ACCESSING STUDENTS' PRIOR CONCEPTS OF PHYSICAL CHANGE BY THE USE OF A PURPOSE-DESIGNED SURVEY INSTRUMENT

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The Science Concept Survey (SCS) instrument was developed from interviews with pre-service science teachers in Australia and Fiji and a pilot study undertaken in Fiji. Items consist of questions drawn from Interviews-About-Instances (IAI), Interviews-About-Events (IAE) and Predict-Observe-Explain (POE) activities related to Kinetic Theory. Administration of the instrument to a cohort of pre-service teachers in Fiji (n=143) reveals that the SCS is a useful tool for the elicitation of student scientific and alternative conceptions, and is able to distinguish between different cohorts of students.

INTRODUCTION

Teachers of science in both developed and developing countries face many challenges, not the least of which is the prevalence of alternative conceptions for abstract science concepts like the Atomic and Kinetic Theory. In the minds of many science education researchers, teaching based on a constructive-informed pedagogy offers a way of enhancing learning of science concepts (see, e.g., Tobin, 1993). Whilst there is some debate as to what a 'constructivist-informed pedagogy' actually means (Matthews, 1997), there is consensus about the importance of elicitation of prior knowledge, especially about students' alternative conceptions (Wheatley, 1991). As a result some researchers have developed instruments to provide teachers with simple probes as to students' understanding of specific, commonly

A simple survey instrument provides a useful means of identifying scientific and alternative conceptions for kinetic theory.

problematic areas such as covalent bonding (Treagust, 1986, 1988), and force and energy (Summers & Kruger, 1994). Such instruments enable teachers to quickly ascertain students' understanding and to monitor progression in learning as teaching proceeds.

Kinetic Theory forms one of the central instructional goals of most school science curricula (Nussbaum, 1985). This is hardly surprising, as a meaningful understanding of so many other topics in the physical, life and earth sciences depends on the ideas about the molecular constitution of matter. In fact without reference to a particle model it is impossible to explain the macroscopic properties of matter (Albanese & Vicentini, 1997). As Driver, Leach, Scott and Wood-Robinson (1994, p. 96) suggest:

> There are concepts which are central to students' scientific understanding in a wide range of topics and in such cases giving an appropriate amount of teaching time to them is educationally worthwhile. We would suggest that the conservation of mass and the particle theory of matter are examples of such topics.

Gabel (1993) has demonstrated, albeit with a small group, that improved understanding of Kinetic Theory helps students make connections in other areas of chemistry. Thus, because Kinetic Theory underpins so many other conceptual areas of science, it has been one of the more exhaustively studied topics for conceptual understanding.

Here we describe the development of a survey instrument, the *Science Concept Survey* (SCS) that helps to identify scientific and alternative conceptions for Kinetic Theory. We illustrate its usefulness by describing some outcomes of its application in a multicultural pre-service primary teachers' college in the Fiji Islands.

METHODOLOGY

The SCS was developed as part of a larger study involving pre-service teachers' understanding of science content (Taylor, 1997). The instrument was developed from a series of 34 interviews with pre-service primary teachers about Kinetic Theory. Ten interviews were conducted with pre-service primary teachers at an Australian teacher education college, and 24 with a similar cohort in Fiji's only government run primary teachers college. Each interview lasted approximately 70 minutes and involved Interviews

About Instances, (IAI), Interviews About Events (IAE) and Predict Observe Explain (POE) techniques (White & Gunstone, 1992). The interviews sought to identify the range of alternative conceptions held by these students. By the completion of the final interview, no additional alternative conceptions were appearing and it was considered that sufficient data had been collected to get a clear indication of the alternative conceptions within the student population.

The initial stage of each interview was modelled on research conducted by Kruger and Summers (1989) in which students were asked a series of focus questions about IAI and IAE cards (Figure 1). For example, the focus questions used with card 2 illustrated in Figure 1 were: What has happened to the water?; Where has it gone?; and, Why does this happen?

