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AUTHOR Hewson, Peter W.: Hewson, Mariana G.
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ABSTRACT

Presented is an analysis of a concept teaching technique that was developed according to a theoretical perspective which emphasizes the importance of a student's existing knowledge in influencing that person's subsequent learning. Significant differences between an experimental group which was exposed to this instructional strategy, and the control group which was not, are explained in terms of a conceptual change model. This paradigm emphasizes: (1) different ways in which a person's conceptions may be modified: (2) characteristics of a given conception that determine whether or not it will change: and (3) how a particular conception can change. The experimental strategy was effective because it directly addressed students' misconceptions and demonstrated the fruitfulness of the accepted science concept. It is thus important to reconcile the scientific view with each student's existing knowledge. (Author/WB)

EFFECT OF INSTRUCTION USING STUDENTS' PRIOR KNOWLEDGE AND CONCEPTUAL CHANGE STRATEGIES ON SCIENCE LEARNING
PART II: ANALYSIS OF INSTRUCTION*

Peter W. Hewson
University of the Witwatersrand, Johannesburg, South Africa

Mariana G. Hewson
Science Education Project, Johannesburg, South Africa

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ABSTRACT

One of the factors affecting students' learning in science is their existing knowledge prior to instruction. The students' prior knowledge provides an indication of the alternative conceptions as well as the scientific conceptions possessed by the students. This study is concerned primarily with the students' alternative conceptions and with instructional strategies to effect the learning of scientific conceptions i.e. to effect conceptual change from alternative to scientific conceptions. The conceptual change model used here suggests conditions under which alternative conceptions can be replaced by, or differentiated into, scientific conceptions and new conceptions can be integrated with existing conceptions.

The first part of the study was considered in a preceding paper which outlined the development and application of instructional strategies to effect conceptual change, and evaluated the effect of these strategies in comparison with traditional strategies and materials. The content of instruction included mass, volume, density, relative density and the particulate nature of matter. The results showed a significantly larger improvement in acquisition of scientific conceptions as a result of the strategies which explicitly addressed alternative conceptions.

In this paper both control and experimental strategies are analyzed in terms of the conceptual change model. This analysis provides an explanation of the significant differences between the outcomes of the two strategies.

INTRODUCTION

A preceding paper by one of us (M.G. Hewson 1981) reported on the first part of a study of the role which the knowledge held by students prior to instruction plays in causing student difficulty in learning science.

The objectives of the study were:

1. To develop a strategy of instruction based on students' prior knowledge and on the theoretical principles of conceptual change. The content of instruction was density and included the basic scientific concepts of mass, volume, density and relative density.
2. To apply the strategy of instruction to a specific group of students whose prior knowledge concerning these concepts had been previously identified.
3. To evaluate the effectiveness of the experimental strategy compared with a traditional strategy used as a control.
4. To analyse both experimental and control strategies in terms of the conceptual change model developed by P.W. Hewson (1980) and Posner, et al. (in press) in order to account for the differences obtained.

The preceding paper deals with the first three objectives, while this paper considers the last of these objectives.

In the next section the essential aspects of the conceptual change model are summarized. Thereafter both control and experimental strategies are analysed in terms of the model; the analysis providing an explanation of the significant differences between the outcomes of the two strategies. Finally the results are summarized and their implications for science education are discussed.

A MODEL OF CONCEPTUAL CHANGE

Conceptual change in an individual could happen in a number of different ways. There could be the addition of new conceptions through

further experience, through personal development by the individual concerned, through interaction with other people, etc. There could be the differentiation and clarification of existing conceptions, triggered either externally by some novel idea, some new experience, or internally as the result of some process of thought. There could be reorganization of existing conceptions, similarly triggered. There could be the rejection of some existing conception perhaps as a result of a conceptual differentiation, perhaps because of a conceptual reorganization, perhaps because of displacement by some new conceptions. Obviously, these ways are not independent, with one giving rise to another in complex patterns. Nevertheless they are all aspects of the same theme - the relationships between conceptions. Since the issues are seen perhaps most clearly in dealing with new ideas, we shall take the additions of new conceptions as our starting point and discuss differentiation, reorganization and rejection as they arise.

Consider, therefore, a person whose existing conceptions include one particular conception C which might, for example, be a theory about a particular set of natural phenomena. This person is then faced with a conception C' which might be an alternative theory about the same set of phenomena. The following questions are then of interest: What could happen to C'? What are the conditions which determine what will happen to C'? How do these conditions change, thereby influencing what happens to C'?

