

EXPLORING STUDENTS' INTUITIVE IDEAS BASED ON PHYSICS ITEMS IN TIMSS - 1995

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Abstract

The TIMSS - 1995 tests have not only an achievement aspect, but also an important diagnostic aspect. The aim of this paper is to demonstrate how the diagnostic perspective can be brought into focus when analysing the results of individual TIMSS items. Some TIMSS items (both multiple choice and free response items) from the Physics Specialists Test are studied in order to show their potential for understanding and exploring students' thinking and the nature of students' misconceptions. This paper also makes the claim that students' alternative conceptions do not constitute a consistent naive theory, and often so-called alternative conceptions could better be described as intuitive ideas, more or less unstructured, fragmented pieces of knowledge. Intuitive ideas do not need to be replaced but rather developed and refined.

INTRODUCTION

The aim of this paper is to demonstrate how the diagnostic perspective can be brought into focus when analysing the results of individual TIMSS items. Some TIMSS items (both multiple choice and free response items) from the Physics Specialists Test (Mullis et al., 1998) are studied in order to show their potential for understanding and exploring students' thinking and the nature of students' *misconceptions* or *intuitive ideas*.

Crucial for making diagnostic quantitative analyses of free response items is a coding system that encompasses both the correctness and the diagnostic dimensions. In TIMSS this was provided by a two-digit system (Angell and Kobberstad, 1993; Lie et al., 1996). We have demonstrated elsewhere (Angell, Kjærnsli and Lie, 2000; Kjærnsli, Angell and Lie, 2002) that we can obtain valuable insight into students' thinking by analysing responses based on this coding system. However, multiple

choice items can also provide significant information about students' ideas.

This paper makes the further claim that students' alternative conceptions do not constitute a consistent naive theory, and often so-called alternative conceptions could better be described as *intuitive ideas*, or more or less unstructured, fragmented pieces of knowledge. Intuitive ideas do not need to be replaced but rather developed and refined.

Large-scale, quantitative studies have been criticised by researchers in science and mathematics education. There seems to be a gap between the statistical, psychometric testing approach on the one hand and the qualitative subject matter oriented point of view on the other. Nevertheless, the quantitative and qualitative approaches for probing student thinking and reasoning might work together in a combined approach instead of opposing each other.

EXAMPLES FROM THE TIMSS TEST FOR PHYSICS SPECIALISTS

The *physics* items in TIMSS concern fundamental laws and principles that were supposed to be part of typical physics curricula at this level in schools. Most items deal with one central problem, and to a lesser degree deal with contextualised or everyday problems. This fact might well be criticised, but this is also the strength of many of the TIMSS physics items, as they are well suited for diagnostic analysis of students' fundamental understanding in physics.

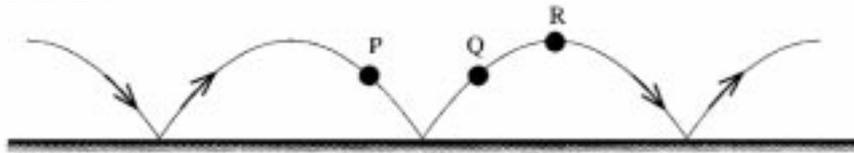
The analyses of physics items in TIMSS show that many students express what are usually called misconceptions. But it should be noted that several responses involve partly correct thinking: it seems that there are some fragments or pieces of knowledge in the responses which in a way are correct. And furthermore, these fragments of correct understanding might be the foundation for further and deeper understanding (diSessa, 1993). The following examples are presented in order to explore students' thinking, and more specifically to explore the nature of their (mis)conceptions.

Acceleration arrows for a bouncing ball

Newton's laws involving force and motion represent an area within physics that is taught at many levels in schools around the world. These laws are apparently simple; at least the mathematical formulation of the second law, $F = ma$, seems to be simple. But it is not! All the concepts involved, force, mass and acceleration, are complicated and difficult to understand. Few students get a deep understanding of Newton's second law by calculating one unknown quantity from two known ones. A more qualitative approach is necessary to lay a foundation for understanding the concepts involved. The following item is about a bouncing ball. The number refers to the number in the population 3 physics achievements items booklets.