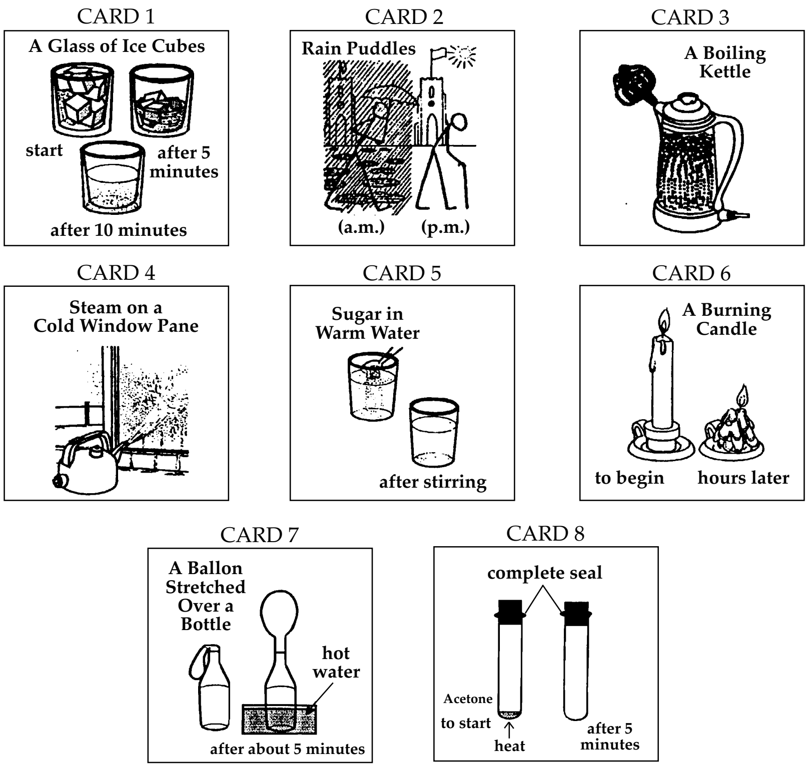


Figure 1: The Interviews-About Instances (IAI) and Interviews-About-Events (IAE) cards used to develop items for the Science Concept Survey (SCS) instrument.

Further questions were then framed according to the responses until the expression of students' ideas had been exhausted. In each case students were asked to provide the best scientific explanation they could in explaining the various phenomena.

The second part of each interview involved the use of the POE technique with five practical activities. In this technique, participants are told about an activity and asked to predict the outcome of a demonstration. Afterwards, they are asked to explain the outcome, whether or not their prediction was borne out by the demonstration. In the case of the SCS, these activities included: depressing syringes filled with air and water; submerging in water an inverted glass which contained compressed cotton wool in its inner base; using body heat to warm a gas thermometer consisting of a conical flask and delivery tube containing a bead of water; and, operating a set of model lungs.

This range of cards and activities was used to determine whether the students could apply Kinetic Theory consistently when explaining a variety of phenomena involving changes in matter. Thus cards provided the opportunity to probe the students' understanding of change of state, conservation of matter, solubility, heat and pressure, all concepts to which Kinetic Theory can be applied.

The outcomes of the interview analysis were validated by six judges, all of whom were experienced science educators (Rollnick & Rutherford, 1990). The judges were asked to analyse the transcripts of two sample interviews and identify those conceptions they believed were represented in each. The results from the judges were compared with the analysis of the researchers and the percentage agreement for each concept calculated. An averaged agreement of 89% was obtained and this was considered a satisfactory indication of the validity of the analysis.

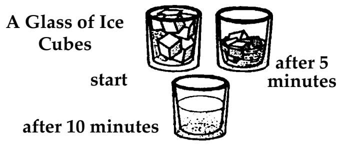
Development of the SCS

The analysis was used to develop a Concept Profile Inventory (CPI) for the 34 interviewed students. A CPI is one way of representing the pattern of beliefs about a certain phenomenon expressed by a particular subject or group of subjects (Erickson, 1980). In this instance the CPI was compiled from the students' scientific and alternative conceptions obtained from the interview transcripts which were grouped into 5 categories: Change of state, Conservation of Matter, Solubility, Heat and Gaseous Pressure. Items for the SCS were drawn from this inventory.

Items for the SCS were constructed in accordance with guidelines provided by Gronlund and Linn (1990) for developing unambiguous true/false items. These used illustrations from the IAI cards and POE activities with accompanying statements being taken and adapted from the interviews. Students were provided with three possible responses to each item, 'true,' 'false' and 'not sure.' Each item also included a free response section to allow for justification of the answer chosen. These additions were aimed at reducing the incidences of guessing and also provided the researchers with data to construct a richer understanding of the participants' responses.