Firstly, what could happen to the new conception C'? It could be:

- <u>rejected</u> (either outright or until further investigation suggests otherwise); or
- incorporated in three possible ways. It would
  - be <u>rotely memorized</u> i.e. it would not be reconciled with existing conceptions;

- replace C and be reconciled with the remaining conceptions by the process of conceptual exchange (CE);
- be reconciled with existing conceptions, including C, by the process of conceptual capture (CC).

Both conceptual capture and conceptual exchange depend on reconciliation between conceptions. This is the process whereby a person makes sense of a new conception and gives it meaning by seeing it in the context of his or her present knowledge and understanding. Reconciling two or more conceptions implies that there are significant inferential links between them, that they do not contradict one another, that they are parts of the same integrated set of ideas, that there is consistency between them. Thus rote memorization places no demands on the relationship between conceptions, whereas both conceptual capture and conceptual exchange do.

Secondly, what conditions determine what will happen to C'? Three questions must be asked of each conception:

- is it intelligible (I)? Does the person know what it means? Can he or she construct a coherent representation of it and see that it is internally consistent, without necessarily believing that it is true?
- is it initially plausible (P)? In addition to being intelligible, is it also true? Is it reconcilable with other existing conceptions? Is it how the world really is?
- is it fruitful (F)? In addition to being plausible, is it useful? Does it clear up anomalous results? Does it suggest further experiments, new approaches? i.e. Does it have explanatory and predictive power?

The answers to these three questions can be summarized thus: a conception can have

- no status (not intelligible, plausible or fruitful)

- status I (intelligible, but not plausible or fruitful)
- status IP (intelligible and plausible, but not fruitful)
- status IPF (intelligible, plausible and fruitful)

For simplicity the model assumes that all existing conceptions not under threat have status IP or IPF. Further if two conceptions are reconcilable, both have a status of at least IP or neither do; and if two conceptions are irreconcilable, only one can have a status of at least IP.

Once status for the new conception C', and any existing conceptions, C, which relate to the same topic, has been determined, it is possible to say what will happen to C'. The various possibilities are summarized in Figure 1. In actual practice it is easier to see what happens to C' first, and then infer what status each conception has. In planning instruction to achieve specified outcomes, however, it is necessary to consider status directly rather than inferentially.

(Figure 1 about here)

Thirdly, how does the status of a conception change? Status does not change spontaneously - it is only lowered if there is cause for dissatisfaction; it only rises if sources of dissatisfaction are removed, if some advantage is gained. Dissatisfaction with an existing conception C can occur

- if a reanalysis of experience shows that C is no longer necessary;
- if C is seen to be irreconcilable with new knowledge C' <u>which cannot be ignored</u>, i.e. C' constitutes an anomaly (if C' can be ignored, then there is no dissatisfaction with C);

- if C is seen to violate some epistemological standard, such as appearing inelegant, clumsy, unduly complicated, ad hoc, etc.

Alternatively dissatisfaction with a new conception C' can occur

- if C' is seen to be irreconcilable with firmly held existing conceptions C, i.e. C' is counterintuitive, and can thus be ignored;
- if the implications of C' are seen to be unacceptable;
- if the experimental or logical basis for C' appears to be doubtful.

Clearly if C and C' are seen as irreconcilable, the relative strengths of commitment to them will determine whether C loses status, leading to conceptual exchange with C', or whether C retains its status and prevents C' from gaining status, thereby leading to its rejection. Finally, rises in status can only occur when the conditions for intelligibility, plausibility and fruitfulness are satisfied.

The same considerations which determine the relationship between new and existing conceptions apply to those between two or more existing conceptions. It is clear from the preceding discussion that these relationships are not fixed when conceptions are incorporated, but are influenced by new knowledge. We might expect that initially conceptions are relatively ill-defined and loosely connected with existing knowledge, even to the extent that there is confusion between similar conceptions, confusion of which the person holding them is unaware. The incorporation of some new conception could then help to identify the confusion, leading to a reconsideration of the two conceptions and their relationship, and as a result to their further differentiation. Alternatively the effect of new knowledge on two or more

clearly resolved conceptions could be a reconsideration of their interrelationships, leading perhaps to a large scale conceptual reorganization. In either event, however, conceptions, their relationships and the extent of their reconciliation need to be considered in just the same terms discussed above.