G15

The figure shows the trajectory of a ball bouncing on a floor, with negligible air resistance.



Draw arrows on the figure showing the direction of acceleration of the ball at points P, Q and R.

The problem in this item is well known from a number of research studies (e.g., Viennot, 1979; 2001; Sjøberg and Lie, 1981; Finegold and Gorsky, 1991; Wandersee et al., 1993), but it should be noted that most of these studies *focused* on which forces are acting and not on the *acceleration*. Such research studies have revealed a very common alternative conception referred to as "impetus" or "Aristotelian" ideas. Impetus is a historical idea about "a moving force within the body" which pulls the body along the path after it has been thrown. "Aristotelian" ideas refer to Aristotle's "law of motion" where a force is needed to maintain motion, the force acts in the direction of the motion, and force and motion are proportional to each other. However, when a ball is bouncing on a floor and we can neglect the air resistance as described, the acceleration is always pointing vertically downwards as long as the ball is not in contact with the floor. The only force acting on the ball is the gravity pointing downwards, and due to Newton's second law, the acceleration and the sum of forces have the same direction. Table 1 shows the actual codes for this item and the result for the international average in percent.

Table 1: Coding Guide and Results in Percent

Code	Response	Int. average
	Correct Response	
10	The acceleration is parallel to g, downwards at P, Q and R	16
	Incorrect Response	
70	The acceleration is parallel to g, downwards arrow at P, upwards at Q and zero at R	7
71	The acceleration is parallel to g, downwards arrow at P, upwards at Q and either upwards or downwards at R	4
72	The acceleration has the same direction as the motion (at least in P and Q). Any response at R.	34
73	The acceleration has the same direction as the motion at P, the opposite direction from the motion at Q. Any response at R.	6
74	The acceleration has the direction perpendicular to the motion (at least at P and Q)	5
79	Other incorrect responses	21
	Nonresponse	
90/99		7

First of all, results indicate that this item is very demanding for students in many countries. An overall average of 16 % correct response is rather low. There are considerable differences between countries, correct answers varying from 4 % to 46 %.

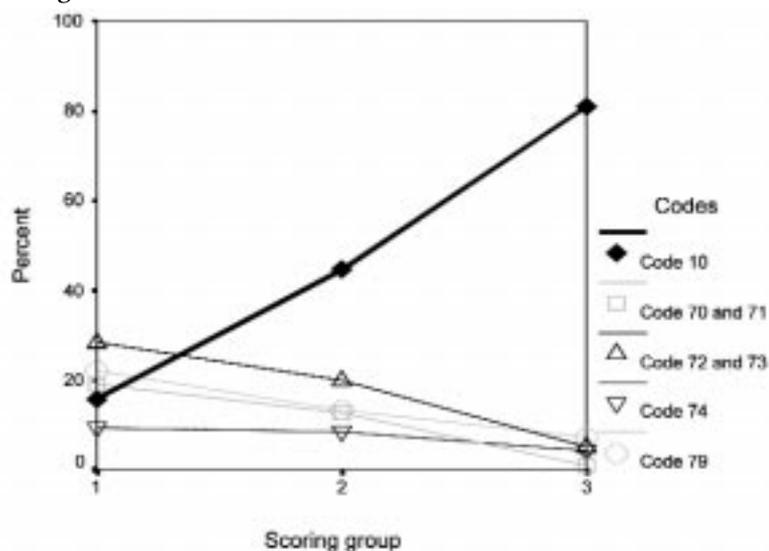
In many countries the students' answers indicate misconceptions (intuitive ideas) in at least two different ways or combinations of these: the acceleration always has the same direction as the motion (i.e., parallel to the velocity), and the acceleration points upwards when the ball is moving upwards.