The final instrument consisted of 50 items. An example of a series of items is provided below and the complete instrument is available from the authors in electronic form.

The drawing on the right shows ice cubes in a glass at the start then after 5 and 10 minutes. Use this drawing to answer questions 1-4.



1. The ice cubes in the glass release heat energy when they change into water.

   true false not sure

   Reason: ______________________________

2. The particles which make up the ice cubes are constantly vibrating.

   true false not sure

   Reason: ______________________________

3. The water droplets on the outside of the glass after 10 minutes have come from the atmosphere.

   true false not sure

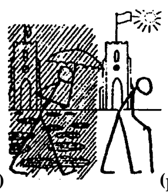
   Reason: ______________________________

4. High humidity around the ice cubes has caused them to melt.

   true false not sure

   Reason: ______________________________

The drawing on the right shows a change in the weather conditions between the morning and afternoon. Use the drawing to answer questions 5 and 6.



5. The puddles of water have disappeared in the afternoon because they have been absorbed by the sun's rays.

   true false not sure

   Reason: ______________________________

   ____

6. Both heat and light energy are needed for evapouration to take place.

   true false not sure

   Reason: ______________________________

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Figure 2: The first six items of the Science Concept Survey (SCS) instrument.

To ensure the final version of the SCS had content validity (see Trochim, 1999), it was again submitted to six judges who were asked to match each item to a specific subcategory within the CPI. The same task was carried out by the researchers and the results compared. The judges were also asked to check for ambiguities of wording in the survey items.

To confirm the construct validity of the instrument, the SCS was piloted with a first year class at the teachers college of 29 students, of whom 15 were Indian and 14 were Fijian. When the test was completed a response frequency table was compiled. This highlighted items where a large number of students had chosen the 'wrong' option. The free responses that accompanied these items were carefully examined to determine whether this was due to a high prevalence of alternative conceptions or poorly worded items. On the basis of this trial a number of the questions were altered and additional labels were added to some of the diagrams. For example, item 2 (Figure 2) originally read: 'The particles which make up the ice cubes are constantly moving,' a number of students chose the 'false' option for this but responded that the particles were not moving, only vibrating. This suggested that the term movement had been interpreted as free movement, rather than movement around a fixed point. Thus the item was reworded accordingly.

Administration of the SCS Instrument

The SCS instrument was administered to the entire second year cohort (n=143) at the college. Since the intake to the college is based on a racial and gender quota system aimed at obtaining approximately equal representation of both sexes and of both major ethnic groups, this cohort provided a representative sample of the total college population and negated the need to carry out stratified sampling. As a result there was almost equal representation of both major ethnic groups with 73 Indian students and 70 Fijian students completing the survey. No time restriction was placed on the completion of the instrument, but on average it took about 20 minutes to complete.

Typically instrument reliability would be determined using a test-re-test correlation, but the risk of students becoming familiar with the test was considered to be unacceptably high. Furthermore, Helm (1980) has pointed out that calculating any measure of reliability for a misconceptions test or survey serves little purpose, and it is generally agreed that traditional techniques of item analysis are inappropriate for criterion referenced tests. Certainly, other workers such as Rollnick (1988) and Za'rour (1975) who have used similar surveys to determine the prevalence of alternative conceptions within large groups have made no attempt at any estimate of reliability.

The scoring of the SCS entailed allocating each correct response a single mark. Although the items were true/false and designed to be objective, the addition of the free response meant that, occasionally, a subjective judgement was required when a student made a correct true/false selection, but his/her free response indicated an alternative conception. For example, item 20 which depicts some sugar being stirred into a glass of water, states that: 'The sugar crystals melted before they mixed with the water.' If students selected 'false,' which is the correct objective response, but went on to a state that 'sugar melted *after* it mixed with the water,' this was in fact an alternative conception about the solubility of sugar in warm water and such responses were allocated no mark (see, Treagust, 1988). So, although the free response section of each item introduced a degree of subjectivity, it provided an added probe of students' understanding.

To illustrate the utility of the SCS, we first show how it can provide information on the understanding of conceptions related to Kinetic Theory among a large group, and then illustrate how it can be used to probe specific aspects of this domain in more depth.