There is some ambiguity inherent in the ideas of conceptual exchange and conceptual differentiation. On the one hand it is most unlikely that there would be no overlap whatsoever between two conceptions which are exchanged. For example, a change from a belief that time is absolute to one that time is relative to the observer can properly be termed a conceptual exchange even though time is involved in both. On the other hand, when a conception is differentiated one cannot say that nothing is exchanged. Thus when the conception "density is denseness" is differentiated into "density is mass per unit volume" and "denseness (of trees) is number (of trees) per unit measure (area)", it could also have been regarded as being exchanged for "density is closely related to denseness". Despite this ambiguity, however, there is value in maintaining the two separate terms because they focus on different aspects of a conceptual change. Thus conceptual exchange focusses on that which changes and conceptual differentiation on that which is carried through.

ANALYSIS OF CONTROL STRATEGIES

The detailed analysis of the strategies involved in the instructional materials will focus on just one of the four units, since this will be sufficient to exemplify the essential differences between control and experimental strategies.

Figure 2 outlines the essential elements of the control materials for unit 4 on density. Anyone who is at all familiar with the topic will recognize the logic inherent in the sequencing of the unit: each new stage

is built on the foundation of the stages preceding it, and all stages together form an appropriately integrated whole. The teaching moves

(Figure 2 about here)

at each stage were designed with the express intention of integrating new material with old, and as presented there are no problems about reconciling different parts of the content with each other. For example, given that it has been determined experimentally that the ratio of mass to volume for different sized chunks of the same material remains constant, it is logically consistent to define this ratio to be the density of the material. The generalization that the density of any chunk of the same material remains constant independent of its particular size and shape, follows inductively.

In terms of the conceptual change model, each teaching move was intended to produce conceptual capture of the new material through its reconciliation with the material which had preceded it. It is obvious that provided a student is able to form an appropriate representation of the new conception, e.g. the definition of density as the ratio of mass to volume, he or she would find it intelligible. For conceptual capture to occur, however, the student has also to find it plausible, that is, reconcilable with other conceptions which are held. If one can assume that the only other conceptions relevant to the topic which are held, are just those which preceded it in the teaching sequence, then the new conception could indeed be plausible. The evidence presented in Part I, however, shows that this assumption is simply not valid: students did hold alternative conceptions of density prior to instruction and they also held conceptions of mass and volume significantly different to those aimed for in the teaching materials. For example, a conception of "density is denseness" was prevalent, and this is irreconcilable with a conception of "density is the ratio of mass to volume". Thus for any

student holding this alternative conception prior to instruction, the scientific conception of density could not be plausible, and it could not be incorporated by means of conceptual capture.

In other words the conceptual change model provides an explanation for the relative lack of success of the control materials in assisting students who hold alternative conceptions of mass, volume and density to change to the appropriate scientific conceptions.

ANALYSIS OF EXPERIMENTAL STRATEGIES

The essential elements of the experimental materials for the same topic - density - are shown in Figure 3. All elements of the control materials are included and identified as such, making it easy to identify the differences between the two sets of materials. The

(Figure 3 about here)

differences in this and other units predominantly fall into two categories. Firstly, the identified alternative conceptions are explicitly considered. Secondly, the concepts developed and the conclusions reached are directly related back to the bridging concept (the central question behind each of the units) which provided the context in which all investigations were pursued.

In terms of the conceptual change model, in order for each conception to be incorporated meaningfully into existing conceptions, it has to be seen as intelligible and plausible. If in addition it is also fruitful there is a more powerful reason for its incorporation. As we saw above, the teaching moves common to both sets of materials are sufficient to ensure that the new conception is intelligible. These moves, however, do not on their own ensure plausibility in the event that irreconcilable alternatives are already present. In this case a prevalent alternative conception equated density with denseness or crowdedness, a view which leads directly to one in which the packing of the

particles of different materials determines density. The problem arises because for the person holding them these conceptions are plausible - they do, after all, contain a grain of truth - and they are, as they stand, irreconcilable with the conceptions presented in the unit. Before the new conceptions can be incorporated meaningfully, then, the status of the existing conceptions has to be reduced from IP to just I. This unit contains two related examples of teaching moves designed to reduce status. Firstly the conception "density equals denseness" is differentiated into the different but closely related concepts of density and denseness. Secondly the issue of the packing of particles is shown to refer to denseness rather than density, and thus in order to think about density one needs to consider the mass of the particles as well as the way in which they are packed. The original conception has been exchanged for two others. (In this second case, there are strong elements of conceptual differentiation occurring, but the importance of the breaking of the link between density and the packing of particles on its own justifies it being identified as conceptual exchange). Thus the end result of these teaching moves, if successful, would be the reduction in status of the alternative conceptions which prevented the scientific concept of density from being seen as plausible, thereby opening the way for its incorporation by means of conceptual capture.

