 'W' and a thermodynamic (macroscopic) quantity called entropy 'S'. Infact one of the biggest achievements of the Statistical Physics has been to provide a physical picture of the value of entropy dependent on the actual macroscopic state enumerated in terms of the count of microstates of the system.

The theme on entropy involved two questions (Questions 4, 5). Figure 3 gives the question wise response of students in this theme.
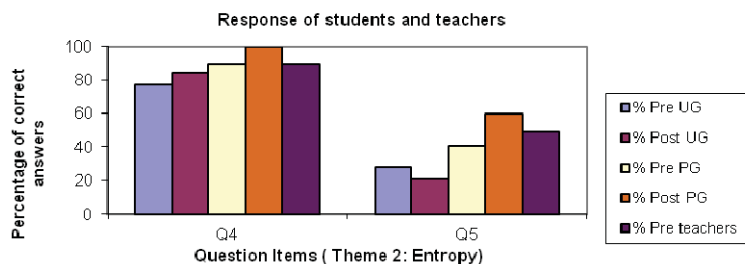

Figure 3: Response of UG, PG students and teachers on theme 2 (entropy)

Q4 was designed to check whether students are able to establish a connection between entropy and the meaning of order and disorder as enunciated in the second law of thermodynamics and thermodynamic processes. More than 70% of UG, PG students as well as teachers ticked the correct option showing that learners have a feeling of a link between the meaning of order /disorder and entropy. Q5 was designed to further probe the link between meaning of order/ disorder with entropy in terms of number of microscopic and macroscopic states.

For any system, the most probable macroscopic state is one with the greatest number of corresponding microscopic states, it is also the macroscopic state with the

(a) least disorder and the greatest entropy

(b) least disorder and the least entropy

(c) greatest disorder and the least entropy

(d) greatest disorder and the greatest entropy

In this question students were supposed to consider entropy as a statistical quantity and were expected to know that entropy is a measure of accessible microstates of system and thus most probable macroscopic state will have greater disorder and hence entropy. Very less percentage of students as well as teachers could give correct answer.

Again, here since both the questions were based upon same concept, we were expecting consistency in the answers of the learners. Instead, we found inconsistency in answers of Q4 and Q5. We noticed that students were able to recall definition of entropy but they found it difficult to relate entropy with the microstates of a given macro state the very basis of the development of Statistical Physics. On further probing during interviews, students were unable to relate that thermal equilibrium means all parts of system are at the same temperature and this is the state of maximum probability. Instead, they were interpreting equilibrium state as a state of minimum entropy. There was an alternative conception that thermal equilibrium means thermodynamical stability and thermodynamical stability automatically implies order i.e. they interpreted the question that in equilibrium, system should have least disorder, and

thus least entropy. All UG, PG students and teachers scored less than 60% in Q5 of this theme. This situation clearly marks the fact that important properties of entropy have been completely missed and indicates general confusion, which learners bring with them in the classroom about a much, talked but least understood concept. Table 3 gives the pre-post values of item discrimination index (D), item difficulty index (d), point biserial coefficient (rpb) of each question item, and alternative conception identified thereafter.

Q.no	Concept	Class	D			d			r_{pb}			Alternative conception(s) identified
			Pre	Post	Avg.	Pre	Post	Avg.	Pre	Post	Avg.	
4	Entropy	UG	0.19	0	0.1	0.77	0.84	0.81	0.17	0.08	0.13	No alternative conceptions was revealed
		PG	0.08	0	0.04	0.89	1	0.95	0.1	0	0.05	
		Teachers	0.27	-	-	0.89	-	-	0.36	-	-	
5	Entropy	UG	0.13	0.22	0.18	0.28	0.20	0.24	0.19	0.29	0.24	In thermos dynamical equilibrium system should have least disorder and hence least entropy, hence belief is equilibrium means order
		PG	0.25	0.17	0.21	0.41	0.59	0.5	0.2	0.07	0.2	
		Teachers	0.44	-	-	0.49	-	-	0.47	-	-	

Table 3: Item analysis results and alternative conceptions identified in theme 2 (entropy)

CONCLUSIONS

One of the best ways to check the learning of various concepts is, to use the concept inventory or survey. We have developed research based diagnostic tool, which should access the knowledge of two basic concepts used in Statistical Physics: thermodynamic state variables and entropy taught to students at undergraduate level.

The alpha version (1.0) of tool was administered to UG students (pre-post), PG students (pre-post) and teachers (pre). The responses were analyzed for both test analysis and item analysis to check the reliability and validity of the tool. The values of discrimination index, difficulty index of some of the items do not fall in the prescribed range. However, we think that it does not necessarily mean that these items are not satisfactory to a certain extent. We intend to work on item response curves in future to get detailed information of quality of this tool.

Looking at the responses given we could identify some alternative conceptions prevailing in the minds of students which need to be changed from the target group and prepare it for the better understanding of the topics/subjects.

One can conclude that the developed concept inventory can indeed help to see the student's performance vis-à-vis their understanding of basic concepts. It can also give us insights into desirable changes in teaching and remedial measures, which needed to set the learning in the right direction. The identified alternative conceptions can also be used to design improved Statistical Physics curriculum, which takes care of these conceptions.

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Appendix A

1. Consider a homogeneous system in equilibrium. Suppose the system is divided into two parts. If the macroscopic variable x of the system has the values x_1 and x_2 in each of these parts and $x = x_1 + x_2$, then x is said to be:

   (a) an extensive parameter   (b) an intensive parameter   (c) local parameter

2. Out of these given parameters choose the set of intensive parameters:

   (a) S,T,F   (b) M,P,S   (c) M,V,T   (d) P,T,F

   (where P,T,F,M,S,V represent respectively pressure, temperature, surface tension, mass, entropy and volume of the system).

3. Suppose there is an isolated system consisting of large number of particles. It neither gains nor loses energy and is also in thermal equilibrium, so it has maximum probability W_m. Hence change in Its entropy ΔS is:

   (a) zero   (b) less than zero   (c) cannot be defined

4. Entropy is a measure of :

   (a) chemical potential and number of particles (b) order and disorder (c) pressure and volume

5. For any system, the most probable macroscopic state is one with the greatest number of corresponding microscopic states, it is also the macroscopic state with the :

(a) least disorder and the greatest entropy   (b) least disorder and the least entropy

(c) greatest disorder and the least entropy   (d) greatest disorder and the greatest entropy