The most distinctive result is, however, the high percentage for code 72 which includes two misconceptions: the acceleration is parallel to the motion and the acceleration points upwards when the ball is moving upwards. The misconception becomes even clearer if we put some codes together: these codes, 70, 71 and 72, include the misconception that the acceleration points upwards when the ball is moving upwards. Internationally, an average of 45 % of students gives answers involving this misconception.

As mentioned, the concepts of acceleration and force are complicated, and many students have vague ideas and poor understanding. The idea of a force within the body (impetus), which pulls it along a path after it has been thrown, is clearly wrong from a physicist's point of view. Nevertheless, this idea includes a correct notion, but the "moving force" is not a force, it is momentum. According to this interpretation the concept of impetus should probably not be eliminated, but rather developed and brought nearer the scientific concept of momentum.

Figure 1 shows the results of an extended analysis of the Norwegian data. The students are categorised in three scoring groups. Scoring group 1 is the 25 % lowest achieving students measured at the total score scale, scoring group 2 is the 50 % in the middle and scoring group 3 is the 25 % best achieving students. In this analysis the codes 70 and 71 are combined, as well as 72 and 73.

Figure 1: Norwegian Results



Despite Norway's good overall result in TIMSS compared to many other countries, it is important to emphasise that it was only among the best students (scoring group 3) that a majority of students answered correctly. But the middle achieving Norwegian students also performed better and above the international average on this item. The most frequent type of non-correct responses are responses with the acceleration parallel to the motion (velocity). This is true for both scoring groups 1 and 2.

In Norway as well as in many other countries, much research in science education has focused on students' conceptions of force and motion. For example, the Aristotelian concept of force and the impetus theory should be well known among physics teachers around the world. Norway has emphasized conceptions of force and motion for many years. This issue has been focused on in textbooks and in teacher education and in-service courses for teachers. But in spite of this, students, not only in Norway, seem to a large extent to have the same ideas as before the focus on alternative conceptions was emphasised. From this perspective, the large effort in revealing students' alternative conceptions is discouraging.

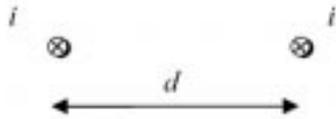
As mentioned, many earlier studies have dealt with the concept of force and not acceleration. After the TIMSS study we did a small survey in Norway to investigate this difference (Angell 1996). On a free-response item, very similar to this TIMSS item, we asked a sample of students to draw arrows showing the force acting on the ball. As many as 71 % of the Norwegian students drew correct force arrows (downwards in all cases), but only 46 % drew correct acceleration arrows in the TIMSS test. Even though we cannot compare these results directly, they provide some indication that the understanding of kinematics (about movement) is different from the understanding of dynamics (about force). It seems that students have greater difficulties with the concept of acceleration than the concept of force when it comes to understanding the direction of these two quantities. A possible interpretation of this result is that understanding the vector concept is easier in relation to a force than acceleration. Moreover, we may interpret this as indicating that students' understanding is fragmented and context dependent. From a scientific point of view the directions of force and acceleration are obviously the same due to Newton's law. But many students do not see this. Even if they have a correct idea of the direction of the force, their understanding is not deep enough to include the direction of acceleration. Nevertheless, there are some fragments of correct thinking that might be the foundation for further and deeper understanding.

Direction of forces on parallel wires

Electromagnetism is a substantial part of the school physics curriculum in many countries. The subject includes many complex models and concepts, which the following apparently simple item illustrates.

G17

The diagram shows two long parallel wires a distance d apart. Each carries a current i directed into the page.



Draw an arrow on the right-hand wire to show the direction of the force on it due to the current in the left-hand wire.

The magnetic field from the left wire points downward at the right wire. The right-hand rule gives the force on the right wire pointing to the left in the diagram. Table 2 shows the actual codes for this item and the result for the international average in percent.