The second difference between control and experimental strategies is the use of a cognitive bridge: this was, in this case, the central question which set the context for all four units. The purpose of this in terms of the conceptual change model is clearly to show the fruitfulness of the new conceptions. A problem had been set: how can I determine whether any given object will float or sink in water? leading to the more fundamental questions - what determines whether an object will float or sink? Once the concept of density was seen to be plausible, it was a

small step to show that it could explain why a steel ball sank and a wooden block floated and could predict whether any object would float or sink without having to test it. In other words, the concept was not only intelligible and plausible, but also fruitful, and thus very likely to be incorporated meaningfully.

SUMMARY AND DISCUSSION

In summary, the conceptual change model can explain why the experimental materials were more likely to lead to pupils learning science than the control materials. The latter provided all that was needed to make new conceptions intelligible, but did nothing about the obstacles imposed by alternative conceptions. The former, however, addressed these obstacles directly, thus allowing the new conceptions to become plausible, an essential prerequisite for conceptual capture. In addition they also showed the fruitfulness of the new conceptions, thereby increasing the motivation for incorporating them.

The claim made in this paper is that the significant differences between the experimental and control groups' performances are due to the different strategies employed. One may ask whether the additional teaching moves did not require significantly larger amounts of time, particularly in the light of Carroll's (1963) contention that time is a significant variable in learning. In this case, however, we are inclined to disregard its effect. Firstly, the concepts of mass, volume and density had been taught to both groups on two previous occasions. Secondly there was a time difference of one hour between the control group (5 hours) and the experimental group (6 hours). Taken over the total amount of teaching time spent on these topics, the extra time was probably somewhat less than 10%. It seems unlikely that this of itself could lead to the significant differences reported.

A second question to consider is the quality of the control materials. In other words were the reported differences only significant because of a poor base line? In this regard, three points need to be

made. First, density is very widely regarded as a difficult concept to teach at this level. It has, in fact, been suggested that abstract concepts (of which density is a prime example) should be left until much later. (See, for example, Chiapetta 1976). So poor student performance on density is not exclusive to this control group. Secondly, the control materials were prepared by the Science Education Project (SEP) which was able to draw on the experience of American and British curriculum developers. The SEP materials require active student involvement in experimentation and discussion. Evaluation of these materials has shown significant improvement in student examination results compared with those from non-SEP schools (Rogan 1980) so there is good reason to believe that the control materials were comparable with the best that are available.

Finally, there was substantial overlap between the experimental and control materials. Thus any unidentified weaknesses would have affected both groups equally. In the light of these three points, therefore, it seems very unlikely that the reported differences are merely an artefact of the particular set of control materials used.

Many generations of students through the years, like students reported in this study, have found density, and indeed many other scientific concepts, difficult to learn. In a nutshell, the view has been that science is logical, and thus the teaching of science should follow the logical sequence. Many students have successfully followed such a path and those who haven't have probably failed because of their inability to think logically. But since science is considered to be difficult, one should not expect everyone to cope anyway. If, however, the results and their explanations reported in this paper have any generalizability to other topics and other students (and here, very clearly, a great deal of work needs to be done), then they suggest

an alternative view of the difficulties involved in the learning and teaching of science. Thus we would like to argue that because students have experienced and thought about the world, they do come to class with ideas, often ill-formed, hazy and inappropriate, but ideas nevertheless. These are what students use to understand their world, i.e. to make it plausible. When the accepted scientific view is presented it is to these same ideas that it must be reconciled if it is to be accepted. If no reconciliation is effected, either by appropriate teaching or by the student's individual efforts, then it is small wonder that science is progressively viewed as abstruse, difficult, incomprehensible and finally and most dangerously, irrational. The research reported in this paper suggests one way out of the impasse.

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FIGURE CAPTIONS

Figure 1: A Model of Conceptual Change. Possibilities of what could happen to a conception, C', being considered as a function of conception status. e.g. If C has status IP and C' is irreconcilable with C, then C' can have status no higher than I and it would be rejected. Alternatively if C has status IP and C' can be reconciled with C, then C' could have status IP in which case it might be rejected but would probably undergo conceptual capture or it could have status IPF in which case it would undergo conceptual capture. For simplicity rote memorization has not be included.