General Findings

The general findings from the administration of the SCS instrument revealed that overall the scientific view was more commonly held by Indian students while alternative conceptions were more prevalent amongst the Fijian students in the sample. As indicated in Figure 3 and 4, over the entire range of 50 items, the scientific conception was more prevalent amongst Indian students in 45 instances, although in a number of cases, for example, items 23 and 36, this difference was minimal. Furthermore, Figures 3 and 4 reveal that for 33 of the 50 items, Fijian students showed a stronger preference for the alternative conception.

The level of uncertainty in responding to the statements was also markedly higher amongst Fijian students, as in all but five greater percentage of Fijians than Indians chose the unsure option. These disparities may have resulted as much from differential schooling in science as any cultural factors. Certainly, fewer Fijian than Indian students who took part in the survey had pursued post-compulsory science at high school. However, it illustrated that the SCS could distinguish between specific cohorts within the study sample.

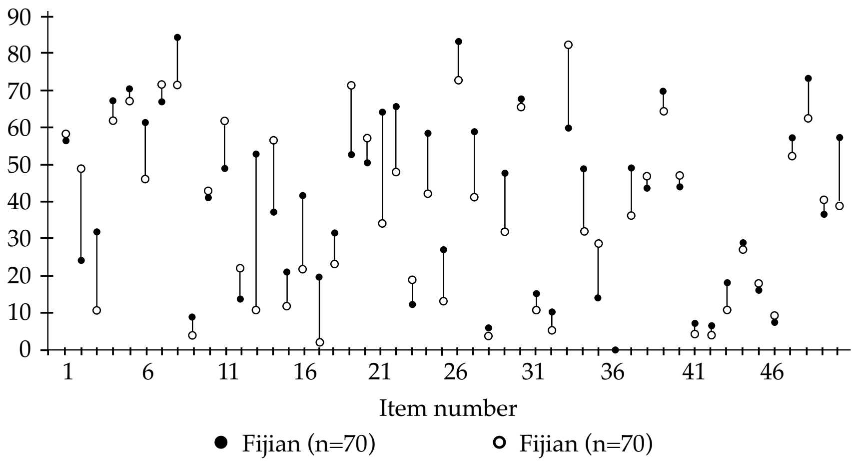

Figure 3: The percentage of Fijian and Indian students with the correct science concept.

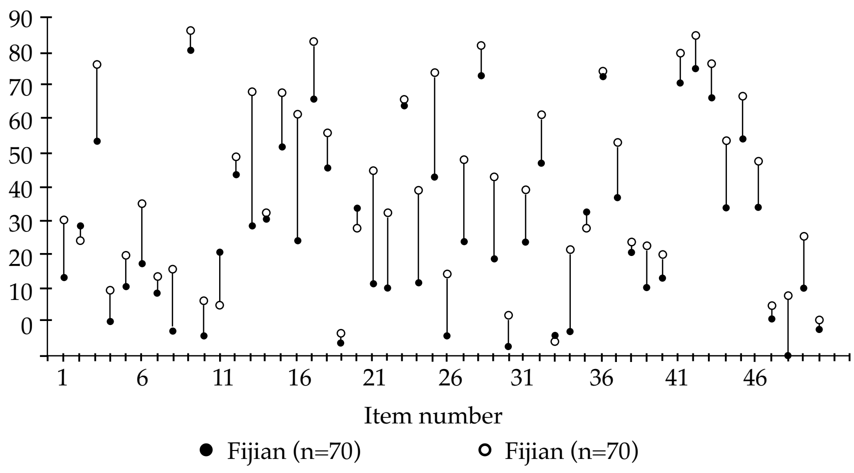

Figure 4: The percentage of Fijian and Indian students with the alternate science concept.

Overall the responses of the 143 student teachers who took part in this survey revealed some significant problems with their understanding of changes occurring in a number of common materials. In particular the SCS revealed that many students had a limited grasp of the relationship between energy and matter during these changes. These findings are elaborated in the following section.