Table 2: Coding Guide and Results in Percent

Code	Response	Int. average
	Correct Response	
10	Arrow showing attraction	31
	Incorrect Response	
70	Arrow showing repulsion	28
71	Arrow pointing upwards	6
72	Arrow pointing downwards	7
79	Other incorrect responses	10
	Nonresponse	
90/99		19

Results for this item might seem surprising: only 31 % drew arrows correctly, showing attraction, and a significant number drew arrows showing repulsion. In Norway for example, it was even worse. About 40 % of the Norwegian students drew arrows showing repulsion. This was true even among the best achieving students.

Because so many students believe the force must be repulsive, they probably base their answer on an idea of the type: "*equal is repulsive*". Many students have experienced that equal magnetic poles show repulsion, and they might also know that equal charges repulse each other. The currents in the wires have the same direction, and one might associate this situation with the cases of magnets or equal charges and assume that the forces on the wires are repulsive as well.

We may interpret this result as another indication of students' intuitive ideas or pieces of knowledge. And furthermore, experts (i.e., physicists) know the limitations

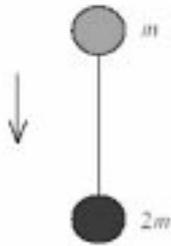
of a notion such as "equal is repulsive". The students may not.

Free fall

The following is a multiple-choice item, examining the tension in a string when the system falls freely.

H04

Two spheres with masses m and $2m$ respectively are connected by a light string and suspended at rest. The system is released and falls freely, as shown in the figure.



If g is the acceleration due to gravity, what is the tension in the string as the system falls?

A. 0
B. mg
C. $2mg$
D. $3mg$

Since the balls fall freely, we ignore air resistance and both spheres fall with the same acceleration, and consequently the tension in the string is zero.

Table 3: International Response Distribution in Percent

A. 34
B. 36
C. 17
D. 12

The international average correct response for this item was 34 %. One might, however, say that there is an element of "trickery" in this item because the sphere with the greater mass is placed below the sphere with less mass. But this is done deliberately, and the results show that only the best achieving students are able to solve the problem correctly. For example in Norway, it is only among the 25 % best students that as many as 80 % have correct answer. The most frequent incorrect answer is alternative B which indicates that many students seem to believe there must be a force from the heaviest and that this force is connected to the difference of weight between the two spheres.

However, all the distractors involve the idea that there is a force from the heaviest sphere although the system is falling freely. Once again we may interpret the result as an indication of student's fragmented knowledge. The actual problem may be somewhat strange or unfamiliar, but it is crucial for understanding that one can perceive the relation between the concepts involved and the phenomenon described.

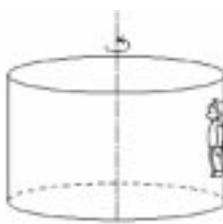
It has been claimed that physics has certain characteristics that make it "inherently difficult". Dolin (2002) suggests that physics appears difficult because it requires pupils to cope with a range of different forms of representation (experiments, graphs, mathematical symbols, verbal descriptions etc) simultaneously and to manage the transformation between these different representations. Many students do not have this ability to grasp the entirety, and only perceive different pieces independent of each other.

Forces acting on the rider

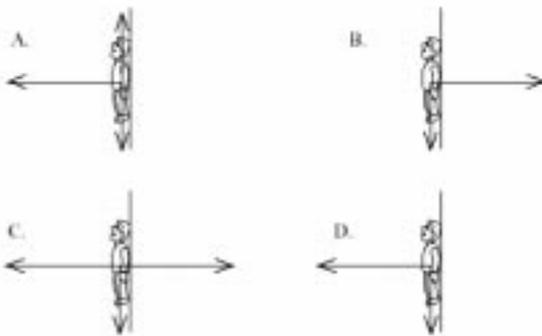
The next item is about rotation, and the question asks which forces actually act on the rider.

G09

The figure below shows a special sort of amusement park ride. As the ride starts to rotate about its central vertical axis the floor slowly drops but the rider does not. The rider is pressed against the rough inside wall of the rotating cylinder and remains at rest with respect to the wall. The rider's feet are not in contact with the floor.