Figure 2: Representation of teaching moves and conceptions involved in the control instruction on the topic of DENSITY and RELATIVE DENSITY

Figure 3: Representation of teaching moves and scientific and alternative conceptions involved in the experimental and control instruction on the topic of DENSITY and RELATIVE DENSITY

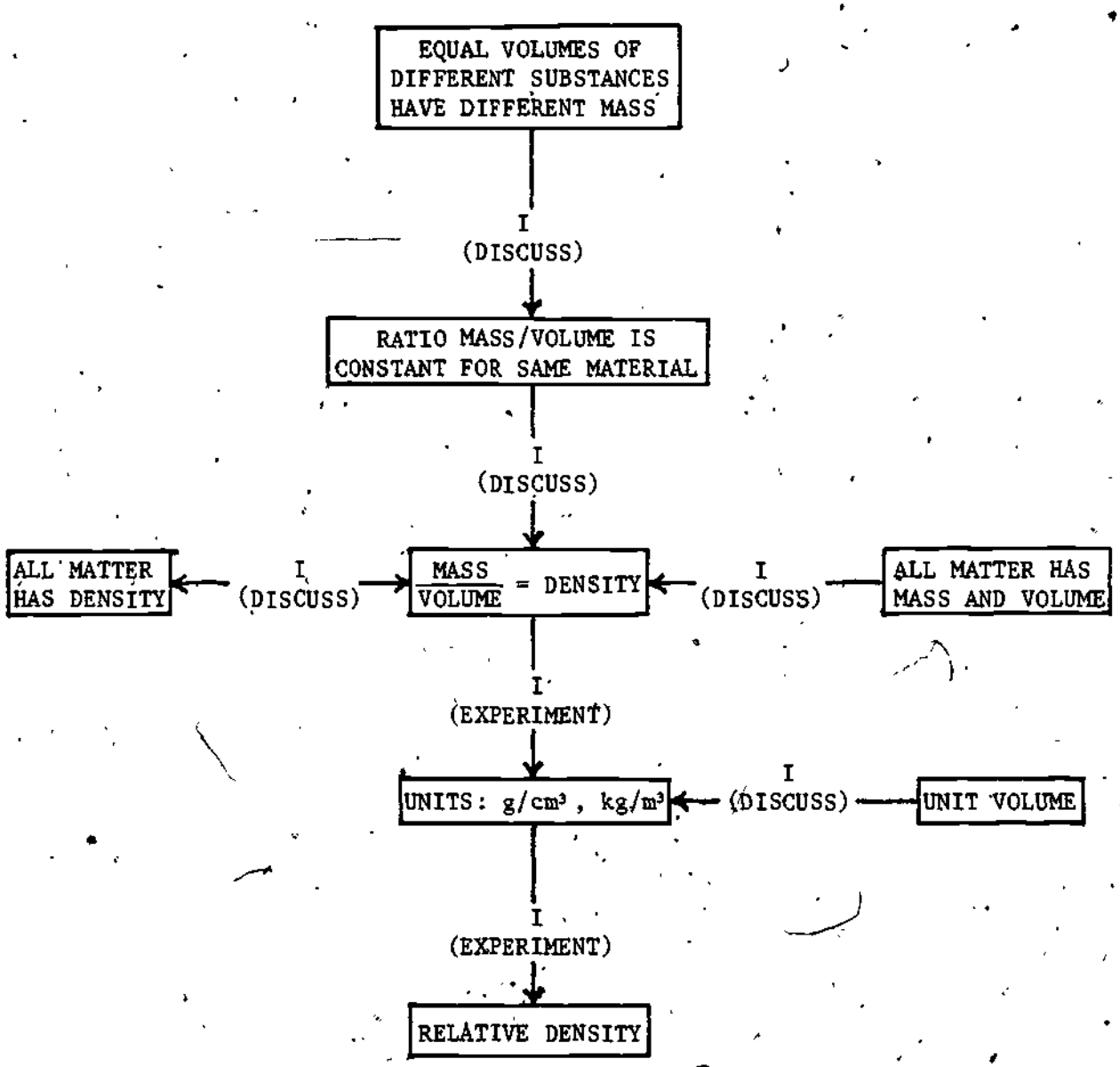
		Status of conception being considered. C′					
		I		IP		IPF	
		irrecon.	recon.	irrecon.	recon.	irrecon.	recon.
Status of existing conception C	I	R	R	CE		CE	
	IP	R			CC (or R)		CC
	IPF	R			CC (or R)		CC