Using the SCS to Develop an In-depth Understanding of Students' Alternative Conceptions

Figure 5 shows the percentage scientific and alternative responses of both ethnic groups to the 14 items from the SCS that fell into the category of change of state. Of these, seven items showed a degree of consistency in respect of response, in so far as there was no noteworthy difference between the prevalence of either the scientific or alternative conceptions between the two ethnic groups. Furthermore, the qualitative free responses provided by each group to these items were very similar. For example, items 4 and 5 (see Figure 1) that dealt with the relationship between humidity and melting, and the concept of evaporation respectively, revealed almost identical response frequencies for the alternative conceptions held by the two groups with distinct similarities between their justifications. Both ethnic groups favoured the views that 'humidity provides the heat energy for melting to occur' and that 'the sun's heat absorbs water during the process of evaporation.'

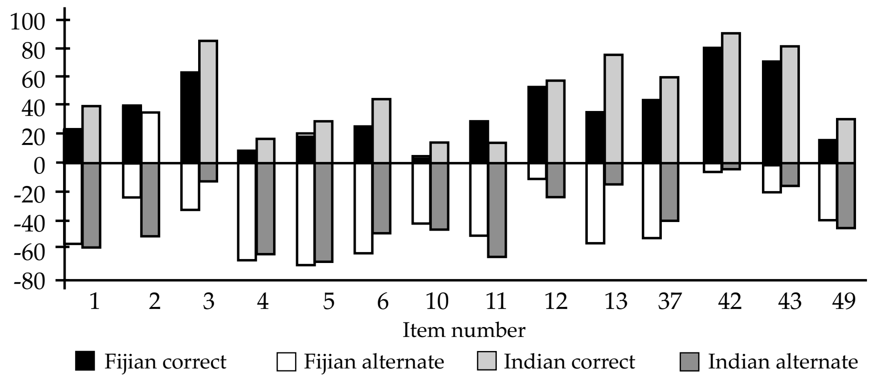

Figure 5: The correct and alternate response frequencies of Fijian and Indian students to items relating to change of state.

However, the remaining seven items either displayed greater divergences between the groups, or the quality of the free responses made some of them worthy of particular mention.

Thus in the category for change of state, items 2, 3, 6, 11, 13 and 37 revealed large discrepancies between the responses of the Fijian and Indian students. For example, although item 2 indicated that a very similar proportion of Indian and Fiji students held the scientific view that particles in ice constantly vibrate, significantly more Indian students (53.4% compared to 24.2%; $Z=3.569$; $p<.05$) selected the alternative view. The majority of both groups who made this selection justified it by stating that in solids the particles are held together tightly with no space to vibrate, a view which is clearly intuitive and strongly supported by the diagrammatic representation of solids in Fiji science course books.

The analysis for item 3, showed that 63% of the Fijian students selected the scientific view, in contrast with 86% of Indians ($Z=33.731$;$p<.05$), while 33% and 11% respectively opted for an alternative view. The most common alternative conception, provided by the members of both ethnic groups in the free response section, was the belief that the condensation on the outside of the glass originated from the ice cubes or water within the glass. This is surprising as, Fiji's hot and humid climate, condensation on cold objects is a very common phenomenon, and all of the students would have encountered condensation on sealed containers. This item also provided some evidence of the poor understanding of the relationship between energy and matter, with a number of students stating the heat energy became water vapour when it contacted a cold surface.

The view that light *and* heat were necessary for evaporation to take place (item 6) was also quite prevalent amongst both groups (Fijians 64% an Indians 46% $Z=2.558$; $p<.05$). This perhaps derived from the strong association between light and heat in the tropics. Certainly the free responses indicated that this was the case with most students from both groups stating that where there is light there is heat, or that light changes into heat energy.

Item 11 dealt with condensation and although the alternative conception presented in the former item was less popular amongst Fijians (49%) than Indians (62%) this was not statistically significant ($Z=1.850$; NS).

However, the free responses to this item revealed an anthropomorphic view of matter with the most widespread justification for selecting the alternative conception that vapour is attracted to cold surfaces being that 'vapour needs to change to water again.' Fijians also held a popular anthropomorphic view that 'steam will want to find a place to rest.' Equally common to both ethnic groups was the notion that 'hot and cold things attract each other.' There are other domains within science where the concept of 'opposites' attracting' exists such as magnetism and electric charge. Some of the students may have transferred or 'chained' this conception to heat and cold in an effort to derive an explanation (Vygotsky, 1986).