Which one of the following diagrams best represents the real forces acting on the rider?



The aim of the item is to test the students' ability to identify how forces act; here the forces are the gravity and the force from the wall on the person. In school physics it is common to draw the two components of the force from the wall; one

force perpendicular to the wall and one friction force parallel to the wall. Alternative A is correct. Gravity and friction are equal but in opposite directions because there is no motion in the vertical direction. The force perpendicular to the wall is therefore the sum of all real forces. Table 4 shows the international response distribution.

Table 4: International Response Distribution in Percent

A.	19
B.	51
C.	19
D.	10

Only 19 % of students have given correct answer and this underlines the difficulty of circular motion. As seen from Table 4, the most frequent answer is alternative B which encompasses the notion of a centrifugal force. Alternative C also includes an idea of a centrifugal force. Thus, as many as 70 % of the students have this misconception. It is easy to understand that many students believe it must be a force pointing outwards when rotating. We "feel" this "force", but it is not a Newtonian force; i.e., a force from another object (interaction). Alternative C is also interesting because it comprises the concept of equilibrium. The two horizontal forces in the figure are equal and opposite directed and students may assume a situation of dynamic balance where the sum of forces is zero. Furthermore, all the distractors B, C and D show a net force downwards and should, according to Newton's second law, give acceleration downwards. But many students did not notice this either.

This item is another example where students demonstrate fragmented comprehension. Viennot (2001), for example, emphasizes that students' conceptions of forces of interaction are dependent on the kinematic situation. To a lesser degree students will propose a centrifugal force when describing the movement of a pendulum. This also indicates that students' ideas are context dependent and that students do not appear to hold any consistent conceptual framework.

Water level with melting ice

Archimedes' principle (or "law") is usually stated as "*when a body is immersed in a fluid there is a upwards force which is equal to the weight of fluid displaced*". This upward force is called the buoyant force and is a consequence of pressure increasing with depth. According to the principle, the water level in the aquarium remains the same because the ice displaces exactly the same volume of water as when it melts (namely the volume of water that has the same weight as the ice). The next item is about Archimedes' principle.

G11
The water level in a small aquarium reaches up to a mark A. After a large ice cube is dropped into the water, the cube floats and the water level rises to a new mark B.
What will happen to the water level as the ice melts? Explain your reasoning.

Like Newton's laws, Archimedes' principle is very fundamental in physics, and it is presented in science courses at different levels as though it were simple to understand. Even young children in many countries are taught about floating and sinking and Archimedes' law. As we will show, even "physics specialists" have great difficulty in applying the law or even recognising when they should use this principle.

Table 5: Coding Guide and Results in Percent

Code	Response	Int. average
	Correct Response	
20	Same level. Response refers to the fact that the volume (or mass) of the water displaced by the ice is equal to the volume (or mass) of the water produced when the ice is melted (Archimedes' principle)	12
29	Other acceptable responses	1
	Partial response	
10/11	Same level. Incomplete, incorrect or no explanation	11
19	Other partially correct responses	2
	Incorrect Response	
70	Rising level, with or without explanation	29
71	Sinking level. The water has smaller volume/greater density/ <i>"molecules are closer together" than the ice OR the ice has greater volume/smaller density/ "molecules are further apart" than the water.</i>	28
72/73/74	Sinking level. With other or without explanation	10
79	Other incorrect responses	3
	Nonresponse	
90/99		4

Table 5 is a revised coding scheme and shows the international results for this item. It appears that codes 70 and 71 were frequent responses in many countries. Code 71 is particularly interesting. Responses in this category express the idea that the ice has greater volume, or that the molecules are further apart in ice than in water and therefore the water level will sink. In other words, these responses express the fact that ice has greater volume than water and that the volume will decrease when the ice melts. So far the argument is correct, but students do not see that the volume of the displaced water and the volume of the water produced when the ice melts are equal, and that consequently the water level will remain the same.

This is an example where many students express misconceptions or intuitive ideas. But it should be noted that responses coded 71 involve some degree of correct thinking.