Conceptual change possibilities:

R - rejection of C′

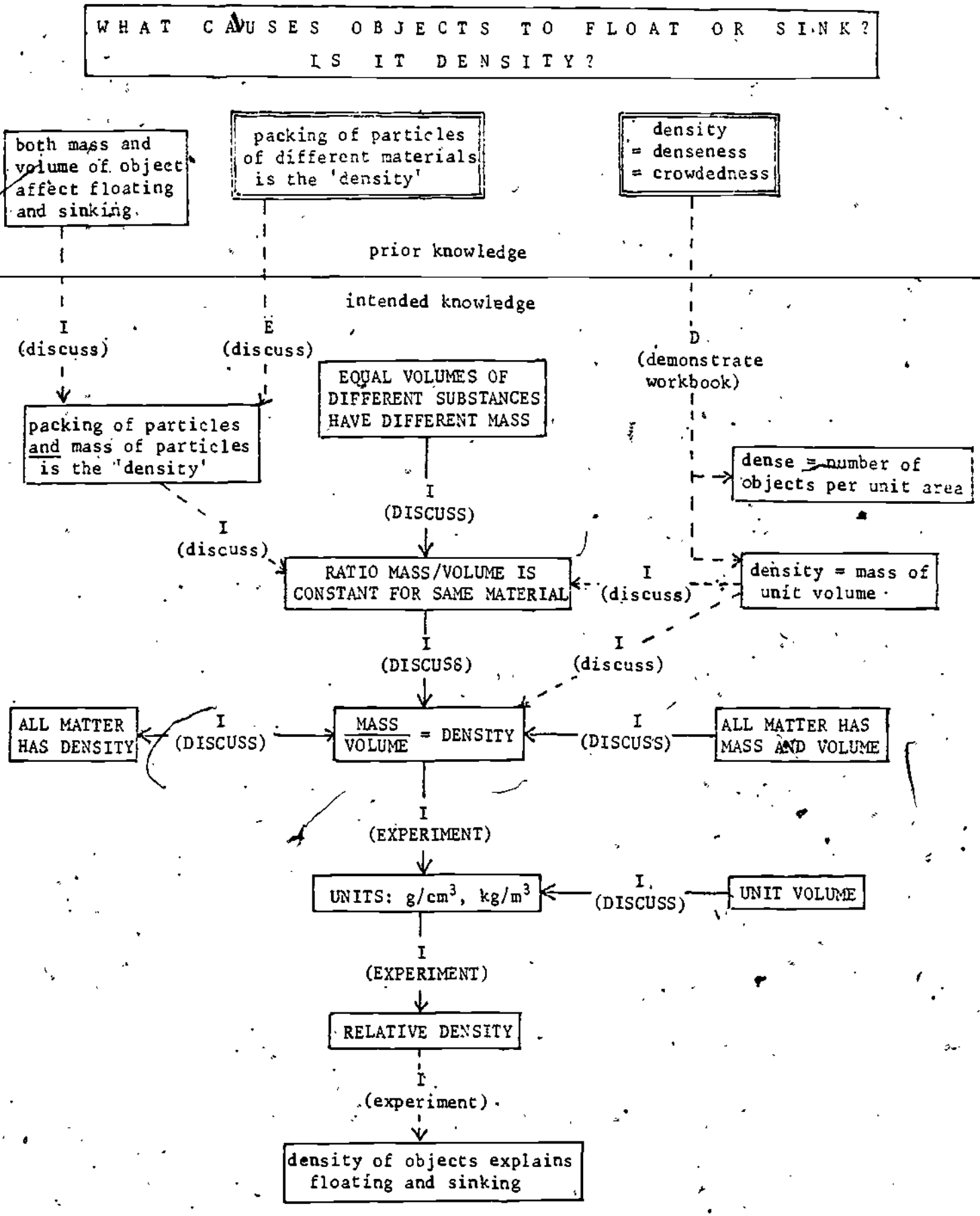
CE - conceptual exchange of C′ for C

CC - conceptual capture of C′



I = integration E = exchange

D = differentiation



I = integration E = exchange
D = differentiation

Identified prior knowledge lies above the line

UPPER CASE: Experimental and control instruction
lower case: Experimental instruction only