Item 37, which depicted sealed syringes of air and water, was intended to provide some insight into the mental models the students applied to a problem based on the different compressibility of liquids and gases. This item was the only negatively worded item in the survey, and although this may have caused some difficulty for the students, it was not apparent in the free responses. While only 47% of Fijian students believed correctly that the statement was false, this compared with 63% of Indians ($Z=2.274$: $p<.05$). Clearly in order to respond to this item it is important to have not only a particulate model of matter, but also one that can discriminate between the spatial distribution of the particles in liquids and gases. The qualitative responses indicated that many students did not make this spatial distinction because the most common response from both groups was 'there is hardly any space for the particles to move.' Others appeared not to consider spatial distribution or perhaps even particles as they stated, again in almost equal proportions, 'because both syringes are sealed and nothing can escape.'

Finally, within this subcategory, item 49 proved to be of interest not because of the disparity between the groups which, for those who selected the alternative conception, was negligible (35.7% Fijian and 39.7% Indian $Z=.584$; NS), but because of the qualitative data it provided. This item stated that the particles that make up matter are living. In response to this the majority of students indicated that they held a variation on this alternative conception. This was the Aristotelian view that the particles can be living or non-living depending on the type of matter. Once again this tenet was common to both ethnic groups, and although more popular amongst the

Indians, it did not appear to derive from any cultural root, but rather the intuitive belief that living tissue would be composed of living particles.

Overall the survey appeared to suggest that Indian students were more likely to evoke a particle model of matter in dealing with states of matter. Certainly the response to item 37 lent support to this assertion. Furthermore, evidence of an anthropomorphic view of matter that emerged from the interviews was shown to be quite widespread by the qualitative justifications provided for certain items in this subcategory.

CONCLUSIONS

It should first be pointed out that there are certain potential weaknesses in using a survey instrument to diagnose alternative conceptions, in the way we have described here. Whereas an interview requires students to construct their own explanations, in the survey they were making decisions based on statements provided for them. In this situation, it is often easier to recognise the scientific view, as the statement can act as a stimulus to the long-term memory (Rollnick, 1988). Furthermore, as Bar and Travis (1991) cautioned, some of the statements provided can act as a source of alternative conceptions not previously held by students, particularly if they appear to be 'scientific.' However, the SCS appears to possess validity as discerned via the panel of experts approach, along with the manifest ability to distinguish between different cohorts of students, namely ethnic Indians and indigenous Fijians. The differential performance in science of these two groups has been noted before (e.g. Stewart, 1983; Tavola, 1992; Taylor & Lucas, 2001), and the ability of the SCS to discern between the groups adds to the confidence of the instrument and is an example of what Trochim (1999) refers to as concurrent validity.

The instrument should be applicable to most cultural context as according to Thijs and van den Berg (1995), in the domain of physical science the same alternative conceptions exist across many countries, with a variety of cultural and environmental contexts. Certainly the interviews with subjects from three quite different cultural groups, from which the instrument was derived, indicated strong similarities for the alternative conceptions held in the domain of Kinetic Theory.

The research findings reported here enabled the researchers to gain an overall view of Fiji pre-service science teachers' scientific and alternative conceptions. As Palmer (1999) points out there is a tendency in much science education research to focus on students' alternative conceptions (see, e.g., Pfundt & Duit, 1997), whereas, students' scientific conceptions are sometimes of greater interest and benefit to teachers since they allow teachers to build on students existing scientific ideas in a manner that does not demean or undermine student views. The SCS also has been developed in a manner that reduces the likelihood of teachers being mislead by students guessing answers and thus provides a detailed picture of the students' conceptions for a variety of aspects of Kinetic Theory in a manner not usually achieved from survey instruments. Such data allows teachers and researchers to devise appropriate pedagogies to attempt to overcome student alternative conceptions in a very targeted way. For example, data from the administration of the SCS to pre-service primary teachers in Fiji informed the development of a teaching programme about changes in matter that began by focusing on the relationship between particles and energy, an area were conceptual understanding was very weak (see, Taylor & Lucas, 1997). As he has been often quoted, Ausubel (1968, p. iv) believes that: "the most important single factor influencing learning is what the learner already knows. Ascertain that and teach him [sic] accordingly." The SCS instrument provides teachers with a simple means of elicitation of students' scientific and alternative conceptions for one of the most important theories that underpins much of chemical science.

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