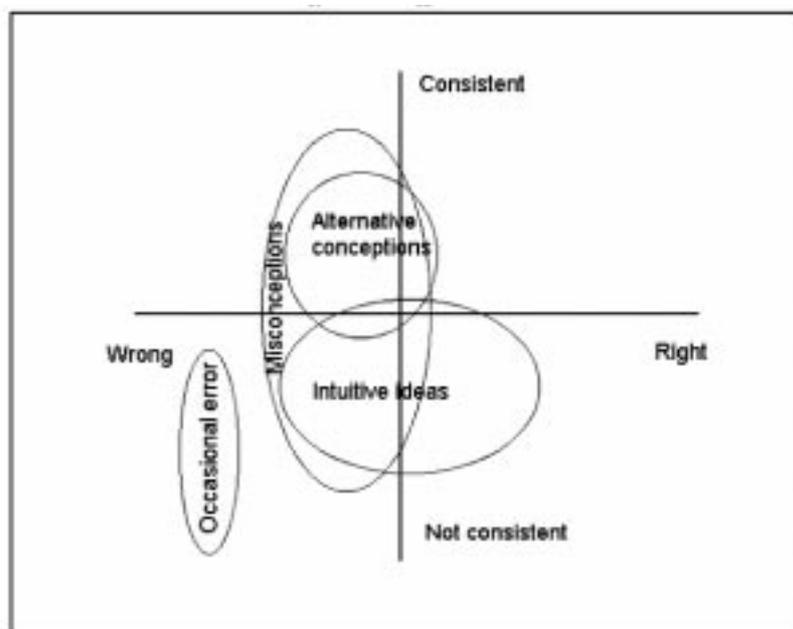
Students' alternative conceptions or intuitive ideas

Within the research domain of science education constructivism has become the leading theoretical position, and more recently the social constructivist and social cultural orientations have been acknowledged as well. In particular, questions regarding students' alternative conceptions or misconceptions have dominated the research field, and analyses of students' understanding have been systematically documented (Pfundt and Duit, 1994; Duit, 2002). However, the consistency of student ideas is questioned in several research projects as well as to what degree students' alternative conceptions constitute some naive theory. Some literature reports how students' alternative conceptions may be consistent, stable and theory-like, and other researchers have the view that students' ideas are inconsistent, fragmented and deeply situated in a specific context (for example, Champagne *et al.*, 1980; McCloskey, 1983; Driver & Erickson, 1983; Clough & Driver, 1986; Palmer, 1993; diSessa, 1988,1993; Kupier, 1994; Tytler, 1994, 1998; Taber, 2000).

Despite the substantial research on students' thinking and ideas, there is no consensus on the terminology used within the field of science education (Abimbola, 1988; Wandersee et al., 1993; Tytler, 1998). For example the term "alternative framework" may imply a form of ordered and schematic understanding of a concept, while the term "student idea" is more neutral. The different use of terminology may reflect different theoretical positions within the field of research.

In order to highlight some aspects of the terminology the following diagram (figure 1) illustrates how different terms may be linked to the dimensions right/wrong and consistent/not consistent.

Figure 1: Different Terms



Occasional errors are definitely wrong and of course inconsistent. These could be calculation errors, for example, and are without interest here. Misconceptions are mainly wrong, but the term is used more or less as an overall descriptor of all non-scientific notions that are not occasional errors. Alternative conceptions are for the most part placed in the diagram area for wrong and consistent ideas. Consequently such conceptions might constitute some sort of naive theory. Intuitive ideas are primarily inconsistent, but may contain a significant portion of correct comprehension. The overlaps in the diagram indicate the somewhat unclear borders between the terms.

DISCUSSION AND CONCLUSION

As already mentioned, there is often something correct in "incorrect" responses. Therefore one can argue that students do not have misconceptions or alternative conceptions that constitute naive theories, but rather their ideas should be characterised as unstructured, fragmented knowledge. In this view the students are not constructing systematic, naive and consistent theories, but different aspects or facets of understanding are brought forward depending on the actual context. Students' experiences from school lessons, textbooks, out of school and other informal settings all contribute to intuitive ideas or spontaneous pieces of knowledge.

The term *alternative conception* implies that students have constructed information and their personal experience in such a way that they have come up with a serious

alternative to the scientific conception. This would mean that this alternative conception has to be challenged by the scientific conception. Over-simplifying this, we may say this is the basis for the classical conceptual change approach, which involves the teacher making students' alternative conceptions explicit prior to instruction consisting of ideas that do not fit the students' existing ideas and which thereby promote dissatisfaction. However, if students do not have such alternative ideas or consistent naive theories but more fragmented pieces of knowledge, this conceptual change approach will not work. There appears to be no study which found that a particular student's conception could be completely extinguished and then replaced by the science view (Duit & Treagust, 2003).

The relation between everyday concepts and scientific concepts was also important for Lev Vygotsky. Central to Vygotsky's perspective is the belief in the significance of the social and cultural dimension, and he emphasises the idea that development and learning involve a passage from social contexts to individual understanding (Vygotsky, 1978, 1986). Everyday concepts are based on concrete occurrence, they are context specific and they are not part of a coherent thinking structure. Vygotsky introduced the notion of the *zone of proximal development*, and refers the role of a teacher or another expert as being that of supporting students' progress. However, the notion also refers to the interaction between spontaneous and scientific concepts. This interaction is essential for the individuals' development and control of knowledge. The social constructivist perspective, which is based significantly on Vygotsky's work, also emphasizes to the change of focus from the student as a lonely thinker to the student in a social context where concepts are integrated into a system of coherent concepts due to interaction with others. Students' everyday concepts or intuitive ideas may therefore be starting points for developing scientific concepts. Or, according to Vygotsky (1986), the development of spontaneous and scientific concepts are related and constantly influencing each other within the teaching situations.

The TIMSS items discussed above are all examples indicating the nature of students' understanding as fragmented, inconsistent and context dependent. The term *intuitive ideas* as used in this paper may be wrong from a scientific point of view, but as mentioned already, may also include elements of correct thinking or reasoning. Accordingly, attention is directed to the correct facets of the students' ideas, and the consequences for teaching should be to build on these correct fragments of knowledge. Intuitive ideas do not need to be replaced but rather developed and refined (diSessa, 1993). Although many commonly held ideas hinder understanding, one should recognise that some actually might constitute helpful bases on which to build knowledge (Viennot, 2001). And furthermore, a fundamental part of the learning process is to see how different perspectives overlap and articulate with one another. This involves dealing explicitly with those issues that seem to sit uneasily between everyday and scientific views. In this way "misconceptions" become sources of key questions to be addressed in the teaching (Mortimer and Scott, 2003). It might therefore be better to describe many students' thinking in terms of *intuitive ideas* and to highlight the continuity from fragmented, unstructured knowledge to more systematic scientific understanding. For example,

in the case of electricity the literature refers to the misconception that electric current is "used up" as it passes around a circuit. But if the students' concept of electric current is blurred and closer to a notion of energy, then they are almost correct. It is something "flowing" in the circuit which is "used up". But it is not current, it is energy.

The consequences for teaching approaches might well be to build on what is correct in "incorrect" kinds of comprehension. Students should expect physics to be coherent rather than fragmented pieces of knowledge. Furthermore, if when students feel they have some right ideas or fragments of correct understanding the teacher considers them seriously, this probably will have a motivating effect on the amount of effort they are willing to put into making sense of physics.

In spite of the considerable amount of research within science education it is still difficult to suggest specific teaching approaches based on this research. However, this should not be the case. After all, numerous research projects to a large extent are relevant for physics teaching and should be a foundation for teachers' choice and justification of teaching methods. One could therefore argue that the consequences of only one teaching approach or only one teaching perspective are to deny for a lot of valuable possibilities.

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